Aus der Klinik für Allgemeine, Unfall-, und Wiederherstellungschirurgie

der Ludwig-Maximilians-Universität zu München

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Verletzungen der Schulter im Kontext hochauflösender Bildgebungsmodalitäten und aktueller Versorgungsstrategien

Als kumulative Habilitationsschrift

für das Fach Orthopädie und Unfallchirurgie

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vorgelegt von

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1. Inhalt

2. Einleitende Zusammenfassung

Verletzungen der Schulterregion kommt zum einen aufgrund ihrer hohen Inzidenz zum anderen aufgrund des heterogenen Patientenkollektivs über viele Lebensdekaden hinweg ein großer Stellenwert zu. In den nächsten Jahren ist mit einer multifaktoriell bedingten, weiter zunehmenden Inzidenz und somit klinischer Relevanz zu rechnen. Sport induzierte Verletzungen rücken aufgrund einer stetig steigenden Anzahl Praktizierender sowie einer stetig längeren Zeit des Aktivseins auch im höheren Alter in den Vordergrund. Der demographische Wandel forciert Schulterverletzungen des alten Menschen im Kontext geminderter Knochenqualität.

Legt man einen ganzheitlichen Maßstab des Verstehens an die verletzte Schulter an, kommt man rasch zu der Feststellung, dass aufgrund der beschriebenen Heterogenität von Schulterverletzungen verschiedene wissenschaftliche Bereiche noch lückenhaft und zu beleuchten sind. Ziel dieses Habilitationsprojektes war es, einige dieser Lücken zu schließen.

Bevor eine klinische Auseinandersetzung mit der Schulter, ihren Verletzungen und deren Diagnostik und Therapie beginnen kann, müssen Aspekte der Grundlagenforschung berücksichtigt und wissenschaftlich aufgearbeitet werden. Daher besteht ein erster Teil dieser Habilitationsschrift aus aktuellen Fragestellungen im Bereich der Grundlagenforschung. Im Anschluss werden klinische Fragestellungen untersucht. Zum einen erfolgten epidemiologische Arbeiten und Arbeiten zur Versorgungsforschung aus dem Bereich des initialen Traumamanagements. Ziel hier war es die Verletzungen der oberen Extremität und im Besonderen der Schulter besser charakterisieren zu können und deren Behandlung zu optimieren. Ein dritter wesentlicher Bestandteil dieser Schrift sind klinische Arbeiten zum Schultergelenk mit diagnostischen und therapeutischen Fragestellungen vor einem operativen Hintergrund.

Die Inzidenz der proximalen Humerusfraktur hat sich in den letzten 30 Jahren verdreifacht. Ihr kommt somit die Hauptrolle meiner Forschungsarbeiten zum Schultergelenk zu. Gemittelt sind Patienten der siebten Lebensdekade am häufigsten betroffen und Knochenumbauprozesse rücken in den Vordergrund. Hier stellen sich im Bereich der Grundlagenforschung zwei wesentliche Fragen, die bislang weitgehend unbeantwortet blieben. Der Einfluss des Alters auf die Frakturentstehung und die Kartierung/Lokalisation der Knochenumbauprozesse auf der Basis hochauflösender bildgebender Verfahren wurden bislang für den proximalen Humerus nicht durchgeführt. Aus diesen Fragestellungen heraus entstanden die ersten beiden Arbeiten:

Die proximale Humerusfraktur gilt als eine Indikatorfraktur für Osteoporose. An welchen Regionen sich die Osteoporose im proximalen Humerus manifestiert war jedoch unbekannt. In der ersten Arbeit erfolgte eine histomorphometrische Bestimmung der Knochenqualität proximaler Humeri von Leichenspendern. Die Spenderknochen wurden anhand einer DXA-Messung in gesunde und osteoporotische Knochen unterteilt. In den Kollektiven wurden die Dicke des subchondralen und trabekulären Knochens sowie die metaphysäre kortikale Dicke analysiert. Alle untersuchten Regionen wiesen im Kollektiv der Osteoporotiker eine signifikant reduzierte trabekuläre Knochenverteilung auf. Auch der Vergleich verschiedener Frakturregionen war in beiden Kollektiven signifikant unterschiedlich. Beide Gruppen wiesen den geringsten Knochenverlust unterhalb der subchondralen Platte auf. Dem gegenüber stand in beiden Kollektiven eine deutlich höhere Knochensubstanzminderung im Bereich der medialen Metaphyse verglichen mit lateral. Die Beobachtungen erklären die häufige Frakturentstehung am Collum chirurgicum und müssen Einfluss in die Beurteilung der Implantatwahl zur Versorgung dieser Region finden. Auch die Osteoporose muss in der Wahl des Implantats unter Kenntnis der Knochenverteilung antizipiert werden.(Sprecher et al., 2015)

In der nächsten Arbeit beschäftigte ich mich mit dem Alter als beeinflussender Faktor der Knochenumbauprozesse. Wir untersuchten proximale Humeri von Leichenspendern eines repräsentativen Alterskollektives (18-100 Jahre) mittels hochauflösender xtremeCT Bildgebung (82 µm). Analysiert wurden die Bone mineral density (BMD), die Trabecular bone volume fraction (Tb.BV/TV), die Cortical thickness (Ct.Th) und die Cortical porosity (Ct.Po) in vier verschiedenen Alterskollektiven. BMD, Ct.Th und Tb.BV/TV zeigten eine altersspezifische Abnahme, während die Ct.Po anstieg. Im ältesten Kollektiv (80-100 Jahre) konnte eine außergewöhnlich hohe Zunahme der Ct.Po verglichen mit dem jüngsten Kollekitv (18-44 Jahre) nachgewiesen werden, während die Ct.Th und Tb.BV/TV signifikant abnahmen. Der größte kortikale Substanzverlust ereignete sich nach dem Alter von 65 Jahren verglichen mit dem jüngsten Kollektiv. Knochenabbauprozesse ereignen sich somit entscheidend ab einem Alter von 65 Jahren und resultierten in einer relevanten Abnahme der knöchernen Stabilität und Zunahme des Frakturrisikos.(Helfen, Sprecher, et al., 2017)

Eine erste präklinische Arbeit befasste sich mit dem Erreichen des Verletzungsstatus „schwer verletzt“ beim Zweiradfahrer als im Straßenverkehr äußerst exponierte Teilnehmergruppe. Ziel der Arbeit war die Gesamterfassung der Verletzungen sowie die Charakterisierung von Verletzungsschwerpunkten in einem standardisierten und repräsentativen Kollektiv schwer verletzter Fahrradfahrer. Im Fokus des Interesses stand die Beteiligung der oberen Extremität in diesem Kontext. Es wurden Daten des

Traumaregisters® der DGU ausgewertet. Insgesamt wurden 2.817 schwer verletzte (ISS ≥ 9 mit zusätzlicher intensivmedizinischer oder Intensivüberwachungstherapie) Fahrradfahrer eingeschlossen. Primärer Endpunkt der Untersuchung war die Evaluation des Gesamtverletzungsmusters und der Verletzungsschwerpunkte. Des Weiteren wurden Parameter wie epidemiologische Aspekte, Unfallumstände sowie Behandlungsschwerpunkte und das Outcome untersucht. Die 3 meistbetroffenen AIS-Regionen waren der Kopf, gefolgt vom Thorax und den oberen Extremitäten. In zweidrittel der Fälle wurde ein ISS ≥ 9 isoliert durch das Schädel-Hirn-Trauma erreicht, in jedem fünften Fall lag eine Monoverletzung vor. Es resultierten eine charakteristische Altersverteilung und Prävalenz der Unfälle in Bezug auf den Unfallzeitpunkt. Mit einer Prävalenz von über 30% sind Verletzungen der oberen Extremitäten und des Thorax relevante Trigger zum Erreichen des Verletzungsstatus.(Helfen, Lefering, et al., 2017) Eine Prestudy mit gleicher Methodik für n=5.427 schwerverletzte Motorradfahrer ergab sogar eine Prävalenz von 50% Verletzungen der oberen Extremitäten. Beine Kollektive stellen das größte jemals untersuchte standardisierte Kollektiv schwerverletzter Zweiradfahrer dar.

Eine zweite präklinische Arbeit befasste sich mit der Schulterluxation als häufige Verletzung. Im Fokus standen epidemiologische Aspekte sowie Fragen aus dem Bereich der Versorgungsforschung. Schulterluxationen wurden prospektiv an 16 Notarztstandorten erfasst. Neben den epidemiologischen Daten wurden auftretende Begleitverletzungen sowie das Management und die Ergebnisse der Repositionen untersucht. Es wurde n=70 Patienten mit einem mittleren Alter von 40,2±19,3 Jahren erfasst. Die Schulterluxation ist somit eine Verletzung des jüngeren Patienten. Eine unmittelbare Reposition erfolgte in etwa zweidrittel der Fälle, 10% der Patienten wiesen eine pathologische Neurologie auf, Gefäßkomplikationen wurden keine beobachtet. Es gab keine signifikant unterschiedlichen Ergebnisse bezüglich des Managements der Verletzung zwischen Notärzten der Fachrichtungen Chirurgie und Anästhesie. Die Überlegenheit einer bestimmten Repositionstechnik wurde nicht beobachtet. Die hohe Anzahl erfolgreicher Repositionen schließt Frakturen des proximalen Humerus als Begleitverletzung überwiegend aus, diese kommen relevant im höheren Alter vor. Diese Ergebnisse unterstreichen die weiter oben aufgeführten altersbezogenen Vorarbeiten aus der Grundlagenforschung. Die Indikation zur frühen Reposition ist abhängig vom neurovaskulären Befund der betroffenen Extremität. Erfahrung spielt eine größere Rolle als die Empfehlung einer bestimmten Repositionstechnik. Eine Reposition im präklinischen Setting ist empfehlenswert aber nicht obligat.(Helfen, Ockert, Pozder, Regauer, & Haasters, 2016)

Ein wichtiges bildgebendes Diagnostikum der Schulterchirurgie ist die Magnetresonanztomographie (MRT). Die Qualität der radiologischen Befundung variiert stark, diese ist jedoch relevant für die Erfassung aller Befunde und Beantwortung aller Fragestellungen des Chirurgen sowie letztendlich ausschlaggebend für eine operative versus konservative Behandlungsstrategie. In einer komparativen Arbeit wurden n=30 pathologische MRT-Befunde der Schulter zum einen mit strukturierten Textbausteinen standardisiert, zum anderen als Freitext von jeweils zwei Schulterchirurgen auf Verständlichkeit und Vollständigkeit hin beurteilt. Evaluationsmedium war ein standardisierter Fragenkatalog. Die Entscheidung zwischen konservativer und operativer Therapie konnte in n=55 (92%) der standardisierten und nur in n=45 (75%) der Freitextgruppe getroffen werden. Die Verständlichkeit der relevanten Informationen wurde mit 92% bei den standardisierten Texten vs. 62% bei den Freitexten bewertet. Die Standardisierung von MRT-Befunden der Schulter steigert die Reliabilität der Befunde signifikant.(Gassenmaier et al., 2017)

Für die proximale Humerusfraktur sind mehrere Versorgungsfragen bislang ungeklärt. In einer Reihe von Arbeiten wurden Kofaktoren untersucht, die einen Einfluss auf das postoperative Outcome der Patienten haben könnten:

Die operative Expertise des Operateurs wurde für viele andere Bereiche der Chirurgie thematisiert und Einflüsse auf das Outcome nachgewiesen. Die Zweifragmentfrakturen des proximalen Humerus vom Typ AO 11-A2 und A3 sind als vergleichbar anzusehen und stellen eine geeignete Verletzung für diese Untersuchung dar. In dieser Arbeit wurden Patienten erfasst, die sich aufgrund einer dislozierten proximalen Humerusfraktur einer operativen Behandlung unterzogen mussten (n=1.411). Davon wurden n=278 Patienten identifiziert, bei denen eine subkapitale 2-Fragment Fraktur vorlag die mittels winkelstabiler Plattenosteosynthese versorgt wurde, eine anatomische Reposition erzielt wurde und ein identisches Nachbehandlungsschema Anwendung fand. Ausgewertet wurde der Weiterbildungsgrad des verantwortlichen Operateurs (Facharzt [FA] vs. Zusatzbezeichnung Unfallchirurgie bzw. Spezielle Unfallchirurgie [SU] vs. Facharzt mit oder ohne Zusatzbezeichnung mit >50 Schulteroperationen/Jahr [SS]). Outcomeparameter waren das funktionelle Ergebnis gemessen am alters- und geschlechtsnormalisierten Constant Score (nCS) sowie die Komplikations- und Revisionsraten. Das funktionelle Outcome (nCS) verbesserte sich mit jedem Anstieg des Weiterbildungsgrades und war am besten im Kollektiv der Schulterchirurgen. Zudem hatten diese signifikant weniger Komplikationen und signifikant weniger Revisionseingriffe. Die Qualität der anatomischen Reposition und des funktionellen Outcomes nach winkelstabiler Plattenosteosynthese der 2-Fragment-Fraktur des proximalen Humerus ist wesentlich beeinflusst von der Expertise des

Operateurs. Zudem sind Komplikationen und Revisionseingriffe relevant seltener bei Chirurgen mit einer Erfahrung von mehr als 50 Schulteroperationen pro Jahr.(Helfen, Siebenburger, Fleischhacker, et al., 2018)

Komplikationsraten nach operativer Versorgung proximaler Humerusfrakturen werden mit einer Inzidenz von bis zu 40% beschrieben. Der langfristige Einfluss frakturspezifischer Versorgungsoptionen sowie der Einzug der Frakturendoprothetik auf die Komplikationsraten wurden bislang noch nicht untersucht. Ziel einer Langzeitstudie war es die Inzidenz der Komplikationen und Revisionszahlen nach Plattenosteosynthese unter Berücksichtigung dieser selektiven Versorgungsoptionen zu analysieren. Über 11 Jahre wurden 788 Patienten eingeschlossen, die eine proximale Humerusfraktur erlitten hatten und sich einer operativen Versorgung mittels winkelstabiler Plattenosteosynthese, primärer Fraktur-Hemiprothese oder einer inversen Frakturprothese unterzogen. Ergebnisse: N=646 (82%) der Patienten wurden mittels winkelstabiler Plattenosteosynthese versorgt, n=82 (10,4%) mittels Fraktur-Hemiprothese und n=60 (7,6%) mittels inverser Frakturprothese. Die höchste Komplikationsrate (12,6%) war in der Gruppe der winkelstabilen Plattenosteosynthesen nachweisbar, Revisionen wurden in 11,6% der Fälle notwendig. In den letzten 5 Jahren des Untersuchungszeitraumes nahm die Indikation der inversen Frakturendoptothese deutlich zu, hierdurch konnte eine Reduktion der Komplikationen vor allem im Bereich der sekundären Dislokationen relevant reduziert werden (14,3% auf 4,8%). Die Komplikationsrate der winkelstabilen Plattenosteosynthese nach proximaler Humerusfraktur konnte in den letzten Jahren relevant reduziert werden. Dies scheint vor allem durch die steigende Indikation der inversen Frakturprothese erreicht worden zu sein. (Haasters et al., 2016)

Ein weiterer beeinflussender Faktor kann der Operationszeitpunkt sein. Ziel einer weiteren Studie war es daher, die Komplikationen des Verfahrens zu verschiedenen Operationszeitpunkten zu analysieren. Über einen Zeitraum von 8 Jahren (2002-2010) wurden 497 Patienten eingeschlossen, die sich eine operationspflichtige proximale Humerusfraktur zuzogen und mittels winkelstabiler Plattenosteosynthese versorgt wurden. Outcomeparameter waren: sekundärer Repositionsverlust, Schrauben-Cutout und avaskuläre Nekrosen. In n=329 Fällen betrug die mittlere Zeit bis zur Operation 3,2 Tage (95% CI: 3,1;3,2). Head-Split-Frakturen wurden nach 2,2 Tagen (95% CI: 2,0;2,4) und Luxationsfrakturen nach 0,8 Tagen (95% CI: 0,7;0,9) versorgt. Patienten mit Komplikation wurden gemittelt nach 2,5 Tagen (95% CI: 1,8;3,2). Die Odds-Ratio in Bezug auf die Komplikationen bei Patienten mit Operation ≤48h lag bei 0,924, für Patienten in denen die Operation 3-5 Tage nach dem Unfall erfolgte bei 0,836 und bei Patienten mit operativer Versorgung > 5 Tage 1,637. Ein

Repositionsverlust nach winkelstabiler Plattenosteosynthese bei proximaler Humerusfraktur konnte nicht unterschiedlich häufig in den Kollektiven mit Versorgung ≤48h und 3-5 Tagen nachgewiesen werden. Dennoch wurde für die Versorgungen nach >5 Tagen mehr Komplikationen nachgewiesen. Daher sollte die osteosynthetische Frakturversorgung in den ersten 5 Tagen erfolgen. Head-Split Frakturen oder Frakturen mit einer Luxationskomponente sollten unter Berücksichtigung des Risikos der avaskulären Nekrose binnen 48 Stunden versorgt werden.(Siebenburger et al., 2015)

Einen ebenfalls hohen Stellenwert haben Verletzungen des Akromioklavikularkomplexes. Hier bestehen Fragen zur operativen Versorgung aber auch zur Verbindung zwischen Verletzungen dieser Region und dem Glenohumeralgelenk im Sinne von Begleitverletzungen.

Ein großes Thema in allen Bereichen der Traumatologie sind die Begleitverletzungen, die sich im Umfeld der Primärverletzung finden lassen und zum Teil erheblichen Einfluss auf die Behandlung und das Outcome haben. Im Zusammenhang mit lateralen Klavikulafrakturen werden glenohumerale Begleitpathologien beschrieben. Zum einen ist die Charakterisierung dieser Begleitverletzungen bislang noch nicht hinreichend durchgeführt worden, zum anderen ist die Wertigkeit und Relevanz sowie die Behandlungsindikation ungeklärt. Ziel dieser Arbeit war die Evaluation der Begleitpathologien sowie deren Wertung im Hinblick auf Therapierelevanz. Über einen Zeitraum von 4 Jahren (2011-2015) wurden 41 Patienten eingeschlossen, die sich eine operationspflichtige laterale Klavikulafraktur zuzogen. N=20 Patienten (Gruppe 1) erhielten eine arthroskopisch gestützte Frakturversorgung mit Augmentation der coracoklavikulären Bänder. N=21 Patienten (Gruppe 2) erhielten eine osteosynthetische Versorgung mittels Hakenplatte, eine Schultergelenksarthroskopie wurde erst zum Zeitpunkt der Materialentfernung durchgeführt. Alle Arthroskopien wurden standardisiert durchgeführt, die intraoperativen Befunde wurden doppelt verblindet von zwei unabhängigen Untersuchern analysiert. Begleitverletzungen bestanden in Labrumläsionen, Rotatorenmanschettenrupturen und Läsionen des Biceps-Pulley-Komplexes. Die Studie konnte akute und zum ersten Mal mittelfristige Prävalenzen von glenohumeralen Begleitverletzungen nach lateraler Klavikulafraktur angeben. Zu beiden Zeitpunkten betrug die Prävalenz gemittelt 27%. Nicht alle Begleitverletzungen waren symptomatisch. Eine Begleitverletzung muss vor allem bei prolongierten Beschwerden antizipiert werden. Unbehandelte symptomatische Pathologien können die Heilung relevant verzögern.(Helfen, Siebenburger, Haasters, Bocker, & Ockert, 2018)

Die operativen Verfahren zur Behandlung der akuten Akromioklavikular(AC)-Gelenk-Instabilität sind vielfältig. Neben den offenen Techniken finden zunehmend arthroskopisch gestützte Verfahren Anwendung. Jedes Vorgehen bietet spezifische Vor- und Nachteile, bisher hat sich jedoch keines als

Goldstandard durchgesetzt. Ziel dieser systematischen, metaanalytischen Auswertung war es daher, die vorhandene Evidenz für arthroskopische und offene Operationstechniken zusammenzufassen. Entsprechend dem Cochrane Handbook for Systematic Reviews of Interventions wurde eine Literaturrecherche in den medizinischen Datenbanken MEDLINE und Embase über den Zeitraum der letzten 10 Jahre durchgeführt. Von 961 Studien wurden 32 Arbeiten in diese Übersichtsarbeit aufgenommen. Drei Arbeiten eigneten sich für eine metaanalytische Auswertung. Die arthroskopischen bzw. minimal-invasiven Techniken zeigten tendenziell bessere funktionelle Ergebnisse anhand des Constant-Scores (gewichtete Mittelwertdifferenz 5,60; 95 %-Konfidenzintervall 0,36–10,64). Hinsichtlich Komplikationsrate, Repositionsergebnis und AC-Gelenk-Instabilität zeigte sich kein signifikanter Unterschied, lediglich Tendenzen pro arthroskopisch gestützte Verfahren. Bei inkonsistenter Studienlage gibt es demnach noch keine Evidenz für eine Überlegenheit offener oder arthroskopischer/minimal-invasiver Verfahren.(Helfen, Siebenburger, Ockert, & Haasters, 2015)

3. Aktueller Stand der Forschung

3.1 Anatomie der Schulter

3.1.1 Der proximale Humerus und das Glenohumeralgelenk

Die Schulter ist ein komplexes anatomisches System und mit all ihren Komponenten als funktionelle Einheit zu betrachten(Terry & Chopp, 2000). Zentrum der Schulter ist das Glenohumeralgelenk, die Artikulation des Caput humeri des proximalen Humerus mit dem Glenoid der Scapula.

Die Capsula articularis besteht aus einer äußeren Membrana fibrosa und einer inneren Membrana synovialis von der aus die Synovialflüssigkeit sowohl produziert als auch resorbiert wird. Sie entspringt medial des Glenoids und zieht nach lateral hinter die Knorpel-Kochen-Grenze des proximalen Humerus (Abbildung 1).

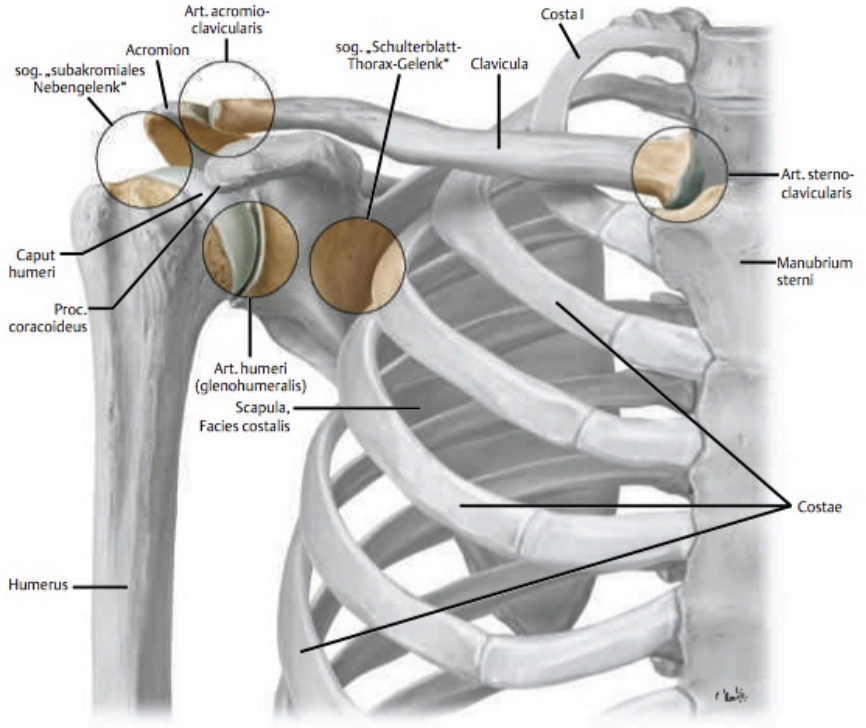


Abbildung 1: knöcherne Anatomie der Schulter mit proximalem Humerus, Glenoid, Scapula, Klavikula, Sternum und Rippenthorax

Die hinteren und insbesondere die drei vorderen glenohumeralen Bänder (oberes, mittleres und unteres glenohumerales Band) stabilisieren die Capsula articularis (Abbildung 2). Diese Verstärkung ist insbesondere relevant für Luxationsmomente. Hinzu kommen mehrere stabilisierende Bänder in der glenohumeralen Umgebung wie die des coraco-acromio-klavikulären Komplexes lateral und die des sterno-costalen Komplexes medial(Burkart & Debski, 2002).

Zur glenohumeralen Zentrierung des Schultergelenks und dessen Bewegung ist die Rotatorenmanschette essentiell. Sie besteht aus vier Muskeln mit ihren Enthesen. Der Musculus supraspinatus entspringt der Fossa supraspinata auf der dorsalen Seite der Scapula und inseriert an der oberen Facette des Tuberculum majus. Die Innervation erfolgt durch den Nervus suprascapularis des Plexus brachialis. Zusammen mit dem Musculus deltoideus führt er die Abduktion und Außenrotation des Oberarmes durch. Der Musculus subscapularis entspringt der ventralen Fossa subscapularis und

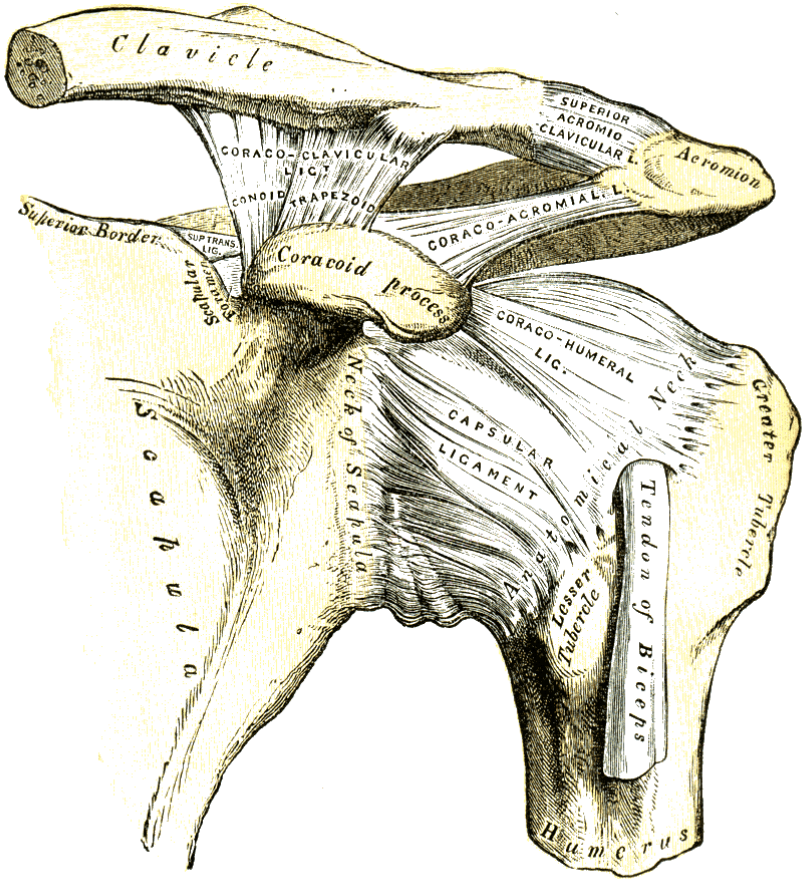


Abbildung 2: Ligamentäre Anatomie der Schulter von ventral

inseriert am Tuberculum minus. Die Innervation erfolgt durch die Nervi subscapularis des Plexus brachialis. Er führt die Innenrotation des Oberarmes durch. Der Musculus infraspinatus entspringt der Fossa infraspinata auf der dorsalen Seite der Scapula, Insertionsstelle ist das Tuberculum majus. Die Innervation erfolgt durch den Nervus suprascapularis, akzessorisch auch durch den Nervus axillaris des Plexus brachialis. Zusammen mit den dorsalen Anteilen des Musculus deltoideus führt er die Außenrotation durch. Der Musculus terres minor entspringt am Margo lateralis der Scapula und inseriert am Tuberculum majus des Humerus. Die Innervation erfolgt durch den Nervus axillaris des Plexus brachialis. Er führt zur Außenrotation, Retroversion und Adduktion des Oberarmes(Maruvada & Bhimji, 2017).

Der Musculus deltoideus mit seiner Pars clavicularis, Pars acromialis und Pars spinalis ist ein kräftiger, das Schultergelenk umhüllender und der Rotatorenmanschette aufliegender Muskel. Insertion ist die Tuberositas deltoidea. Die Innervation erfolgt über den Nervus axillaris des Plexus brachialis. Die Funktion ist vielfältig und komplex.

Der Musculus biceps brachii mit seinem Caput longum und Caput breve entspringt dem Tuberculum supraglenoidale (C. longum) und dem Processus coracoideus (C. breve) und inseriert an der Tuberositas radii. Die lange Bicepssehne passiert auf Höhe der Rotatorenmanschette das Pulley-System, eine Bindegewebsschlinge bestehend aus der Subscapularissehne, der Supraspinatussehne, dem superioren glenohumeralen Ligament und dem coracohumeralen Ligament. Die Innervation erfolgt durch den Nervus musculocutaneus des Plexus brachialis. Die Funktion ist führend die Flexion im Ellenbogengelenk, aber auch die Supination in Flexionsstellung (Abbildung 3,Abbildung 4).

Der Musculus pectoralis major hat einen breiten medialen Ursprung (Pars clavicularis, sternocostalis und abdominalis) und inseriert zur Crista tuberculi majoris des proximalen Humerus. Die Innervation erfolgt aus den Nervi pectoralis medialis und lateralis des Plexus brachialis. Funktionell führt er zur Anteversion, Adduktion und Innenrotation des Armes.

Im Falle einer proximalen Humerusfraktur kommt vor allem den kräftigen Musculi deltoideus und pectoralis major eine für die Frakturkonfiguration relevante Rolle zu. Durch den Delta-Zug an lateralen Fragmenten und den Pectoralis-Zug an medialen Fragmenten entstehen wesentliche Dislokationen. Gleiches ereignet sich im Bereich der Tubercula durch Zug der einzelnen Rotatorenmanschettenanteile.

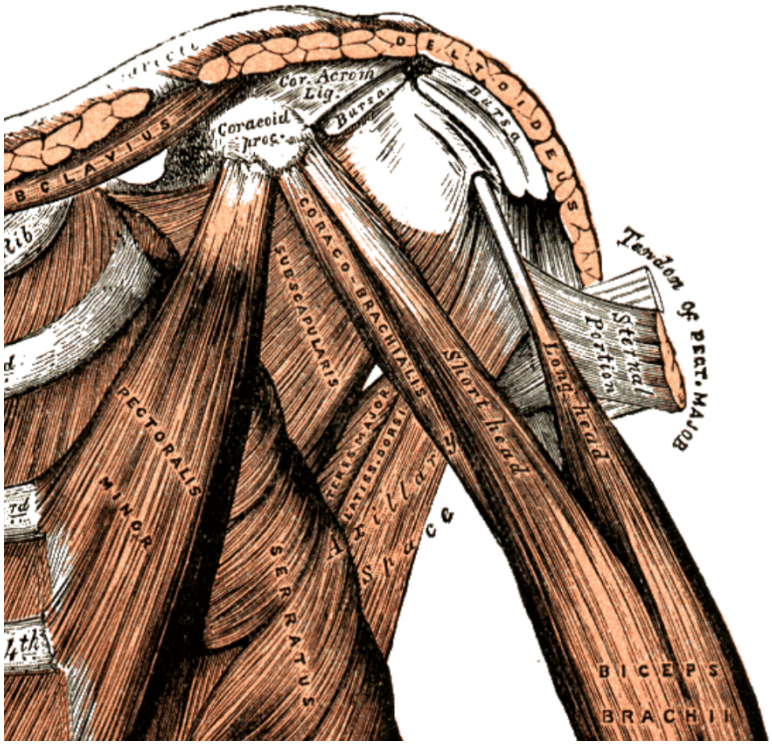


Abbildung 3: Ventrale muskuläre Anatomie der Schulter

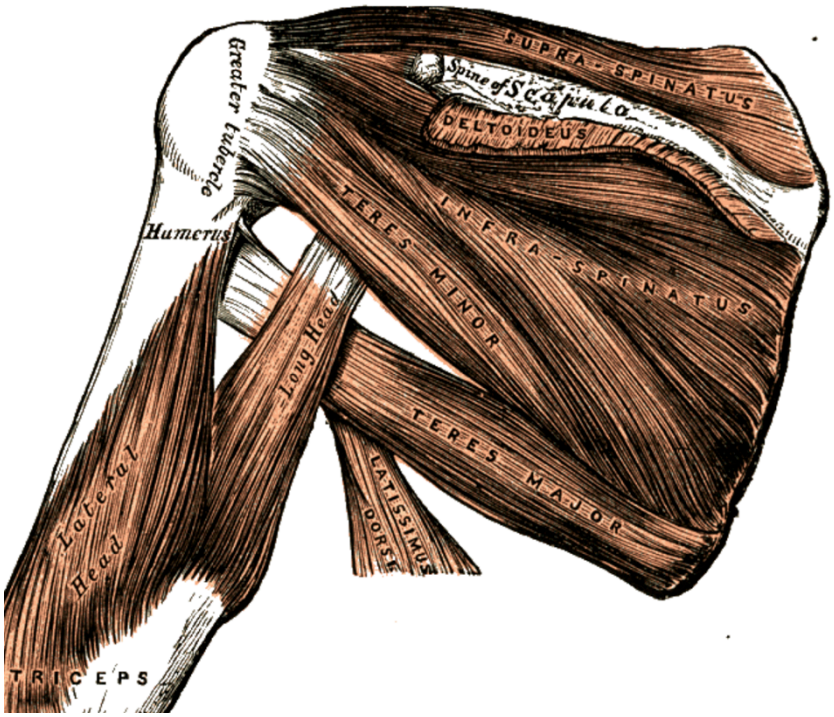


Abbildung 4: Dorsale muskuläre Anatomie der Schulter

Der Bereich des proximalen Humerus lässt sich in vier anatomisch relevante Teile gliedern: Das Caput humeri ist nach kranio-medial und leicht dorsal gerichtet, es bildet die artikulierende Fläche mit der Cavitas glenoidalis der Scapula. Das Collum humeri schließt sich unmittelbar distal des Caputs an. Es ist gegenüber der Gelenkfläche leicht eingezogen und bildet das Collum anatomicum. Die Gelenkkapsel inseriert in diesem Bereich. Das Tuberculum majus mit seinen relevanten Rotatorenmanschettenansätzen befindet sich lateral des Caputs, das kleinere Tuberculum minus liegt auf gleicher Ebene frontal. Der Humerusschaft mit seinen drei Flächen schließt nach distal an das Collum humeri (anatomicum) an. Eine weitere wesentliche anatomische Landmarke ist das Collum chirurgicum. Es liegt unterhalb der Tuberkelebene am Übergang zum Humerusschaft. In der Literatur wird es als „Sollbruchstelle“ bezeichnet (Abbildung 5) (Jo & Gardner, 2012).

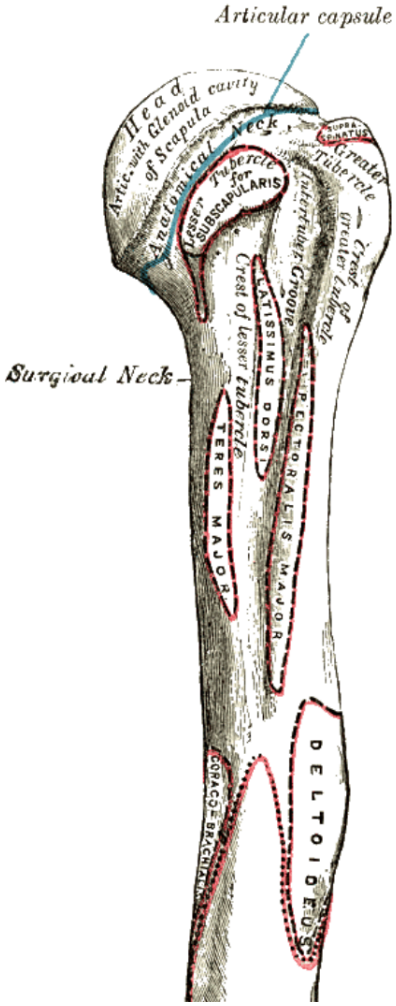


Abbildung 5: Knöcherne Anatomie und Enthesen des proximalen Humerus

3.1.2 Die Klavikula und ihre Gelenke

Die den Schultergürtel bildenden Knochen sind die Klavikula und die Scapula die sich im Acromioklavikulargelenk (ACG) verbinden. Das Acromion und der Processus coracoideus sind knöcherne Fortsätze der Scapula die zusammen mit dem lateralen Teil der Klavikula den knöchernen Teil des sogenannten coraco-acromio-klavikulären Komplexes bilden. Diesem Teil des Schultergürtels kommt eine essentielle Bedeutung zu (Abbildung 2)(Renfree & Wright, 2003).

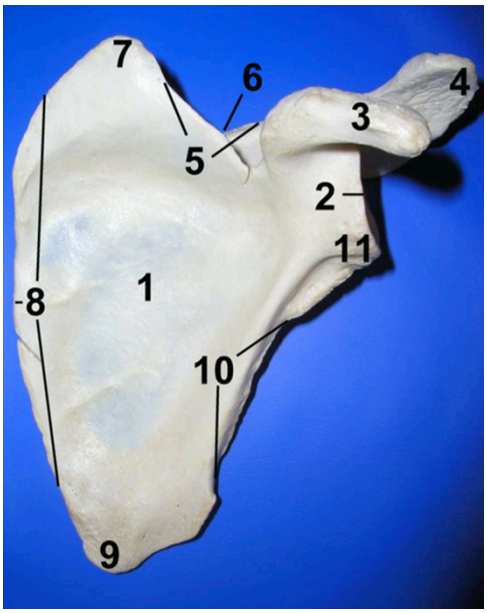
Die Klavikula des Menschen ist etwa 12–15 cm lang und s-förmig gebogen (Abbildung 6). Sie besitzt zwei Enden und den zentralen Corpus claviculae. Das mediale Ende wird als Extremitas sternalis bezeichnet und besitzt eine runde Gelenkfläche (Facies articularis sternalis), die Teil des Gelenks zwischen Sternum und Klavikula (Articulatio sternoclavicularis) ist. Das laterale Ende (Extremitas acromialis) bildet das ACG. Die entsprechende Gelenkfläche ist sattelförmig abgeflacht (Facies articularis acromialis). An der Oberseite der Klavikula setzt der Musculus deltoideus an. Mediokaudal liegt der Sulcus musculi subclavii, durch den der Musculus subclavius zieht. Im Bereich der kaudalen Extremitas acromialis befindet sich die Tuberositas ligamenti coracoclavicularis, die weiter unterteilt werden kann in ein Tuberculum conoideum und eine Linea trapezoidea. An diesen Strukturen inseriert das Ligamentum coracoclaviculare, das aus zwei Anteilen besteht, dem Ligamentum conoideum und dem Ligamentum trapezoideum(Renfree, Riley, Wheeler, Hentz, & Wright, 2003).

Abbildung 6: Vorderansicht der Klavikula

Das Acromion bildet beim Menschen den höchsten Punkt der Scapula. Die Facies superior dient wie auch der Margo lateralis als Ursprung des Musculus deltoideus. Medial bildet das Acromion den korrespondierenden Teil der Articulatio acromioklavikularis. Die Artikulationsfläche beträgt beim Erwachsenen etwa 9 mm in vertikaler und 19 mm in anteroposteriorer Ebene. Der acromioklavikuläre

Gelenkspalt beträgt zwischen 1 und 3 mm(Bonsell et al., 2000).

Der Processus coracoideus ist ein starker hakenförmig gebogener Knochenfortsatz der Scapula (Abbildung 3,7). Er entspringt am Angulus superior und zieht zunächst nach kranio-medial, um dann nach kaudo-lateral zu schwenken. Auf seinem Weg verjüngt er sich. Am Processus coracoideus entspringen das Caput breve des Musculus biceps brachii und der Musculus coracobrachialis. Des Weiteren setzen hier der Musculus pectoralis minor an (Conjoint tendons) sowie das Ligamentum coracoacromiale und das Ligamantum coracoclaviculare (s.u.)(Bhatia, de Beer, & du Toit, 2007).



1 Fossa subscapularis, 2 Angulus lateralis mit Cavitas glenoidalis, 3 Processus coracoideus, 4 Acromion, 5 Margo superior, 6 Incisura scapulae, 7 Angulus superior, 8 Margo medialis, 9 Angulus inferior, 10 Margo lateralis, 11 Tuberculum infraglenoidale

Abbildung 7: Vorderansicht der Scapula mit Acromion (4) und Processus coracoideus (3)

Im ACG befindet sich ein Discus dessen Konfiguration jedoch sehr variabel ist. Selten existiert ein vollständiger Discus, häufiger ein meniscoider Discus. Die Dicke variiert zwischen 1,4 und 4 mm und unterliegt einer altersabhängigen Degeneration(Heers et al., 2007; Salter, Nasca, & Shelley, 1987). Die Gelenkkapsel ist sehr dünn, jedoch gut ligamentär integriert. Es existieren 4 verschiedene AC-Ligamente (superior, inferior, anterior und posterior), wobei das superiore Ligament das kräftigste aller darstellt(Salter et al., 1987).

Horizontal wird das ACG neben seiner Gelenkkapsel durch das kräftige Lig. acromioclaviculare

superius und die Faszien des M. deltoideus und des M. trapezius stabilisiert. Die vertikale Stabilität erfolgt durch das vom Processus coracoideus herziehende Lig. coracoclaviculare mit seinem lateralen Lig. trapezoideum und medialen Lig. conoideum. Das Ligamentum coracoacromiale ist ein starkes, dreieckförmiges Band, das sich zwischen dem Processus coracoideus und dem Acromion ausspannt. Die Verteilung der Insertionsflächen sowie die Stärken der einzelnen Bandstrukturen sind deutlich heterogen(Salter et al., 1987).

Das mediale Ende der Klavikula läuft in der Articulatio sternocostalis aus. Dieses Gelenk zwischen Kalvikula und Sternum (Incisura clavicularis) ist ebenfalls von einer Kapsel umgeben und enthält einen Discus (Abbildung 1). Die Region stellt das ventrale Zentrum des Schultergürtels dar und ist vielfältig ligamentär integriert. Das sternoclaviculäre Band stellt die Verbindung zum Sternum dar, darüber hinaus bestehen Verbindungen zur zweiten Klavikula (Lig. interclaviculare) sowie zur 1. Rippe (Lig. costoclaviculare).

3.2 Grundlagen hochauflösender Bildgebung

3.2.1 Histomorphometrie

In der Histomorphometrie werden histologische Dünnschnittpräparate über ein mittels Mikroskop vergrößertes Bild von einer Digitalkamera erfasst. Eine Histomorphometrie-Software kann anschließend verschiedene Parameter des Bildes evaluieren. Die Histomorphometrie wird additiv zur computertomographischen Bildgebung angewandt da sie in erster Linie zu einer Verbesserung der Trennschärfe zwischen Knochen und Markraum im trabekulären Bereich beiträgt. Sie dient der Reduzierung störender „partial Volume“ Effekte wie sie bei der CT-Anwendung unvermeidbar sind.

Der „partial Volume“-Effekt ist ein Bildartefakt in der Computertomographie. Der Effekt entsteht, wenn ein Objekt nur von einem Teil der gewählten Schichtdicke dargestellt wird. Dies geschieht entweder, weil das Objekt nur teilweise in die Schicht hineinragt oder weil das Objekt kleiner als die Schichtdicke ist. Es wird dann die über die Schichtdicke gemittelte Dichte des Objektes angezeigt. Damit kann sich im Bild ein Knochen mit der Dichte eines Weichteilgewebes darstellen. Oft stellen sich Partialvolumeneffekte streifig im Bild dar. Sie sind umso häufiger, je größer die Schichtdicke ist.

Die unterschiedlichen Gewebe werden durch ihr histochemisches Färbeverhalten von der Software selektiert und im Bild markiert. Die Software erstellt aus dem Farbbild ein Binärbild, dieses ist Grundlage für alle weiteren Evaluationen. Knochenflächen, Umfänge oder Gesamtflächen eines Bildausschnittes können ermittelt und weiteren Berechnungen zur Verfügung gestellt werden(Revell, 1983).

Vor allem der trabekuläre aber auch der kortikale Knochen ist räumlich komplex aufgebaut. Mittels Strukturmodellen werden aus den zweidimensionalen Messinformationen Rückschlüsse auf dreidimensionale Parameter kalkuliert. Folgende Strukturparameter können ermittelt werden: Bone Volume per Tissue Volume (BV/TV): Knochenvolumen im Verhältnis zum Gewebevolumen; Trabekeldicke (Tb.Th.): Angabe in µm; Trabekelanzahl (Tb.N.): Absolute Anzahl pro gemessene Fläche; Trabekulärer Abstand (Tb.Sp.): Abstand zwischen den Knochenbalken (Tb.Sp.), Angabe in µm. Folgende statische Knochenstrukturparameter können ermittelt werden: Osteoidvolumen pro Gewebevolumen (OV/TV): Osteoidvolumen im Verhältnis zum Gewebevolumen, Angabe in Prozent; Osteoidvolumen pro Knochenvolumen (OV/BV): Osteoidvolumen im Verhältnis zum Knochenvolumen, Angabe in Prozent; Osteoidoberfläche pro Knochenoberfläche (OS/BS): Osteoidoberfläche im Verhältnis zur Knochenoberfläche, Angabe in Prozent(Dempster et al., 2013; Parfitt et al., 1987).

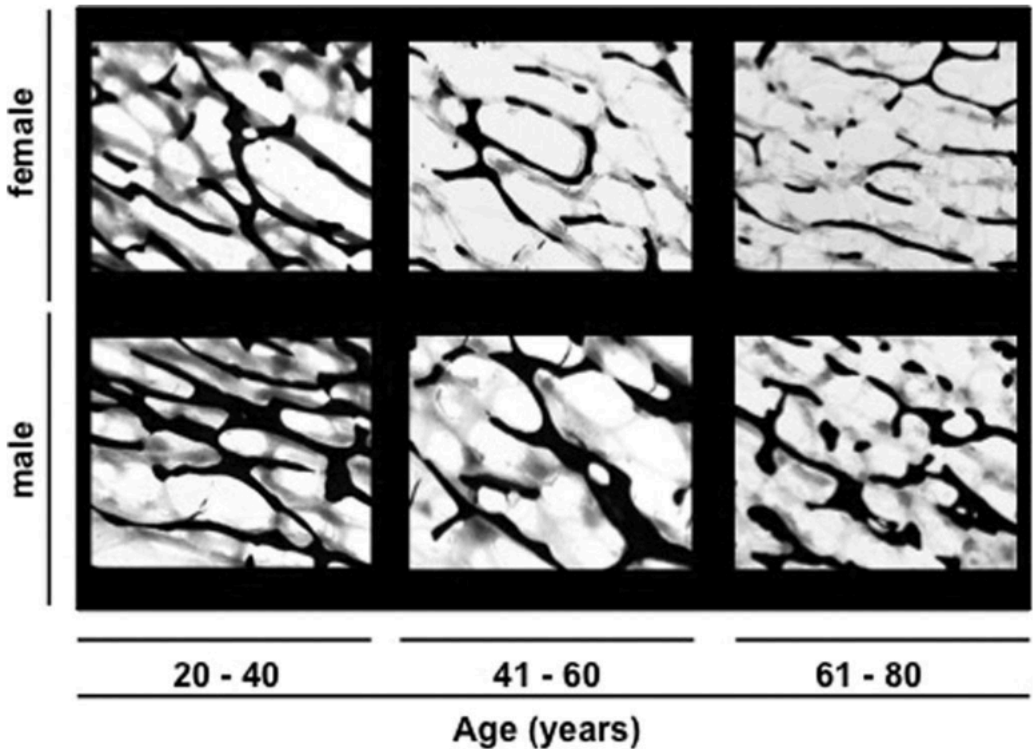


Abbildung 8: Histomorphometrisches Beispiel (Schnittdicke 1 mm; Vergrößerung 20 ; Schwarz: mineralisierter Knochen) Ausschnitte distaler Radii dreier Altersgruppen, getrennt in männliche und weibliche Proben

3.2.2 Hochauflösende periphere quantitative Computertomographie

Die hochauflösende periphere quantitative Computertomographie (HRpQCT) ist eine Form der Computertomographie, die zur Evaluation der Knochenmikrostruktur entwickelt wurde. Verschiedene Knochendichteparameter werden ermittelt, die isotrope Voxelgröße beträgt 82µm. Strukturelle Parameter sind die: Kortikale Dicke, trabekuläre Separation, trabekuläre Zahl und Volumenfraktionen.

Die Bildgenerierung erfolgt analog zu den herkömmlichen Verfahren. Die Größe der scannbaren Präparate ist limitiert. Eine Scanstrecke der Länge 9 mm benötigt knapp 3 Minuten (XtemeCT; Scanco

Medical, Brüttisellen, Schweiz). Nach Kalibrierung mittels Phantom wird das fixierte Präparat gescannt. Die Rohdaten werden zweidimensional rekonstruiert, die Bilder erscheinen nach Abschluss als Graustufenbilder. Zur Evaluation der einzelnen Parameter ist eine Separation notwendig. Hier wird in der Regel semi-automatisch mit Filtern und Thresholds gearbeitet. Aktuelle Studien wiesen mittels hochauflösenden bildgebenden Verfahren Knochenumbauprozesse des Radius, des Femurs und der Tibia auf. Vor allen konnten osteoporotische Veränderungen des kortikalen Knochens erstmals nachgewiesen werden(Nishiyama, Macdonald, Buie, Hanley, & Boyd, 2010; Popp et al., 2012; Zebaze et al., 2010).

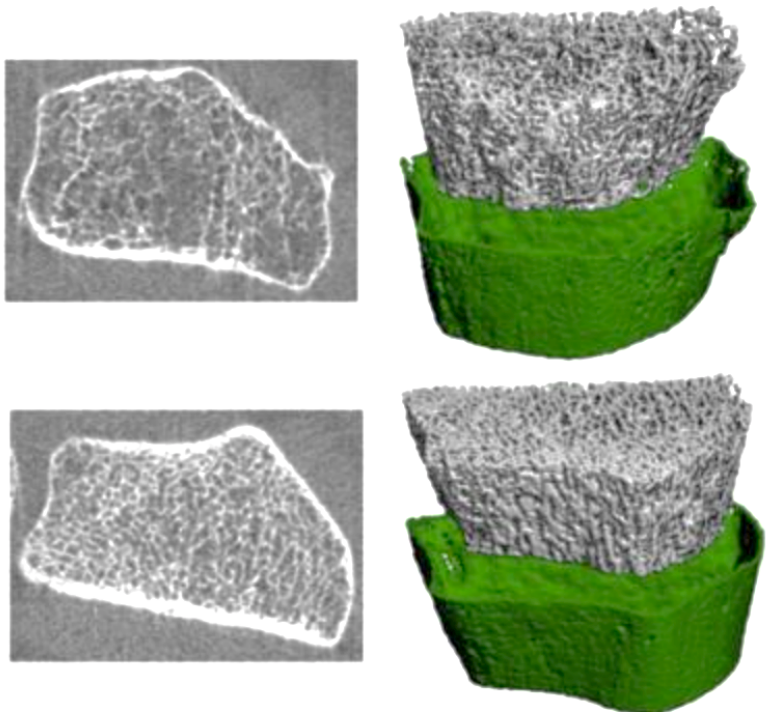


Abbildung 9: HR-pQCT Bilder zweier exemplarischer distaler Radii. Links sind die zweidimensionalen Bilder, rechts die Separation von Kortikalis und Spongiosa abgebildet(Khosla et al., 2006)

3.3 Hauptverletzungen der Schulter

3.3.1 Akutes Management von Schulterverletzungen

Verletzungen der Schulter entstehen äußerst heterogen. Eine häufige Verletzung stellt die Schulterluxation dar. Komplikationen werden mit bis zu 26% beschrieben (Pasila, Jaroma, Kiviluoto, & Sundholm, 1978), das initiale Management bis hin zur Reposition findet vor allem in der Präklinik oft ohne die Anwesenheit eines erfahrenen Chirurgen statt. Handlungsempfehlungen für diese Konstellationen existieren derzeit nicht. Verglichen mit den Frakturen der Schulter besteht aufgrund der potentiell kompromittierten neurovaskulären Strukturen und des Drucks auf den Gelenkknorpel in Luxationsstellung eine deutlich dringlichere Notwendigkeit der Soforttherapie im Sinne einer Reposition. Daher liegt der Fokus der Versorgung hier im initialen notfallmedizinischen Management.

Der Mehrheit isolierter Schulterverletzungen steht eine gewisse Prävalenz von Schulterverletzungen im Kontext einer Mehrfachverletzung, oft auch einer Polytraumatisierung im klassischen Sinne gegenüber. Der Diagnostik und Therapie der Einzelverletzungen kommt in dieser Situation eine deutlich veränderte Gewichtung zu. Der therapeutische Stellenwert einer Schulterluxation rückt beispielsweise angesichts schwerer weiterer, stark blutenden Verletzungen der gesamten oberen Extremität oder vital bedrohlichen Verletzungen der großen Körperhöhlen etc. nach hinten. Für viele Patientenkollektive die häufig mit schweren Mehrfachverletzungen verunfallen existieren keine Daten bezüglich Charakterisierung und Einfluss einzelner Verletzungen in Bezug auf die Gesamtverletzungsschwere. Eine aussagekräftige Gesamterfassung und Evaluation der Verletzungen sowie die Definition von Verletzungsschwerpunkten einzelner Kollektive existiert nur ungenügend, entweder werden in der Literatur lediglich einzelne Regionen betrachtet, nicht standardisierte Kollektive oder zu geringe Fallzahlen untersucht. (Eid et al., 2009)

Die Magnetresonanztomographie der Schulter ist ein Hauptdiagnostikum bei vorliegenden akuter aber auch chronischer Schulterpathologien. Sie ist neben der klinischen Untersuchung des Patienten oftmals das wichtigste Kriterium, wenn eine Operationsindikation zu stellen ist. Daher ist eine enge Zusammenarbeit zwischen Radiologen und Chirurgen notwendig, eine klare Sprache der Befundberichte essentiell. In vielen Bereichen der Medizin erwiesen sich standardisierte und strukturierte Befundberichte als signifikante Verbesserung des Verständnisses und der Entscheidungsfindung. Für die Befundung der zum Teil komplexen Fragestellungen der Schulterregion wurde bislang jedoch noch keine Standardisierung evaluiert. (Langlotz, 2009)

3.3.2 Die proximale Humerusfraktur

Proximale Humerusfrakturen stellen mit einer Inzidenz von 4-5% die dritthäufigste Fraktur des älteren Menschen dar. Unter allen Frakturen der oberen Extremitäten handelt es sich um die zweithäufigste Fraktur nach der distalen Radiusfraktur. 65% aller Patienten mit einer proximalen Humerusfraktur sind älter als 60 Jahre. Unter Berücksichtigung des demographischen Wandels ist mit einem relevanten Anstieg der Inzidenz zu rechnen. Kannus et al. konnte im Kollektiv der über 80-jährigen Patienten eine Inzidenz von 298 pro 100.000 aufweisen(Kannus, Palvanen, Niemi, Sievanen, & Parkkari, 2009). Palvanen et al. sagen eine Anstieg der Inzidenz um 50% bis zum Jahr 2030 voraus(Palvanen, Kannus, Niemi, & Parkkari, 2006).

In diesem Patientenkollektiv besteht eine enge Komorbidität mit dem Krankheitsbild Osteoporose. Die trabekulären Bereiche des proximalen Humerus konnten als Hauptaspekt des Knochenverlustes bei Osteoporose ausgemacht werden, durch den das Frakturrisiko zunimmt. Die kortikalen Bestandteile des proximalen Humerus wurden bisher nicht berücksichtigt obwohl diese die größte Masse des knöchernen Skeletts darstellen.

Nahezu 80% der proximalen Humerusfrakturen sind gering oder nicht disloziert und einer konservativen Therapie gut zugänglich. Die funktionellen Ergebnisse sind zufriedenstellend. In 20% der Fälle besteht eine Operationsindikation. Zur Indikationsstellung tragen im Wesentlichen die Neer-Kriterien bei. Diese sind erfüllt wenn eine Abkippung der Fragmente um mehr als 45°, eine Dislokation von Humeruskopf und -Schaft um mehr als 10 mm oder eine Dislokation des Tuberculum majus um mehr als 5 mm vorliegt(C. S. Neer, 2nd, 1970a, 1970b).

Die Frakturen des proximalen Humerus wurden in der Vergangenheit nach unterschiedlichen Gesichtspunkten klassifiziert. Die im klinischen Alltag gebräuchlichste ist die nach der Arbeitsgemeinschaft für Osteosynthesefragen (AO/OTA) aus dem Jahr 1990. Diese unterscheidet einfache extraartikuläre Frakturen (AO 11-A1-A3) von extraartikulär bifokalen Frakturen (AO 11 B1-B3) und intraartikulären Frakturen (AO 11 C1-C3)(Müller ME).

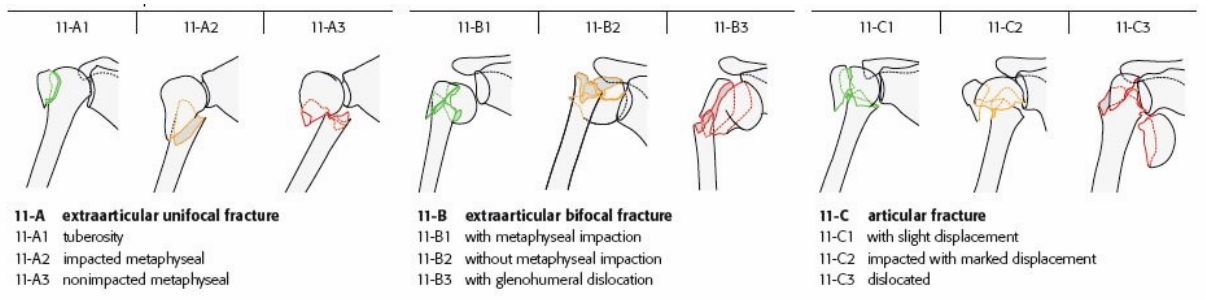


Abbildung 10: Klassifikation der proximalen Humerusfrakturen der AO/OTA.

Die winkelstabile Plattenosteosynthese als am häufigsten genutztes Osteosyntheseverfahren am proximalen Humerus ergab unzufrieden stellende funktionelle Langzeitergebnisse in 16% der Fälle und Komplikationsraten von bis zu 40%. Zudem ergaben Arbeiten zum Frakturtyp aufgrund unterschiedlicher Komplikationsraten die Notwendigkeit der Differenzierung der einzelnen Frakturkonstellationen, die unter dem Begriff „proximale Humerusfraktur“ subsumiert werden. So wurde zum Beispiel ein deutlich höheres Risiko für sekundäre Dislokationen bei den Zweifragment-Frakturen (AO 11-A3) nachgewiesen (Haasters et al., 2016).

Abbildung 11: PHILOS® Plattenosteosynthese,
Fa. DepuySynthes

In den letzten Jahren hat die Zahl der primären endoprothetischen Frakturversorgungen bei proximalen Humerusfrakturen relevant zugenommen, zudem kam eine frakturspezifischere Wahl der Implantate. Diese Optionen könnten zu einer Verbesserung der Komplikationsraten der Osteosynthesen führen, da primär hoch dislokationsgefährdete oder nicht anatomisch rekonstruierbare Frakturen -vor allem 3- und 4-Fragment-Frakturen- sicherer endoprothetisch versorgt werden können (Ockert, Biermann, Haasters, Mutschler, & Braunstein, 2013). Der Einfluss der primären Frakturendoprothetik aber auch die zunehmende Präzision der Implantatwahl auf die langfristigen Komplikationsraten der Osteosynthesen ist bislang unklar.

Abbildung 12: Inverse Schulterfrakturendoprothese Reunion RFX®, Stryker

Eine weitere Frage im Zusammenhang mit der Versorgung auch im Hinblick auf die sehr variablen und zum Teil komplexen Frakturkonfigurationen ist die Determinierung eines geeigneten Operationszeitpunktes. Komorbiditäten, Kompetenzen der Operateure und die klinischen Kapazitäten führen zu einer Variabilität des Operationszeitpunktes. Versorgungsverzögerungen könnten vor allem

die Vitalität einzelner Frakturfragmente kompromittieren und zu Nekrosen führen. In wie weit das Gelingen der Versorgung einer operationspflichtigen proximalen Humerusfraktur durch den Operationszeitpunkt beeinflusst wird ist bislang genauso unklar wie die Beeinflussung durch die Expertise des Operateurs.

3.3.3 Verletzungen der Klavikula

Frakturen der Klavikula stellen mit 35-45% eine weitere Hauptverletzung des Schultergürtels dar(Postacchini, Gumina, De Santis, & Albo, 2002). Hiervon fallen 10-15% der Frakturen auf das laterale Drittel(Craig E. Fractures of the clavicle. The Shoulder). Neer klassifizierte die lateralen Klavikulafrakturen entsprechend ihrer Beziehung zum coraco-acromio-klavikulären Bandkomplex(C. S. Neer, 2nd, Fractures of the distal third of the clavicle. Clin Orthop Relat Res, 1968. 58: p. 43-50.). Jäger und Breitner führten auf gleicher Basis weitere Subklassifikationen durch(Jager & Breitner, 1984). In der Edinburgh-Klassifikation von Robinson(Robinson, 1998) sowie der Craig-Klassifikation (Rockwood, CA, vol 1, & 1216–1217) werden laterale Klavikulafrakturen nach dem Ausmaß der Dislokation und der Beteiligung des ACG unterteilt, diese Einteilung hat sich jedoch im deutschsprachigen Raum noch nicht etabliert. Entscheidender Aspekt aller Klassifikationen ist die Stabilität, die anhand der ligamentären Integration beurteilt wird. Die Klassifikationen unterscheiden stabile laterale Klavikulafrakturen die einer konservativen Therapie gut zugänglich sind von den instabilen lateralen Klavikulafrakturen die eine Operationsindikation darstellen (Abbildung 13).

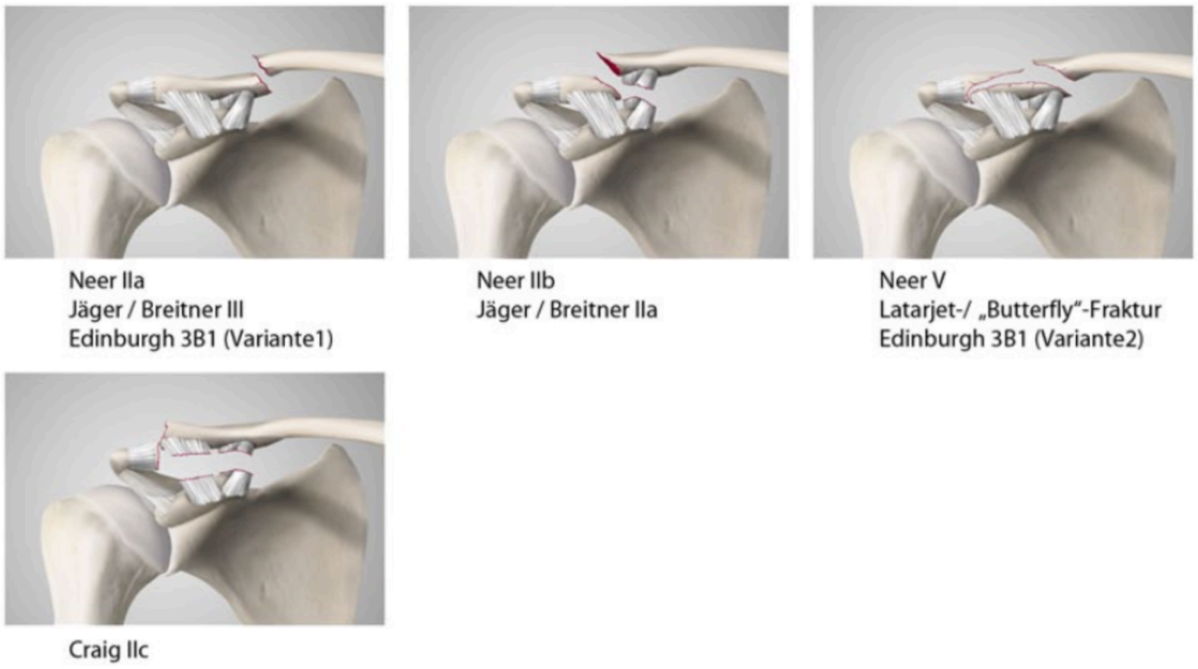


Abbildung 13: Übersicht der instabilen lateralen Klavikulafrakturen anhand der aktuell angewandten Klassifikationen.

Die akute ACG-Verletzung betrifft sehr häufig junge und aktive Erwachsene und ist mit einer Inzidenz von etwa 10% ebenfalls eine der häufigeren Schulterverletzungen(Mazzocca, Arciero, & Bicos, 2007). Diese Verletzungen entstehen durch direkte und indirekte Traumen auf den Schultergürtel(Johansen, Grutter, McFarland, & Petersen, 2011). Die Verletzungsschwere wird nach Rockwood klassifiziert und unterscheidet sich durch die Beteiligung der betroffenen ligamentären Strukturen (Rockwood CA) (Abbildung 14).

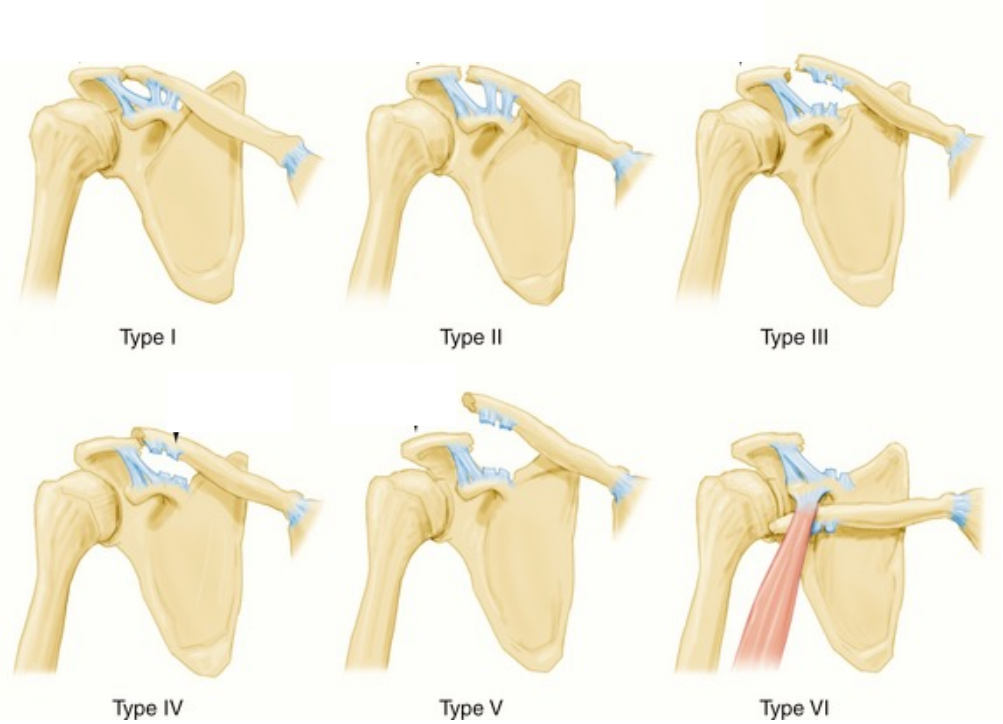


Abbildung 14: Übersicht über die ACG-Verletzungsgrade nach Rockwood.

Es herrscht weitgehend Einigkeit über die konservative Therapie von Verletzungen der Grade I und II, sowie über die operative Therapie von Verletzungen Grad IV–VI nach Rockwood(Salter et al., 1987). Ob die operative Therapie der Rockwood-III-Verletzung der konservativen überlegen ist, wird aktuell noch kontrovers diskutiert. Die funktionellen Ergebnisse nach konservativer Therapie werden hier als vergleichbar zu denen der operativen Behandlung angegeben(Bathis, Tingart, Bouillon, & Tiling, 2000; Beitzel et al., 2013; Gstettner, Tauber, Hitzl, & Resch, 2008; Phillips, Smart, & Groom, 1998). In der Literatur lassen sich hierzu jedoch nur drei qualitativ hochwertige, randomisierte Vergleichsstudien finden(Bannister, Wallace, Stableforth, & Hutson, 1989; Imatani, Hanlon, & Cady, 1975; Larsen, Bjerg-Nielsen, & Christensen, 1986). Bei genauerer Betrachtung liegen diese allesamt über 20 Jahre zurück, moderne Operationstechniken finden keine Beachtung.

In einem aktuellen Übersichtsartikel von Beitzel et al. werden 151 verschiedene operative Techniken zur Behandlung der Instabilität des ACG beschrieben, keinem Verfahren konnte bisher eine herausragende Überlegenheit nachgewiesen werden (Beitzel et al., 2013).

3.4 Zusammenfassung des aktuellen Forschungsstandes

In Gesamtschau des aktuellen Standes der Forschung sind von der Grundlagenforschung über das initiale Management bis hin zur operativen Versorgung von Schulterverletzungen viele Fragen ungeklärt.

Im Kontext des Frakturrisikos und der Frakturentstehung sind die mikrostrukturellen Knochenumbauprozesse des proximalen Humerus derzeit nur unzureichend untersucht. Gerade im am häufigsten betroffenen Kollektiv der Patienten über 60 Jahre scheint die Osteoporose als Komorbidität eine wesentliche Rolle zu spielen. Der kortikale Knochen als anteilsmäßig höchste knöcherne Fraktion wurde in diesem Zusammenhang bislang jedoch noch nicht berücksichtigt.

In der initialen Versorgungsphase von Schulterverletzungen müssen oft zeitkritische therapeutische Maßnahmen eingeleitet werden, die Verletzung jedoch gegebenenfalls gleichzeitig innerhalb eines Gesamtverletzungsmusters prioritätenorientiert versorgt werden. Besonders für diese zeitkritische Phase fehlen derzeit Behandlungsempfehlungen, zudem fehlen approximative Daten zur Prävalenz von Verletzungen der Schulter und der gesamten oberen Extremität vor allem in der Schwerverletztenversorgung.

Die MRT-Bildgebung akut verletzter oder chronisch degenerierter Schultern ist für die Therapieentscheidung ein essentielles Diagnostikum. Die Standardisierung und Strukturierung von Befundberichten wurde zur schnelleren, qualitativeren und effizienteren Versorgung von Patienten in mehreren Bereichen der Medizin bereits publiziert, für die zum Teil komplexen Fragestellungen der Schulter existieren hier keine Daten.

Die Anteile unzufrieden stellender funktioneller Ergebnisse der operativ versorgten proximalen Humerusfraktur sowie Komplikationen und Revisionen nach Osteosynthese mittels Standardverfahren ist je nach Frakturtyp relevant hoch. Der Versorgungszeitpunkt der proximalen Humerusfraktur ist durch Faktoren wie Implantatwahl, operative Expertise oder patienten- sowie klinikabhänge Begleitumstände variabel. Solche Kofaktoren könnten sich negativ auf den Behandlungserfolg auswirken und Komplikationen oder gar Revisionsindikationen steigern. Die Untersuchung der Auswirkung dieser Kofaktoren wurde für die osteosynthetische Versorgung der proximalen Humerusfraktur bislang noch nicht durchgeführt.

4. Projekte und Bedeutung für das Fachgebiet

4.1 Grundlagenforschung

4.1.1 Histomorphometrische Bestimmung der Knochenverteilung sowie der Einfluss der Osteoporose am proximalen Humerus

Hintergrund: Die proximale Humerusfraktur ist eine Indikatorfraktur für Osteoporose. Ziel dieser Arbeit war es die Knochenverteilung typischer Frakturzonen des proximalen Humerus in osteoporotischen und gesunden Probanden zu untersuchen.

Material und Methodik: Es erfolgte eine histomorphometrische Bestimmung der Knochenqualität proximaler Humeri von 12 Leichenspendern. Die Spenderknochen wurden anhand einer Dualenergie Röntgen Absorptiometrie(DXA)-Messung in gesunde und osteoporotische Knochen unterteilt. In den Kollektiven wurde eine standardisierte Kartierung (Abbildung 15) vorgenommen und die Dicke des subchondralen und trabekulären Knochens sowie die metaphysäre kortikale Dicke in definierten Arealen analysiert.

Ergebnisse: Das mittlere Alter der gesunden Knochen betrug 59±29 Jahre, das der osteoporotischen Knochen 79±9 Jahre. Der T-Wert der gesunden Gruppe betrug -0,9 bis 1,6, der T-Wert der Osteoporotiker -2,7 bis -6,5. Die Ergebnisse der histomorphometrischen Knochenmatrixmessungen sind den Abbildungen 17 & 18 zu entnehmen. Alle untersuchten Regionen wiesen im Kollektiv der Osteoporotiker eine signifikant reduzierte trabekuläre Knochenverteilung auf. Auch der Vergleich verschiedener Frakturregionen war in beiden Kollektiven signifikant unterschiedlich. Beide Gruppen wiesen den geringsten Knochenverlust unterhalb der subchondralen Platte auf. Dem gegenüber stand in beiden Kollektiven eine deutlich höhere Knochensubstanzminderung im Bereich der medialen Metaphyse verglichen mit lateral.

Schlussfolgerung: Die Beobachtungen erklären die häufige Frakturentstehung am Collum chirurgicum und müssen Einfluss in die Beurteilung der Implantatwahl zur Versorgung dieser Region finden. Auch die Osteoporose muss in der Wahl des Implantats unter Kenntnis der Knochenverteilung antizipiert werden. (Sprecher et al., 2015)

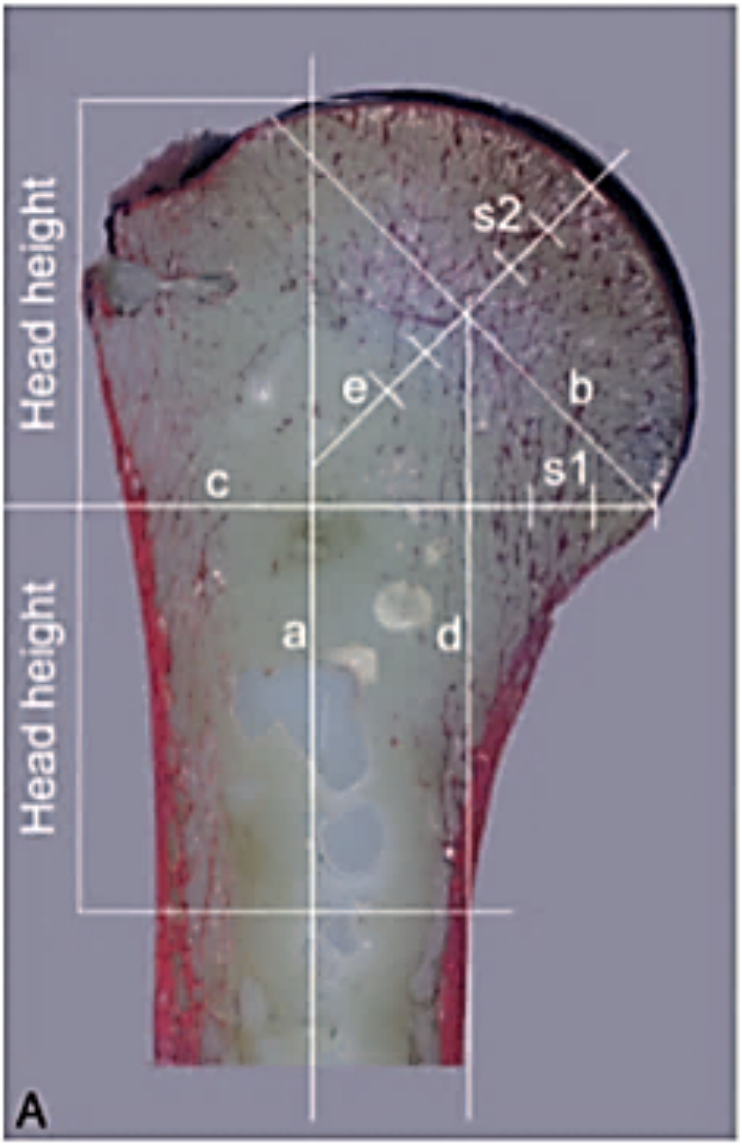


Abbildung 15: Kartierung des proximalen Humerus der zu untersuchenden Regionen

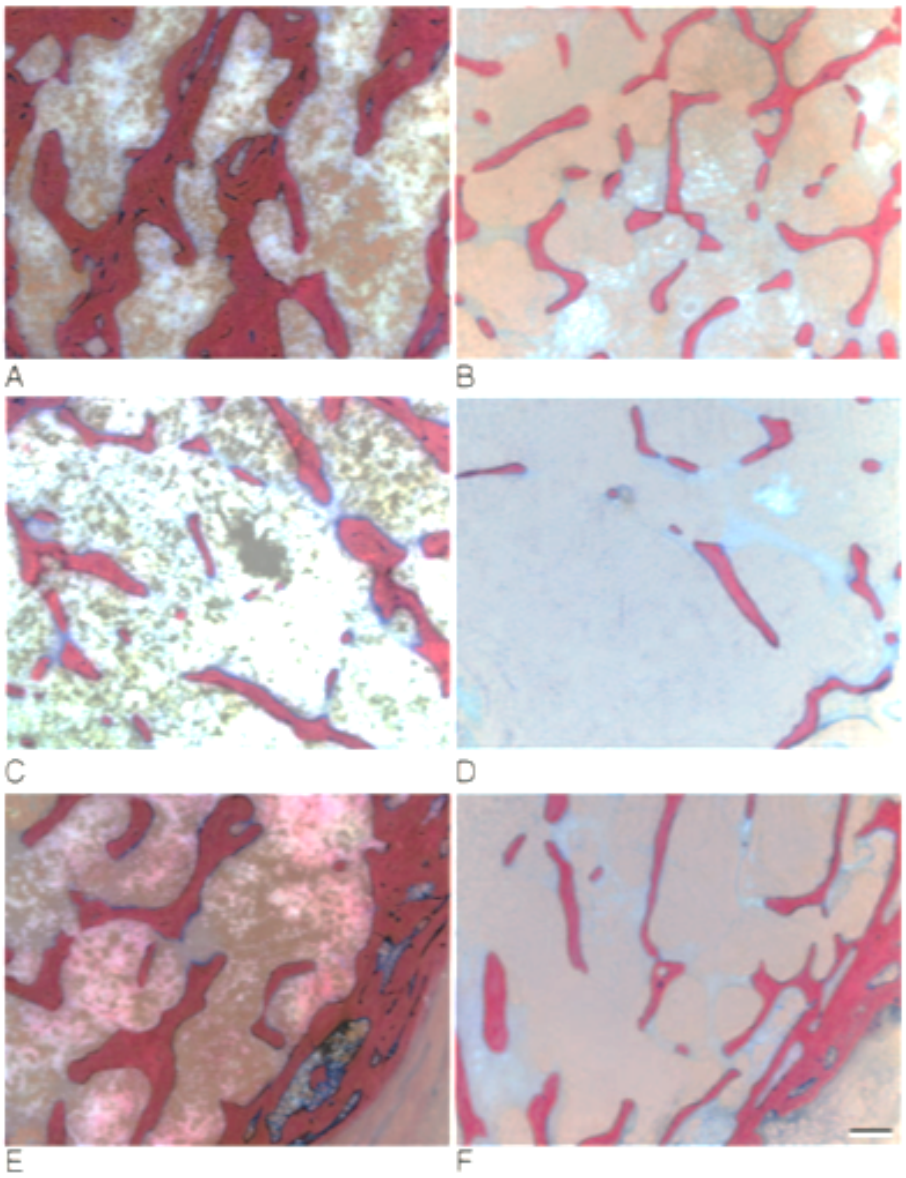


Abbildung 16: Giemsa Eosin Färbung von Methylmethacrylat-Schnitten. Beispiele für die Morphologie des trabekulären Knochens im Gesunden (A,C,E) und bei Osteoporose (B,D,F). (A,B) Humeruskopf, (C,D) mediale Metaphyse, (E,F) laterale Metaphyse

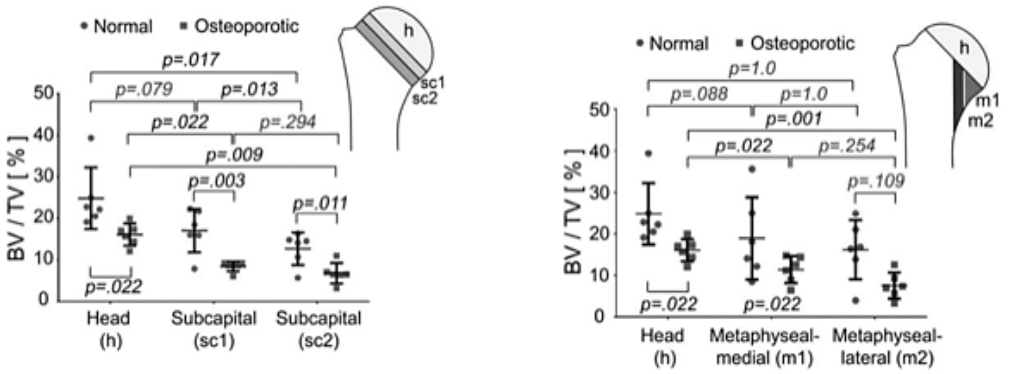


Abbildung 17: Graphische Darstellung der Untersuchung der Knochenqualität beider Kollektive in den kartierten Regionen

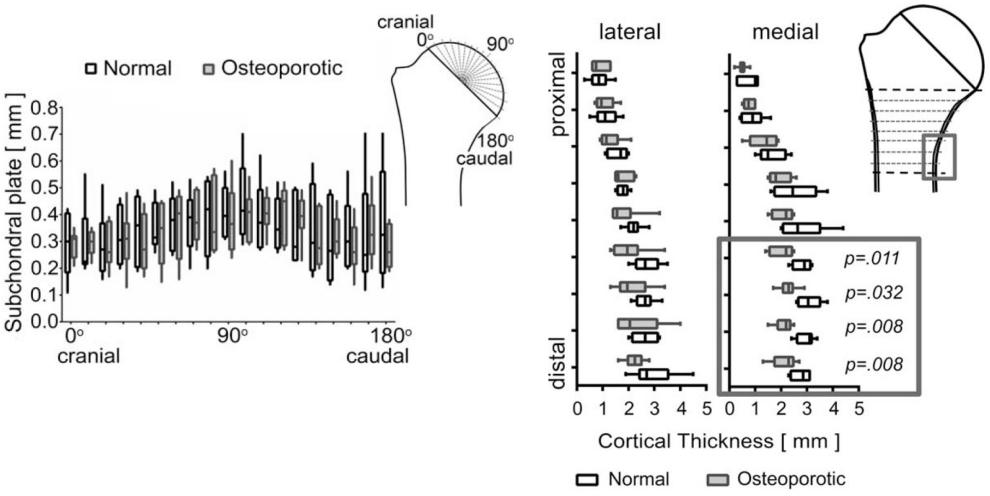


Abbildung 18: Graphische Darstellung der unterschiedlichen Dicken [mm] entsprechend den kartierten Regionen

4.1.2 Altersbezogene, hochauflösende kortikale CT-Bildgebung am Collum chirurgicum

Hintergrund: Proximale Humerusfrakturen sind relevant beeinflusst durch das Alter und osteoporotische Knochenumbauprozesse. Vorausgehende Studien haben den Verlust des kortikalen Knochens als Hauptaspekt beleuchtet, die gesamten mikrostrukturellen Veränderungen sind jedoch noch nicht ausreichend geklärt.

Material und Methodik: Wir untersuchten 64 proximale Humeri von Leichenspendern eines repräsentativen Alterskollektives (18-100 Jahre) mittels hochauflösender xtremeCT Bildgebung (82 µm). Analysiert wurden die Bone mineral density (BMD), die Trabecular bone volume fraction (Tb.BV/TV), die Cortical thickness (Ct.Th) und die Cortical porosity (Ct.Po) in vier verschiedenen Alterskollektiven (18-44, 45-64, 65-79, 80-100 Jahre).

Ergebnisse: BMD ($r = -0.42$), Ct.Th ($r = 0.57$), und Tb.BV/TV ($r = 0.68$) zeigten eine altersspezifische Abnahme, während die Ct.Po anstieg ($r = -0.55$). Im ältesten Kollektiv (80-100 Jahre) konnte eine außergewöhnlich hohe Zunahme der Ct.Po von +87% verglichen mit dem jüngsten Kollekitv (18-44 Jahre) nachgewiesen werden, während die Ct.Th und Tb.BV/TV mit -35 and -49% ($p < 0.05$) signifikant abnahmen. Der größte kortikale Substanzverlust ereignete sich nach dem Alter von 65 Jahren mit einer Ct.Th -34% und einem Tb.BV/TV -40% sowie einer Ct.Po +93% verglichen mit dem jüngsten Kollektiv.

Schlussfolgerung: Knochenabbauprozesse ereignen sich relevant ab einem Alter von 65 Jahren und resultierten in einer relevanten Abnahme der knöchernen Stabilität und Zunahme des Frakturrisikos. (Helfen, Sprecher, et al., 2017)

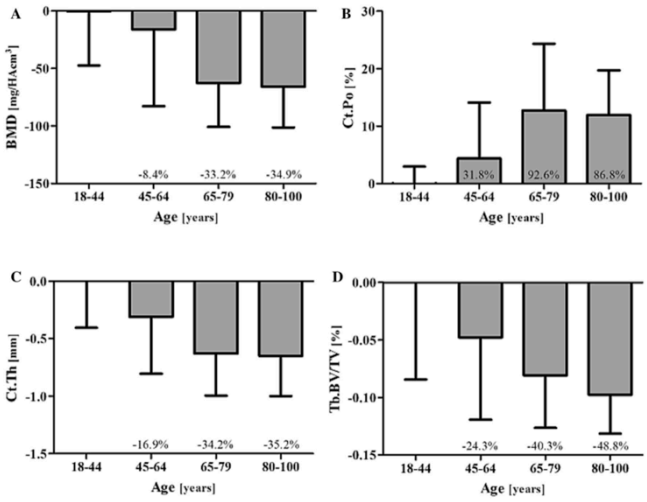


Abbildung 19: Differenzen der gemessenen Parameter verglichen mit dem Basiskollektiv (18-44 Jahre)

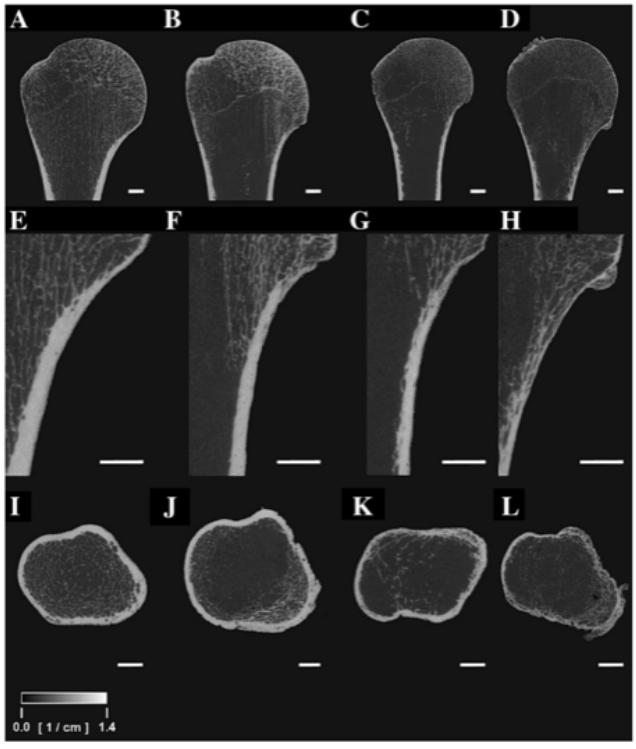


Abbildung 20: Graphische Darstellung der Dicken und Porositäten jeweils eines Beispiels der vier Gruppen von links nach rechts: (18-44, 45-64, 65-79, 80-100 Jahre).

4.2 Klinische Forschung

4.2.1 Stellenwert der oberen Extremität im Verletzungsmuster des schwerverletzten Zweiradfahrers

Hintergrund: In Straßenverkehrsstatistiken kommt den Fahrradfahrern als Verkehrsteilnehmergruppe eine besondere Bedeutung zu. Auch in der Medizin wurden bereits viele Arbeiten um dieses Kollektiv publiziert. Meist werden einzelne verletzte Regionen bei heterogener Gesamtverletzungsschwere analysiert. Verletzungsmuster, epidemiologische Aspekte, Behandlungsschwerpunkte und das Outcome scheinen daraus resultierend charakteristisch verteilt zu sein. Ziel der vorliegenden Arbeit war die Gesamterfassung der Verletzungen sowie die Charakterisierung von Verletzungsschwerpunkten in einem standardisierten und repräsentativen Kollektiv schwer verletzter Fahrradfahrer.

Material und Methodik: Es wurden Daten des Traumaregisters der DGU® über den Zeitraum 2002–2010 ausgewertet. Insgesamt wurden 2.817 schwer verletzte (ISS≥9 mit zusätzlicher intensivmedizinischer oder Intensivüberwachungstherapie) Fahrradfahrer eingeschlossen. Primärer Endpunkt der Untersuchung war die Evaluation des Gesamtverletzungsmusters und der Verletzungsschwerpunkte. Des Weiteren wurden Parameter wie epidemiologische Aspekte, Unfallumstände sowie Behandlungsschwerpunkte und das Outcome untersucht.

Ergebnisse: Das mittlere Alter lag bei 50,3 ± 20,9 Jahren. 68,9 % (n=1.940) der Fahrradfahrer waren männlich. Der mittlere ISS betrug 23,7 ± 12,6. Die 3 meistbetroffenen AIS-Regionen waren der Kopf mit 71,9 %(n=2.025), gefolgt vom Thorax mit 44,9 % (n=1.264) und den oberen Extremitäten 33,6 % (947). In 68,2 % der Fälle wurde ein ISS ≥ 9 isoliert durch das Schädel-Hirn-Trauma erreicht, in 21,1 % der eingeschlossenen Fälle lagen Monoverletzungen vor. Es resultierten eine charakteristische Altersverteilung und Prävalenz der Unfälle in Bezug auf den Unfallzeitpunkt.

Schlussfolgerung. Die vorliegende Arbeit untersuchte das bislang größte Kollektiv schwer verletzter Fahrradfahrer nach medizinischer Definition. Das Schädel-Hirn-Trauma konnte hier klar als Hauptverletzung charakterisiert werden, zudem wurde gezeigt, dass es sich bei jedem 5. Fall um eine SHT-Monoverletzung handelt die zum Status „schwer verletzt“ führt. Weitere relevante Triggerverletzungen zum Erreichen dieses Status sind Verletzungen des Thorax und der oberen Extremitäten. (Helfen, Lefering, et al., 2017)

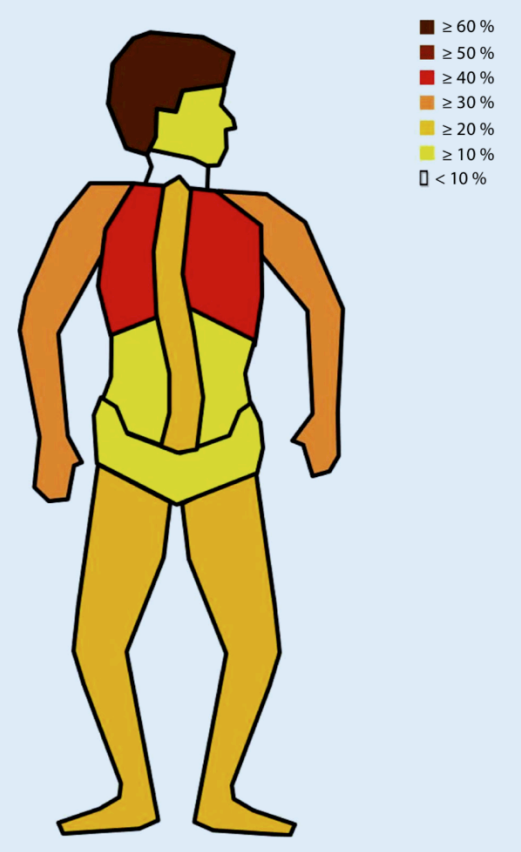


Abbildung 21: Graphische Darstellung der Hauptverletzungszonen des schwerverletzen Fahrradfahrers entsprechend ihrer Häufigkeit.

4.2.2 Untersuchung glenohumeraler Luxationen, Epidemiologie, Begleitumstände und präklinisches Management

Hintergrund: Schulterluxationen sind angesichts der Heterogenität der initialen Begleitumstände wie Unfallmechanismus, multipler Repositionstechniken, Erfahrung oder Fachrichtung des Arztes komplex. Dies trifft besonders auf das präklinische Setting zu. Schulterluxationen sind eher eine glenohumerale Verletzung des jungen, sportlich aktiven Patienten. Ziel dieser Arbeit war die Evaluation der Begleitumstände, Epidemiologie und des Managements dieser Verletzung sowie die Erarbeitung einer Therapieempfehlung.

Material und Methodik: Über 12 Monate wurden prospektiv an 16 Notarztstandorten Schulterluxationen und deren Management erfasst. Erhobene Parameter waren epidemiologische Daten, die Fachrichtung des Arztes, auftretende Begleitverletzungen sowie der Umgang und die Ergebnisse der Repositionen.

Ergebnisse: Es wurde n=70 Patienten mit einem mittleren Alter von 40,2±19,3 Jahren erfasst. Eine unmittelbare Reposition erfolgte in n=47 (66,6%) der Fälle, n=7 (10%) wiesen bereits vor der Reposition eine pathologische Neurologie auf, Gefäßkomplikationen wurden keine beobachtet. Es gab keine signifikant unterschiedlichen Ergebnisse bezüglich des Managements der Verletzung zwischen Chirurgen und Anästhesisten. Eine Überlegenheit einer bestimmten Repositionstechnik wurde nicht beobachtet. Die Repositionsversuche führten in keinem Fall zu einer Verschlechterung des neurovaskulären Status.

Schlussfolgerung: Anhand der epidemiologischen Daten ist die Schulterluxation eine Verletzung des jungen Patienten. Der hohe Prozentsatz erfolgreicher Repositionen schließt Frakturen des proximalen Humerus als Begleitverletzung überwiegend aus, diese kommen relevant im höheren Alter vor. Diese Ergebnisse unterstreichen die altersbezogenen Vorarbeiten aus der Grundlagenforschung. Die Indikation zur frühen Reposition ist abhängig vom neurovaskulären Befund der betroffenen Extremität. Erfahrung spielt eine größere Rolle als die Empfehlung einer bestimmten Repositionstechnik. Eine Reposition im präklinischen Setting ist empfehlenswert aber nicht obligat. (Helfen et al., 2016)

4.2.3 Qualitätssteigerung strukturierter MRT-Befunde bei Pathologien der Schulter

Hintergrund: Ein Diagnostikum der Wahl in der Beurteilung akuter und chronischer Schulterpathologien ist die Magnetresonanztomographie (MRT). Die Qualität der radiologischen Befundung variiert stark, diese ist jedoch relevant für eine konservative versus operative Bahnung der Behandlung.

Material und Methodik: In einer komparativen Arbeit wurden n=30 pathologische MRT-Befunde der Schulter einmal standardisiert, einmal als Freitext von zwei Schulterchirurgen auf Verständlichkeit und Vollständigkeit hin untersucht. Evaluationsmedium war ein standardisierter Fragenkatalog. Eingeschlossen wurden folgende Pathologien: Schulterluxationen, Schulterinstabilitäten, Rotatorenmanschettenrupturen und Impingementsyndrome. Die Fälle wurden aus einer MRT-Datenbank mit 367 von 1.004 passenden Datensätzen ausgewählt.

Ergebnisse: Das mittlere Patientenalter betrug 47±17,9 Jahre, 70% der Patienten waren männlich. N=11 MRTs wiesen eine stattgehabte Schulterluxation, n=14 eine Pathologie der Rotatorenmanschette und n=5 ein Impingementsyndrom auf. Es wurden n=58 (97%) der Fragestellungen an das MRT in der standardisierten Gruppe, n=56 (93%) in der Freitextgruppe beantwortet (p=0.625). Die Entscheidung zwischen konservativer und operativer Therapie konnte in n=55 (92%) der standardisierten und nur in n=45 (75%) der Freitextgruppe getroffen werden (p=0.013). Eine weitere Korrespondenz mit dem befundenden Radiologen war in n=5 (8%) standardisiert versus n=15 (25%) Freitext-Fällen notwendig. Zudem waren weitere spezielle Fragestellungen zur Operationsplanung in n=8 (13%) standardisiert versus n=20 (33%) Freitext-Fällen notwendig (p=0.008). Die Verständlichkeit der relevanten Informationen wurde von den Befundern mit 92% bei den standardisierten Texten vs. 62% bei den Freitexten bewertet (p<0.001).

Schlussfolgerung: Die Standardisierung von MRT-Befunden der Schulter steigert die Reliabilität der Befunde signifikant. (Gassenmaier et al., 2017)

4.2.4 Der Einfluss selektierter Implantate und Prothesen zur Frakturversorgung auf die Komplikationsraten der proximalen Humerusfraktur

Hintergrund: Komplikationsraten nach operativer Versorgung proximaler Humerusfrakturen werden mit einer Inzidenz von bis zu 40% beschrieben. Der langfristige Einfluss frakturspezifischer Versorgungsoptionen sowie der Einzug der Frakturendoprothetik auf die Komplikationsraten wurden bislang noch nicht untersucht. Ziel dieser Langzeitstudie war es die Inzidenz der Komplikationen und Revisionszahlen nach Plattenosteosynthese unter Berücksichtigung dieser selektiven Versorgungsoptionen zu analysieren.

Material und Methodik: Über 11 Jahre (2002-2013) wurden 788 Patienten eingeschlossen, die eine proximale Humerusfraktur erlitten hatten und sich einer operativen Versorgung mittels winkelstabiler Plattenosteosynthese, primärer Fraktur-Hemiprothese oder einer inversen Frakturprothese unterzogen. Die Patienten wurden einschließlich Röntgenbildgebung an Tag 1, Woche 6 sowie Monat 3,6 und 12 nachuntersucht. Komplikationen und ungeplante Revisionseingriffe wurden erfasst.

Ergebnisse: N=646 (82%) der Patienten wurden mittels winkelstabiler Plattenosteosynthese versorgt, n=82 (10,4%) mittels Fraktur-Hemiprothese und n=60 (7,6%) mittels inverser Frakturprothese. Die höchste Komplikationsrate (12,6%) war in der Gruppe der winkelstabilen Plattenosteosynthesen nachweisbar, Revisionen wurden in 11,6% der Fälle notwendig. In den letzten 5 Jahren des Untersuchungszeitraumes nahm die Indikation der inversen Frakturendoptothese deutlich zu, hierdurch konnte eine Reduktion der Komplikationen vor allem im Bereich der sekundären Dislokationen relevant reduziert werden (14,3% auf 4,8%).

Schlussfolgerung: Die Komplikationsrate der winkelstabilen Plattenosteosynthese nach proximaler Humerusfraktur konnte in den letzten Jahren relevant reduziert werden. Dies scheint vor allem durch die steigende Indikation der inversen Frakturprothese erreicht worden zu sein. Zudem scheinen die selektierte, frakturspezifischere Implantatwahl sowie die Präzisierung der Operationstechniken hierzu beizutragen. (Haasters et al., 2016)

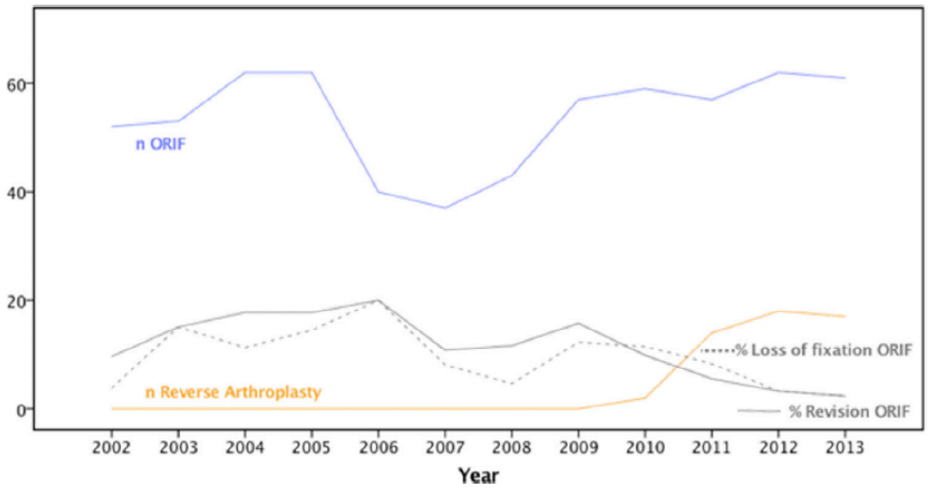


Abbildung 22: Übersicht über die verschiedenen Implantatformen und Inzidenzen der Dislokationen und Revisionen nach winkelstabiler Plattenosteosynthese (ORIF) [%]

4.2.5 Der Einfluss des Operationszeitpunktes auf die Komplikationsraten nach proximaler Humerusfraktur

Hintergrund: Die winkelstabile Plattenosteosynthese ist ein etabliertes Verfahren in der Versorgung proximaler Humerusfrakturen. Dennoch existieren keine Daten zum Einfluss des Operationszeitpunktes und dessen Auswirkungen im Hinblick auf Komplikationen für diese Art der Versorgung. Ziel der vorliegenden Studie war es daher, die Komplikationen des Verfahrens zu verschiedenen Operationszeitpunkten zu analysieren.

Material und Methodik: Über einen Zeitraum von 8 Jahren (2002-2010) wurden 497 Patienten eingeschlossen, die sich eine operationspflichtige proximale Humerusfraktur zuzogen und mittels winkelstabiler Plattenosteosynthese versorgt wurden. Outcomeparameter waren: sekundärer Repositionsverlust, Schrauben-Cutout und avaskuläre Nekrosen. Diese Parameter wurden mit epidemiologischen Daten und der Zeit zwischen Fraktur und operativer Versorgung korreliert.

Ergebnisse: In n=329 Fällen (68,4% Frauen, mittleres Alter 69,9 Jahre (95% CI: 63,4;66,5)) betrug die mittlere Zeit bis zur Operation 3,2 Tage (95% CI: 3,1;3,2). Die Operationen erfolgten im Falle der 2-Fragment-Frakturen nach 3,3 Tagen (95% CI: 3,2;3,4), Im Falle der 2 Fragment-Frakturen nach 3,3 Tagen (95% CI: 3,1;3,4) und im Falle der 4-Fragment-Frakturen nach 2,9 Tage (95% CI: 2,8;3,0). Head-Split-Frakturen wurden nach 2,2 Tagen (95% CI: 2,0;2,4) und Luxationsfrakturen nach 0,8 Tagen (95% CI: 0,7;0,9) versorgt. Ein Repositionsverlust wurde bei n=42 Patienten (12,8%), ein Schrauben-Cutout bei n=16 Patienten (4,9%) und eine avaskuläre Nekrose in n=20 (6,8%) der Fälle erfasst. Patienten mit Komplikation wurden gemittelt nach 2,5 Tagen (95% CI: 1,8;3,2) dem gegenüber erfolgte die Operation bei den Patienten ohne Komplikationen nach 3,2 Tagen (95% CI: 2,8;3,8, p=0.35). Die Odds-Ratio in Bezug auf die Komplikationen bei Patienten mit Operation ≤48h lag bei 0,924, für Patienten in denen die Operation 3-5 Tage nach dem Unfall erfolgte bei 0,836 und bei Patienten mit operativer Versorgung > 5 Tage 1,637.

Schlussfolgerung: Ein Repositionsverlust nach winkelstabiler Plattenosteosynthese bei proximaler Humerusfraktur konnte nicht unterschiedlich häufig in den Kollektiven mit Versorgung ≤48h und 3-5 Tagen nachgewiesen werden. Dennoch wurde für die Versorgungen nach >5 Tagen mehr Komplikationen nachgewiesen. Daher sollte die osteosynthetische Frakturversorgung in den ersten 5 Tagen erfolgen. Head-Split Frakturen oder Frakturen mit einer Luxationskomponente sollten unter

Berücksichtigung des Risikos der avaskulären Nekrose binnen 48 Stunden versorgt werden. (Siebenburger et al., 2015)

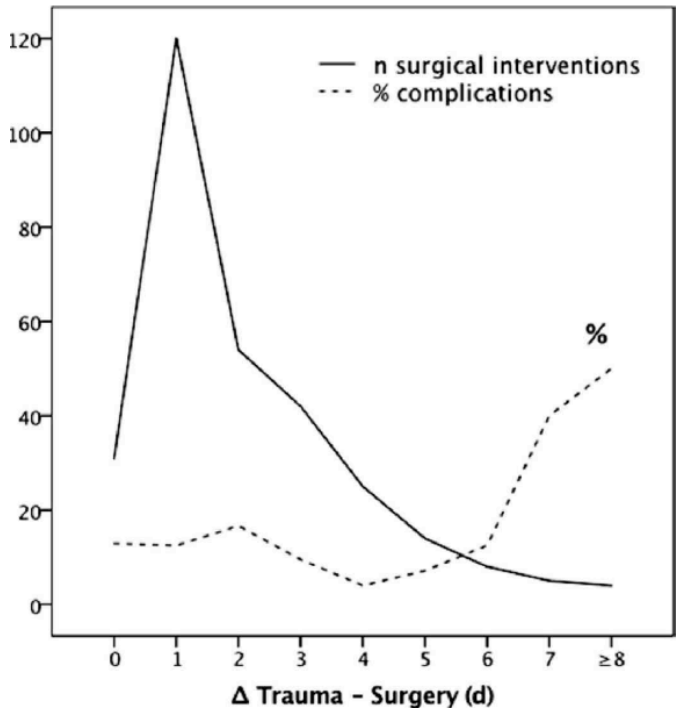


Abbildung 23: Gesamtzahl der Versorgungen und Angabe der Komplikationen [%] im Verhältnis zum Operationszeitpunkt.

4.2.6 Der Einfluss der operativen Expertise auf das Outcome nach proximaler Humerusfraktur

Hintergrund: Die operative Expertise des Operateurs wurde für viele andere Bereiche der Chirurgie bereits evaluiert und Einflüsse auf das Outcome nachgewiesen. Die subkapitale 2-Fragment-Fraktur des proximalen Humerus vom Typ AO 11-A2 und A3 sind als vergleichbar anzusehen und stellen eine geeignete Verletzung für diese Untersuchung dar.

Material und Methodik: In dieser retrospektiven Arbeit wurden Patienten erfasst, die sich aufgrund einer dislozierten proximalen Humerusfraktur einer operativen Behandlung unterzogen mussten (n=1.411). Davon wurden n=278 Patienten identifiziert, bei denen eine subkapitale 2-Fragment-Fraktur vorlag die mittels winkelstabiler Plattenosteosynthese versorgt wurde, eine anatomische Reposition erzielt wurde und ein identisches Nachbehandlungsschema Anwendung fand. Ausgewertet wurde der Weiterbildungsgrad des verantwortlichen Operateurs (Facharzt [FA] vs. Zusatzbezeichnung Unfallchirurgie bzw. Spezielle Unfallchirurgie [SU] vs. Facharzt mit oder ohne Zusatzbezeichnung mit >50 Schulteroperationen/Jahr [SS]). Outcomeparameter waren das funktionelle Ergebnis gemessen am alters- und geschlechtsnormalisierten Constant Score (nCS) sowie die Komplikations- und Revisionsraten.

Ergebnisse: Die Kollektive verteilten sich auf: [FA](n=68, 25.7%), [SU](n=110, 41.5%) und [SS](n =77,29.1%). Das funktionelle Outcome (nCS) verbesserte sich mit jedem Anstieg des Weiterbildungsgrades und war am besten im Kollektiv der Schulterchirurgen [SS] (93.3) vs. [FA] (79.6; p=0.01) vs. [SU] (83.0; p=0.05). [SS] (7.8%) hatten signifikant weniger Komplikationen als [FA] (11.3%; p=0.003) und [SU] (11.7%; p=0.01) sowie signifikant weniger Revisionseingriffe (3.9%) vs. [FA](8.2%) und [SU](7.4%) (p<0.001). Eine primäre Revision aufgrund Malreposition war in 13 Fällen (4.7%) notwendig (Abbildung 25).

Schlussfolgerung: Die Qualität der anatomischen Reposition und des funktionellen Outcomes nach winkelstabiler Plattenosteosynthese der 2-Fragment-Fraktur des proximalen Humerus ist wesentlich beeinflusst von der Expertise des Operateurs. Zudem sind Komplikationen und Revisionseingriffe relevant seltener bei Chirurgen mit einer Erfahrung von mehr als 50 Schulteroperationen pro Jahr. (Helfen, Siebenburger, Fleischhacker, et al., 2018)

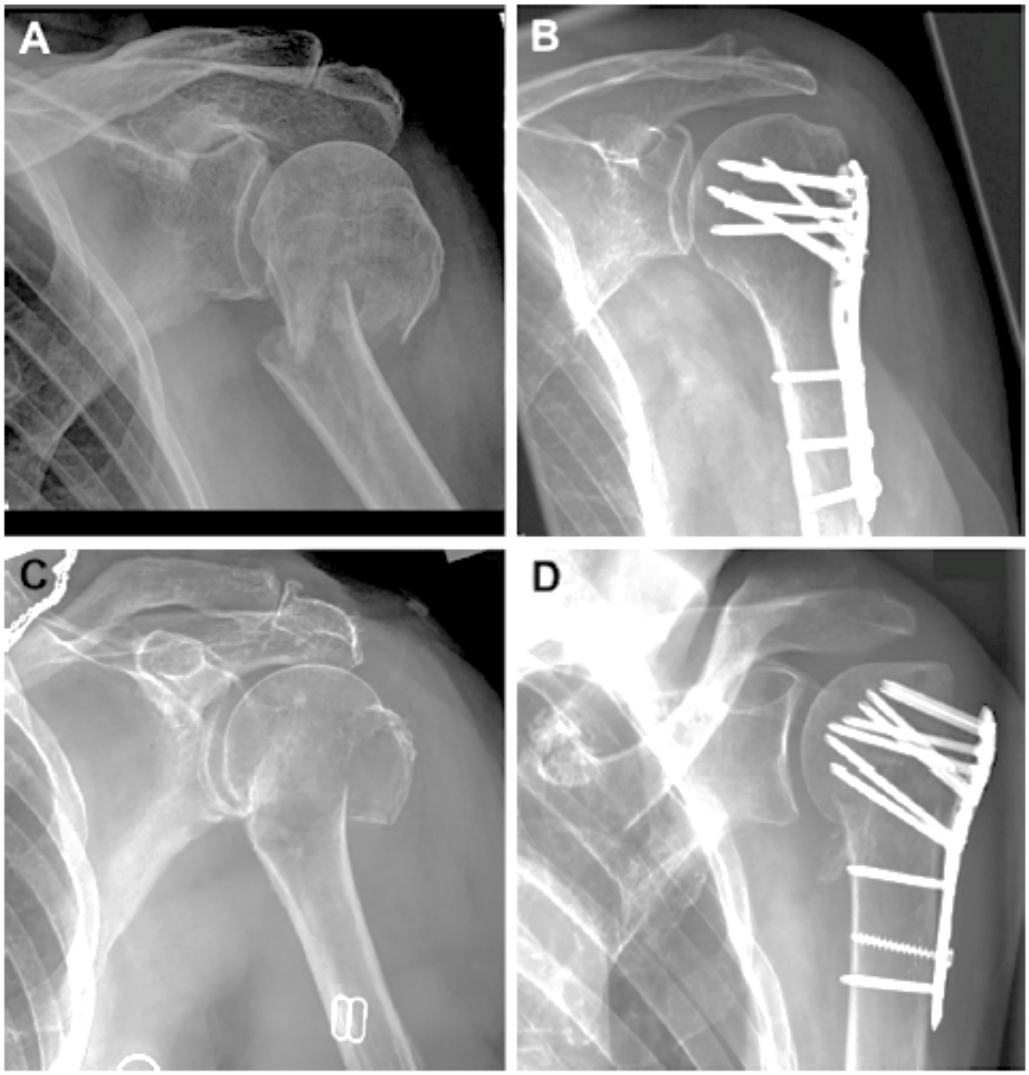


Abbildung 24: AO 11-A3 Frakturen prä- und postoperativ. Bild A und B zeigen eine 69-jährige Patientin mit postoperativer anatomischer Frakturreposition, Bild C und D eine 72-jährige Patientin mit primärer Malreposition.

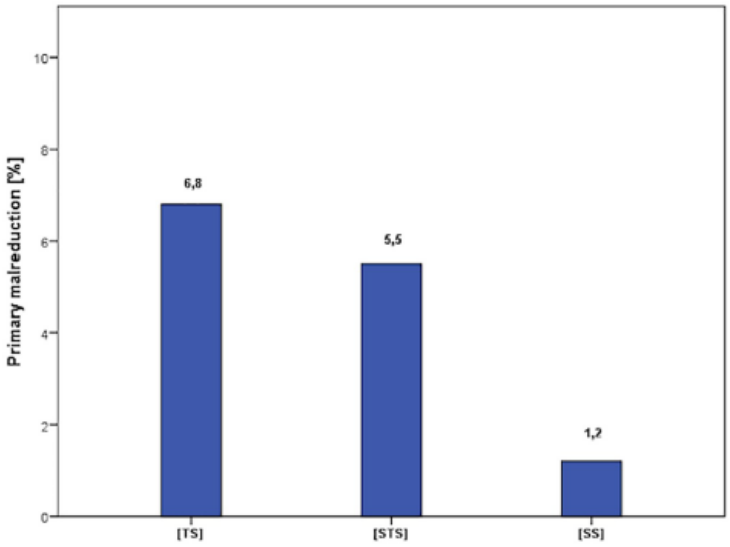


Abbildung 25: Übersicht der primären Malrepositionen[%] (Ausschlusskriterium). Links: Facharzt, Mitte: Spezieller Unfallchirurg, rechts: Chirurg mit ≥ 50 Schulteroperationen/Jahr.

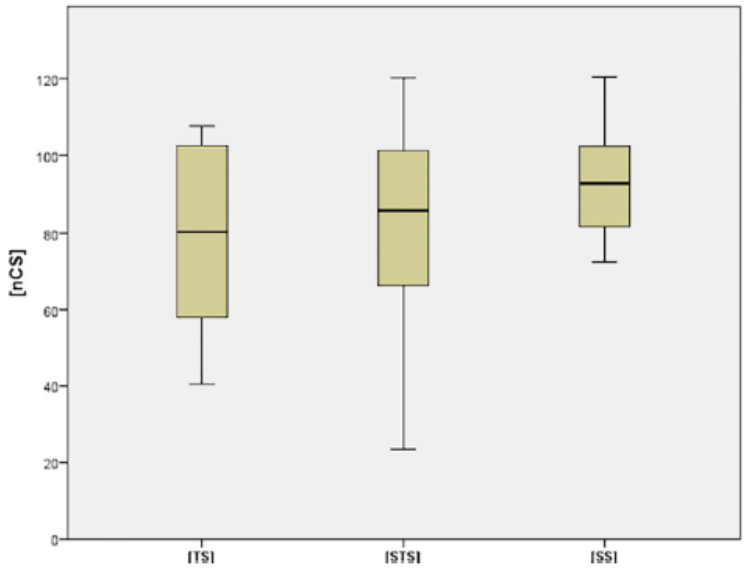


Abbildung 26: Verteilung des funktionellen Outcomes (Constant Score) in Abhängigkeit der Expertise. Links: Facharzt, Mitte: Spezieller Unfallchirurg, rechts: Chirurg mit ≥ 50 Schulteroperationen/Jahr.

4.2.7 Metaanalyse der Versorgungsoptionen der Akromioklavikulargelenksluxation

Hintergrund: Die operativen Verfahren zur Behandlung der akuten Akromioklavikular(AC)-Gelenk-Instabilität sind vielfältig. Neben den offenen Techniken finden zunehmend arthroskopisch gestützte Verfahren Anwendung. Jedes Vorgehen bietet spezifische Vor- und Nachteile, bisher hat sich jedoch keines als Goldstandard durchgesetzt. Ziel dieser systematischen, metaanalytischen Auswertung war es daher, die vorhandene Evidenz für arthroskopische und offene Operationstechniken zusammenzufassen.

Material und Methoden: Entsprechend dem Cochrane Handbook for Systematic Reviews of Interventions wurde eine Literaturrecherche in den medizinischen Datenbanken MEDLINE und Embase über den Zeitraum der letzten 10 Jahre durchgeführt.

Ergebnisse: Von 961 Studien wurden 32 Arbeiten in diese Übersichtsarbeit aufgenommen. Drei Arbeiten eigneten sich für eine metaanalytische Auswertung. Die arthroskopischen bzw. minimal-invasiven Techniken zeigten tendenziell bessere funktionelle Ergebnisse anhand des Constant-Scores (gewichtete Mittelwertdifferenz 5,60; 95 %-Konfidenzintervall 0,36–10,64). Hinsichtlich Komplikationsrate, Repositionsergebnis und AC-Gelenk-Instabilität zeigte sich kein signifikanter Unterschied.

Schlussfolgerung: Bei inkonsistenter Studienlage gibt es keine Evidenz für eine Überlegenheit offener oder arthroskopischer/minimal-invasiver Verfahren. Die arthroskopischen bzw. minimal-invasiven Techniken zeigten Tendenzen besserer funktionelle Ergebnisse. Um herauszufinden, ob die arthroskopische Versorgung zu einem signifikant besseren funktionellen Behandlungsergebnis führt, sind vergleichende Studien mit randomisiertem, kontrolliertem Design notwendig. (Helfen et al., 2015)

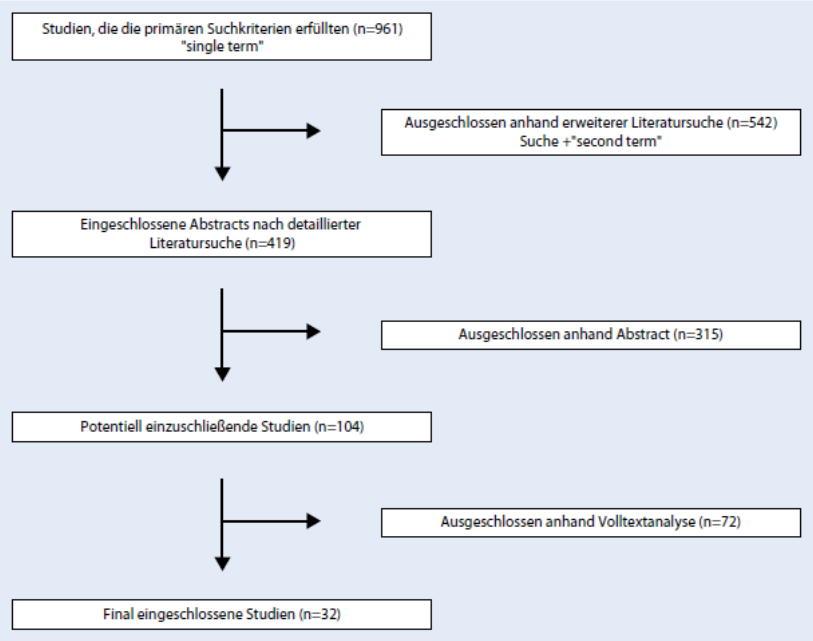


Abbildung 27: Flussdiagramm für den Studieneinschluss

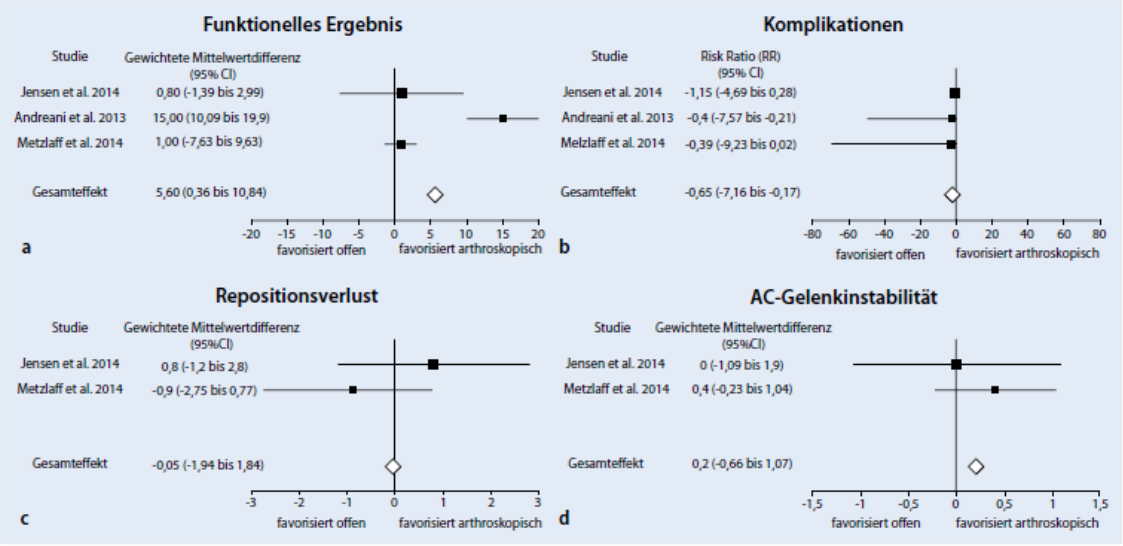


Abbildung 28: Analysen in Bezug auf a) funktionelles Outcome, b) Komplikationsraten, c) Repositionsverlust, d) postoperative AC-Gelenk-Instabilität

4.2.8 Untersuchung relevanter glenohumeraler Begleitpathologien nach lateraler Klavikulafraktur

Hintergrund: Im Zusammenhang mit lateralen Klavikulafrakturen werden glenohumerale Begleitpathologien beschrieben. Zum einen ist die Charakterisierung dieser Begleitverletzungen bislang noch nicht hinreichend durchgeführt worden, zum anderen sind die Wertigkeit und Relevanz sowie die Behandlungsindikation ungeklärt. Ziel der vorliegenden Arbeit war die Evaluation der Begleitpathologien sowie deren Wertung im Hinblick auf eine Therapierelevanz.

Material und Methoden: Über einen Zeitraum von 4 Jahren (2011-2015) wurden 41 Patienten eingeschlossen, die sich eine operationspflichtige laterale Klavikulafraktur zuzogen. N=20 Patienten (Gruppe 1) erhielten eine arthroskopisch gestützte Frakturversorgung mit Augmentation der coracoklavikulären Bänder. N=21 Patienten (Gruppe 2) erhielten eine osteosynthetische Versorgung mittels Hakenplatte, eine Schultergelenksarthroskopie wurde in dieser Gruppe erst zum Zeitpunkt der Materialentfernung durchgeführt. Alle Arthroskopien wurden standardisiert durchgeführt, die intraoperativen Befunde wurden doppelt verblindet von zwei unabhängigen Untersuchern analysiert.

Ergebnisse: Insgesamt wurden glenohumerale Begleitpathologien in 26,8% der Fälle nachgewiesen. (mittleres Alter 43,6±16 Jahre). In Gruppe 1 lag die Prävalenz bei 25%, in Gruppe 2 bei 28,5% (p=0,75). Begleitverletzungen bestanden in Labrumläsionen, Rotatorenmanschettenrupturen und Läsionen des Biceps-Pulley-Komplexes. Die Verletzungen wurden in 2 Fälle von Gruppe 1 und in 3 Fällen von Gruppe 2 operativ versorgt (p=0,68).

Zusammenfassung: Die Studie konnte akute und zum ersten Mal mittelfristige Prävalenzen von glenohumeralen Begleitverletzungen nach lateraler Klavikulafraktur angeben. Zu beiden Zeitpunkten betrug die Prävalenz gemittelt 27%. Nicht alle Begleitverletzungen waren symptomatisch. Eine Begleitverletzung muss vor allem bei prolongierten Beschwerden antizipiert werden. Unbehandelte symptomatische Pathologien können die Heilung relevant verzögern. (Helfen, Siebenburger, Haasters, et al., 2018)

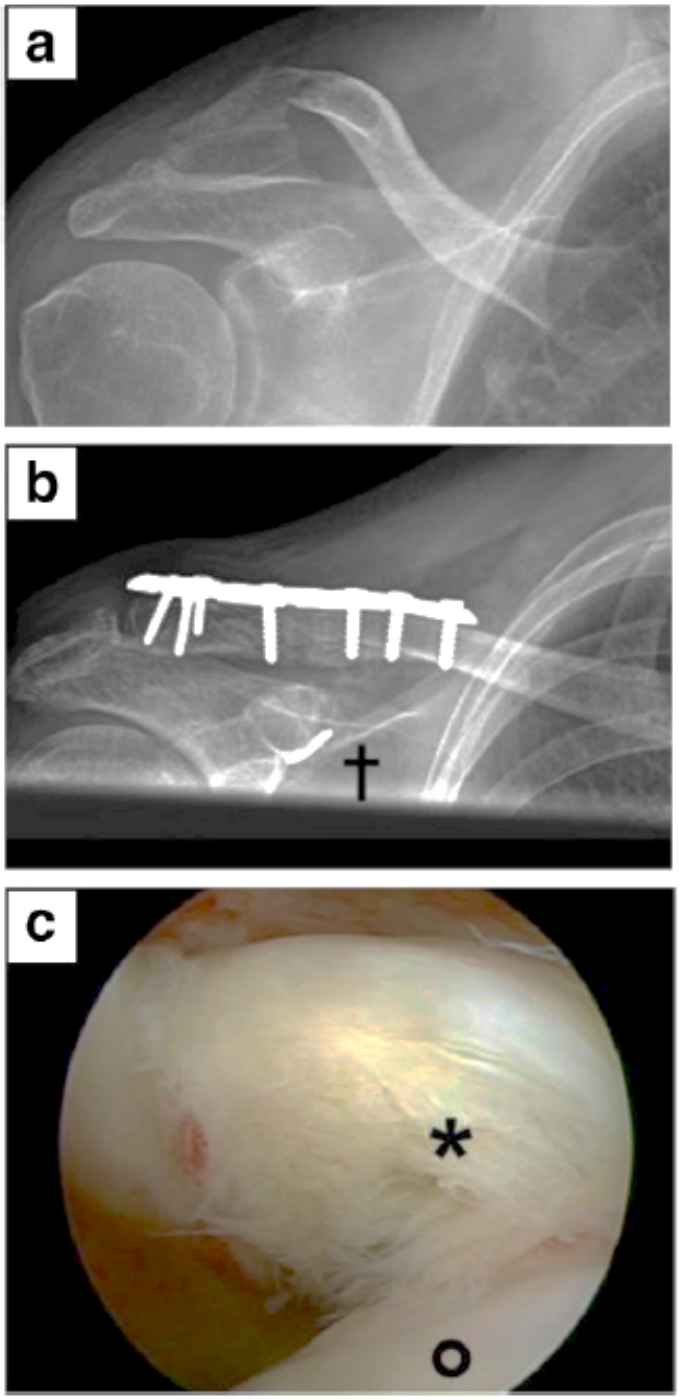


Abbildung 29: Befunde in Gruppe 1. 53-jährige Patientin mit Neer Typ IIb Fraktur. a) präoperativer Röntgenbefund, b) postoperativer Röntgenbefund (+ DogBone) c) Läsion der Subscapularissehne* (Fox/Romeo Ib), (o Humeruskopf)

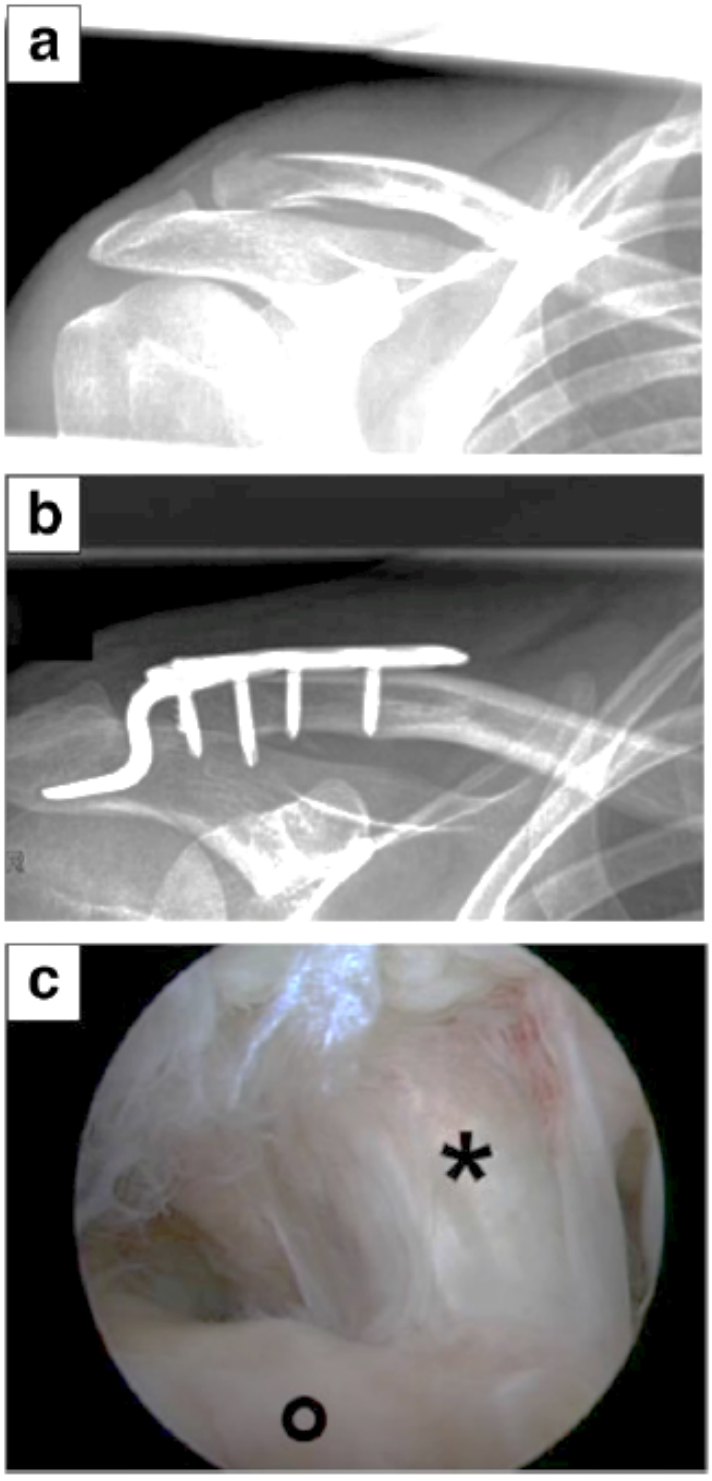


Abbildung 30: Befunde in Gruppe 2. 40-jähriger Patient mit Neer Typ IIb Fraktur und Hakenplattenversorgung. a) präoperativer Röntgenbefund, b) postoperativer Röntgenbefund, c) Läsion der Supraspinatusssehne* (Bateman III), (o Humeruskopf)

5. Liste der zur kumulativen Habilitation beitragenden Publikationen

1. Sprecher CM, Schmidutz F, **Helfen T**, Richards RG, Blauth M, Milz S. Histomorphometric Assessment of Cancellous and Cortical Bone Material Distribution in the Proximal Humerus of Normal and Osteoporotic Individuals: Significantly Reduced Bone Stock in the Metaphyseal and Subcapital Regions of Osteoporotic Individuals. Medicine (Baltimore). 2015;94(51):e2043. Epub 2015/12/26. doi: 10.1097/MD.0000000000002043. PubMed PMID: 26705200; PubMed Central PMCID: PMC4697966.

2. **Helfen T**, Sprecher CM, Eberli U, Gueorguiev B, Muller PE, Richards RG, et al. High-Resolution Tomography-Based Quantification of Cortical Porosity and Cortical Thickness at the Surgical Neck of the Humerus During Aging. Calcif Tissue Int. 2017;101(3):271-9. Epub 2017/04/23. doi: 10.1007/s00223-017-0279-y. PubMed PMID: 28432379.

3. **Helfen T**, Lefering R, Moritz M, Bocker W, Grote S, Traumaregister DGU. [Characterization of the seriously injured cyclist : An evaluation of the injury and treatment focus areas of 2817 patients]. Unfallchirurg. 2017;120(5):403-8. Epub 2016/07/01. doi: 10.1007/s00113-016-0208-y. PubMed PMID: 27357351.

4. **Helfen T**, Ockert B, Pozder P, Regauer M, Haasters F. Management of prehospital shoulder dislocation: feasibility and need of reduction. Eur J Trauma Emerg Surg. 2016;42(3):357-62. Epub 2015/07/15. doi: 10.1007/s00068-015-0545-5. PubMed PMID: 26156391.

5. Gassenmaier S, Armbruster M, Haasters F, **Helfen T**, Henzler T, Alibek S, et al. Structured reporting of MRI of the shoulder - improvement of report quality? Eur Radiol. 2017;27(10):4110-9. Epub 2017/03/16. doi: 10.1007/s00330-017-4778-z. PubMed PMID: 28289942.

6. **Helfen T**, Siebenburger G, Fleischhacker E, Biermann N, Bocker W, Ockert B. Open reduction and internal fixation of displaced proximal humeral fractures. Does the surgeon's experience have an impact on outcomes? PLoS One. 2018;13(11):e0207044. Epub 2018/11/07. doi: 10.1371/journal.pone.0207044. PubMed PMID: 30399160.

7. Haasters F, Siebenburger G, **Helfen T**, Daferner M, Bocker W, Ockert B. Complications of locked plating for proximal humeral fractures-are we getting any better? J Shoulder Elbow Surg. 2016;25(10):e295-303. Epub 2016/04/16. doi: 10.1016/j.jse.2016.02.015. PubMed PMID: 27079217.

8. Siebenburger G, Van Delden D, **Helfen T**, Haasters F, Bocker W, Ockert B. Timing of surgery for open reduction and internal fixation of displaced proximal humeral fractures. Injury. 2015;46 Suppl 4:S58-62. Epub 2015/11/07. doi: 10.1016/S0020-1383(15)30019-X. PubMed PMID: 26542867.

9. **Helfen T**, Siebenburger G, Haasters F, Bocker W, Ockert B. Concomitant glenohumeral injuries in Neer type II distal clavicle fractures. BMC Musculoskelet Disord. 2018;19(1):24. Epub 2018/01/21. doi: 10.1186/s12891-018-1944-7. PubMed PMID: 29351746; PubMed Central PMCID: PMC5775546.

10. **Helfen T**, Siebenburger G, Ockert B, Haasters F. [Therapy of acute acromioclavicular joint instability. Meta-analysis of arthroscopic/minimally invasive versus open procedures]. Unfallchirurg. 2015;118(5):415-26. Epub 2015/05/13. doi: 10.1007/s00113-015-0005-z. PubMed PMID: 25964021.

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7. Abkürzungsverzeichnis

AC	-	acromioclavicular
ACG	-	Acromioclaviculargelenk
BMD	-	Bone mineral density
BV/TV	-	Bone Volume per Tissue Volume
CC	-	coraco-clavicular
Co.Po.	-	Cortical porosity
Co.Th.	-	Cortical thickness
CS	-	Constant Score
DGU	-	Deutsche Gesellschaft für Unfallchirurgie
DXA	-	Dual-energy X-ray Absorptiometry
LCP	-	Locking Compression Plate
Lig.	-	Ligament
MRT	-	Magnetresonanztomographie
n	-	Anzahl
OS/BS	-	Osteoidoberfläche pro Knochenoberfläche
OV/BV	-	Osteoidvolumen im Verhältnis zum Knochenvolumen
OV/BV	-	Osteoidvolumen im Verhältnis zum Gewebevolumen
PMMA	-	Polymethylmethaacrylat
s.u.	-	siehe unten
Tb.N.	-	Trabecular number

Tb.Sp. - Trabecular space

Tb.Th. - Trabecular thickness

TR - Traumaregister

TS - Taft Score

TV - Trabecular volume

VAS - Visuelle analog Skala

8. Abbildungsverzeichnis

9. Originalpubikationen des Habilitationsprojektes

Medicine®

CLINICAL TRIAL/EXPERIMENTAL STUDY

OPEN

Histomorphometric Assessment of Cancellous and Cortical Bone Material Distribution in the Proximal Humerus of Normal and Osteoporotic Individuals

Significantly Reduced Bone Stock in the Metaphyseal and Subcapital Regions of Osteoporotic Individuals

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Abstract: Osteoporosis is a systemic disorder predominantly affecting postmenopausal women but also men at an advanced age. Both genders may suffer from low-energy fractures of, for example, the proximal humerus when reduction of the bone stock or/and quality has occurred.

The aim of the current study was to compare the amount of bone in typical fracture zones of the proximal humerus in osteoporotic and non-osteoporotic individuals.

The amount of bone in the proximal humerus was determined histomorphometrically in frontal plane sections. The donor bones were allocated to normal and osteoporotic groups using the T-score from distal radius DXA measurements of the same extremities. The T-score evaluation was done according to WHO criteria. Regional thickness of the subchondral plate and the metaphyseal cortical bone were measured using interactive image analysis.

At all measured locations the amount of cancellous bone was significantly lower in individuals from the osteoporotic group compared to the non-osteoporotic one. The osteoporotic group showed more significant differences between regions of the same bone than the non-osteoporotic group. In both groups the subchondral cancellous bone and the subchondral plate were least affected by bone loss. In contrast, the medial metaphyseal region in the osteoporotic group exhibited higher bone loss in comparison to the lateral side.

This observation may explain prevailing fracture patterns, which frequently involve compression fractures and certainly has an influence on the stability of implants placed in this medial region. It should be considered when planning the anchoring of osteosynthesis materials in osteoporotic patients with fractures of the proximal humerus.

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Abbreviations: BMD = bone mineral density, BV/TV = bone volume to total volume, DXA = dual-energy X-ray absorptiometry, WHO = World Health Organization.

INTRODUCTION

Osteoporosis is a systemic skeletal disorder, which causes reduction of the bone stock or/and quality and impairs biomechanical stability of the skeleton.[1] It affects predominantly postmenopausal women but also occurs in men at an advanced age.[2] Proximal humerus fractures are among the 4 most frequent types of fractures in the elderly population (i.e. aged ≥65 years) and may already occur after minor trauma.[3] These fractures still pose a challenge for adequate stabilization in modern osteosynthesis.[4] Despite all advances in the field of osteosynthesis material development there are still considerable problems related to the occurrence of screw cut-out phenomena as well as short- and long-term implant instability.[4,5]

This is underlined in a previous study[4] involving 53 elderly patients (mean age 63 years, 72% females) who had proximal humeral fracture, which was treated with an angular stable plate. Primary screw perforation during the operation was the most frequent problem with 13.5% followed by secondary screw perforation with 7.3%. In a recently published prospective multicenter study (131 patients, mean age 66 years, 70% females) involving a polyaxial angular stable plate the most frequent implant-related problem was intra-articular screw perforation occurring in 14.5% of patients.[6,7] Several other studies have resulted in comparable outcomes.[8–14]

The current clinical picture indicates a particular problem related to the fact that no surgically accepted ''bone material distribution map'' of the proximal humerus exists to give a good forecast for potentially useful implant anchoring positions. As a result the stable placement of implants can be very difficult, especially in the case of an osteoporotic fracture.

A particular problem in all studies comparing normal and osteoporotic individuals relates to the fact that there are no generally accepted rules for their classification. This question has been addressed in several studies and led to a recommendation by the WHO to classify normal and osteoporotic conditions using the T-score.[15] Currently, the authors follow the WHO classification and differentiate between normal and osteoporotic individuals based on T-scores obtained by DXA measurements of the distal radius.

It is already known that osteoporosis does not affect all regions of the upper skeleton to the same extent[16,17] and thus it cannot be assumed that reduction of the bone stock or/and quality occurs more or less homogenous in all parts of a larger human bone like the humerus.

Therefore, the aim of the present study was to investigate the distribution of bone tissue within the proximal end of the humerus in frontal sections of normal and osteoporotic human samples. Due to physiological differences in the regional bone structure and material distribution, we compared different regions of cancellous and cortical bone in the proximal humerus and defined the regions with respect to the occurrence of typical fracture lines[18] in an elderly patient collective. For cancellous bone we choose the bone volume to total volume (BV/TV) ratio as an appropriate parameter for assessment of material distribution (bone density) whereas in the case of compact bone, we used the cortical or subchondral plate thickness as representative parameters.[19 21]

METHODS

Donors

Upper extremities including the shoulder joint from 12 donors (average age 68.6 years, age range: 19–90 years, 6 males, 6 females; further details are given in Table 1) were obtained from Platinum Medical (Herderson, NV). Specimens were fresh frozen and had been collected postmortem with appropriate consent of the individual or of their relatives. The specimens were handled according to legal regulations of Switzerland.

DXA measurements from the distal radius, ipsilateral to the proximal humerus used for histomorphometry, were obtained for each specimen using a DXA scanner (GE Healthcare Lunar Prodigy DF+14868, Madison, WI) and the T-score was recorded as recommended by the WHO. Donors were grouped into normal and osteoporotic individuals using the T-score as a criterion for decision (details in Table 1). This approach seemed reasonable because Krappinger et al.[14] could demonstrate a correlation (correlation coefficient 0.57) between the average bone mineral density (BMD) values of the radius and humeral head in living human patients.

Specimen Preparation

After thawing, the specimens were dissected and the proximal third of the humerus was removed and fixed for at least 4 weeks in 70% methanol and then were dehydrated in ascending concentrations of alcohol at room temperature. Finally, the proximal humeral end was block embedded in methylmethacrylate and polymerized in a temperature controlled water bath.[20] After hardening of the block, 1 section per specimen was obtained in the frontal plane with a diamond band saw (Exakt Makro Diamond Band Saw, Norderstedt, Germany). Each section with a thickness of ~500 μm was glued on a custom made plastic slide (size 55 × 110 mm), ground and polished with an Exakt grinding 400CS (EXAKT, Norderstedt, Germany) to a thickness of ~400 μm and finally stained with Giemsa Eosin stain.

For overview images the stained sections were scanned with an Umax Powerlook Scanner (Umax 2100XL). Detailed images at higher resolutions at selected locations within the sections were made using a Zeiss Axioplan microscope (Zeiss, Göttingen, Germany) equipped with a high resolution camera (Axiocam HRc).

Definition of the Regions of Interest for Cancellous Bone Material Distribution Assessment

The histological section of the proximal end of the humerus was separated into different regions of interest and these regions then were morphometrically assessed. To achieve an unbiased and reproducible determination of the boundaries of the various regions in all the humeri, the following geometric scheme was applied. First, the central long axis of the humerus was determined (line a in Figure 1A) then line b was drawn as the connection between the cranial and caudal end of the hyaline articular cartilage covering the head. This line was considered as a reproducible identifier for the course of the "collum anatomicum" or anatomical neck. Further, a line c, perpendicular to

TABLE 1. Individual Donor Data Presentation

	ID	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)	Gender	T-Score
Normal	25,743	33	77	160	30.1	f	−0.6
	24,788	50	86	193	23.1	m	0.6
	24,789	19	80	180	24.7	m	0.3
	24,793	80	95	185	27.8	m	3.4
	24,795	90	63	160	24.6	f	1.6
	25,741	80	90	160	35.2	m	−0.9
	Mean	58.7	81.8	173.0	27.6		
	SD	29.0	11.3	14.8	4.5		
Osteoporotic	24,783	82	95	165	34.9	f	−2.7
	24,784	90	49	157	19.9	m	−3.4
	24,785	79	90	177	28.7	m	−5.1
	24,792	69	90	160	35.2	m	−4.3
	24,794	84	54	172	18.3	f	−4.4
	25,739	67	55	180	17.0	m	−6.5
	Mean	78.5	72.2	168.5	25.6		
	SD	8.9	21.5	9.3	8.3		

BMI = body mass index, f = female, m = male, SD = standard deviation.

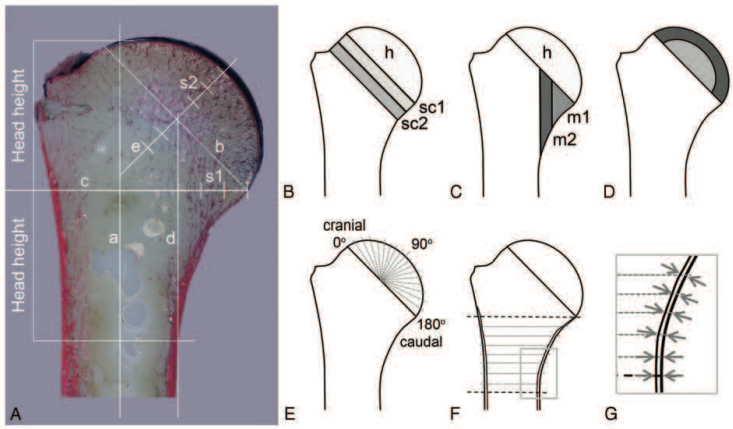

FIGURE 1. Schematic diagram demonstrating the different regions assessed in all humeri. (A) Giemsa Eosin stained section with geometric overlay showing all lines and distances used for definition of the regions of interest and locations of the measuring points. (B) Sketch drawing with the cancellous regions of the humeral head (h), and the 2 subcapital regions (sc1, sc2). (C) Sketch drawing showing the metaphyseal regions m1 (medial region) and m2 (lateral region). (D) Outer subchondral (dark gray) and inner (light gray) cancellous regions of the humeral head. (E) Sketch drawing showing the location of the measuring points where the subchondral plate thickness was measured. The humeral head joint surface forms a semicircle and the head center is used to cover with measuring points every 10 degrees of rotation. (F) The cortical thickness was assessed in 8 regular intervals medially and laterally (for details of the measurements, see also G).

the long axis of the humerus (line a), was constructed in a way that it met the caudal end of line b at the point where the cartilage ended. This line was divided into a medial and a lateral segment by line d, which was parallel to the long humeral axis (line a) and covered the periosteal segment at the distal medial end of the proximal humerus. The medial segment of line c was divided into 3 segments of equal length (s1 in Figure 1A) which were used later to define the long boundaries of the 2 medial metaphyseal regions m1 and m2 as shown in Figure 1C.

The regions of the humeral head were defined through a line e, which ran through the central point of line b and perpendicular through it. Line e ended at the beginning of the subchondral plate, which was not included into the bone density assessment and was divided into 3 segments (s2 in Figure 1A) of the same length. The length of s2 was used to construct the 2 subcapital regions sc1 and sc2 (Figure 1B). Both regions did not include the cortical bone lamellae at either end. The rest of the cancellous bone next to region h (head without subchondral plate) represented the bone stock of the humeral head (Figure 1B and C). In a further step it was divided into an inner and subchondral region (Figure 1D), using again the length of s2 as an unbiased geometric parameter for topographical separation of the regions.

Definition of the Regions of Interest for Cortical Bone and Subchondral Plate Thickness Assessment

The previously defined geometric parameters were used as landmarks for definition of the points where the thickness of the subchondral plate was measured. The latter was defined as the distance from the end of the cartilage, stained in deep blue in the Giemsa Eosin stained sections, to the beginning of the marrow cavity (unstained). Measurements were obtained at intervals of 10 degree using the central point of line b as the centre of the semicircle representing the humeral head (Figure 1E).

The cortical thickness of the medial and lateral compact bone lamella was obtained at 9 points on each side of the humerus. In order to assess comparable skeletal regions in different individuals and to account for the individual geometry of the bones the position of these points was defined using the height of the humeral head as the reference distance, which was divided into 8 segments of equal length. Starting at the level of line c (Figure 1A) 9 medial and lateral cortical thickness values were obtained (Figure 1F and 1G).

Histomorphometry and Statistical Evaluation

Histomorphometric image analysis was performed with the aid of KS400 Image analysis software (Zeiss, Göttingen, Germany). Trabecular bone volume (BV/TV)[19,21] as a surrogate measure for cancellous bone material distribution (bone density), cortical bone, and subchondral plate thickness[20] as a measure for compact bone distribution were determined interactively on the Giemsa Eosin stained sections using custom-made KS400 macros.

Results were statistically evaluated using SPSS version 21 (IBM SPPS, Armonk, NY). For detection of normally distributed values the Shapiro–Wilk Test was used. Regional values were compared using the General Linear Model Repeated Measures or the Related-Samples Wilcoxon Signed Rank Test with Bonferroni correction.

Comparisons between the 2 groups were performed using t-test for normally distributed values and Related-Samples Wilcoxon Signed Rank Test for non-normally distributed values. Significance level was set at $P = 0.05$ for all statistical tests.

RESULTS

Groups and Samples

The average age of the 6 donors from the normal (non-osteoporotic) group was 59 years (± 29 years standard deviation, range 19 90) and 79 years (± 9 years standard deviation,

range 67 90) for the 6 donors of the osteoporotic group. In the normal group the T-score obtained from DXA measurements at the distal radius of the same arm ranged from −0.9 to 1.6 and in the osteoporotic group from −2.7 to −6.5 (Table 1). No information regarding the dominant extremity of the donor was available.

Histomorphometry of the Cancellous Bone of the Humerus

Subcapital Region

The apparent density of the cancellous bone varied between the different subcapital regions of the humeral head in normal and osteoporotic donors (Figures 2 and 3). The cancellous region of the humeral head, which did not include the subchondral plate, showed the highest bone density values. The values were significantly reduced in the subcapital regions near the "collum anatomicum". All regions investigated exhibited a significant decrease of bone density in the osteoporotic group when compared to the normal group (Figures 2 and 3). The most significant difference between the values from the osteoporotic and the normal group was found in the first third of the subcapital region (region labeled sc1 in Figure 2); here the reduction of bone density was most pronounced.

Metaphyseal Region

When the bone density of the humeral head was compared to regions at the medial side of the metaphysis, the 3 regions showed no significant differences in the normal group but in the osteoporotic group significant reduction of bone density occurred in the 2 regions of the metaphysis (Figures 3 and 4).

Subchondral Region

As the region of the humeral head was relatively large compared to the other regions, it was decided to divide the head in 2 regions, 1 of them closer to the subchondral plate than the other. The bone density values in these 2 regions showed no difference for the normal group but a highly significant difference for the osteoporotic group. Both regions showed a significant bone density reduction in the osteoporotic group when compared to the normal group (Figure 5).

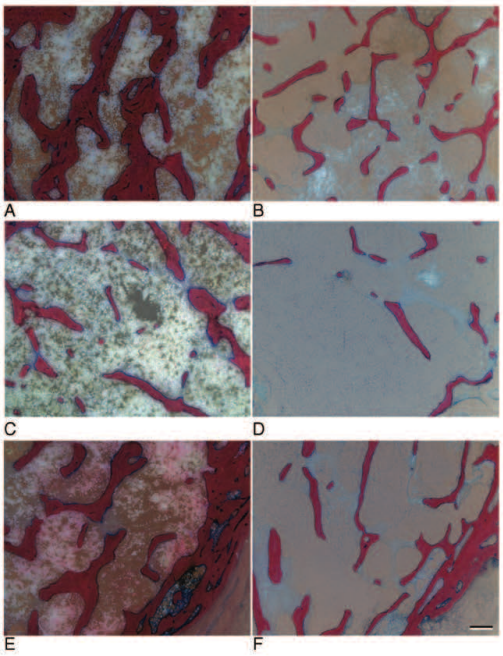

FIGURE 3. Examples of the morphology of cancellous bone in normal bone (A, C, E) and osteoporotic bone (B, D, F) obtained from Giemsa Eosin stained thick methylmethacrylate sections. The regions in the middle of the head are compared in A and B, and the subcapital regions in C and D. In E and F the region at the medial metaphysis is shown and the cortical bone is visible in the lower left corner of each image. (Scale bar 500 μm).

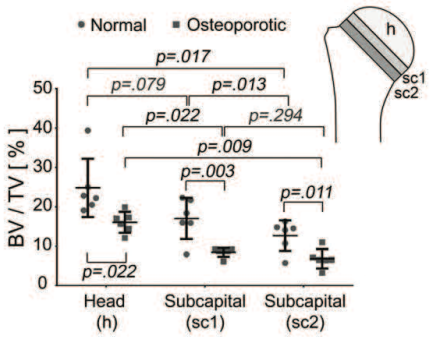

FIGURE 2. Comparison of the histomorphometrically determined bone density (BV/TV) in different regions (h = head, sc1 = subcapital region 1, sc2 = subcapital region 2) of the normal and osteoporotic group. In all regions the bone density was significantly lower in the osteoporotic group when compared with the normal group. Plots indicate average values with standard deviation. BV/TV = bone volume to total volume.

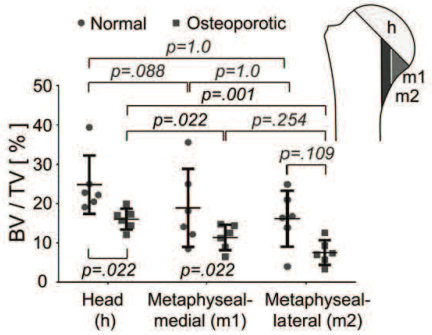

FIGURE 4. Comparison of bone density (BV/TV) between the normal and osteoporotic groups in the head and 2 regions on the medial side of the metaphysis. Significant differences between the regions were found only in the osteoporotic group. Plots indicate average values with standard deviation. BV/TV = bone volume to total volume.

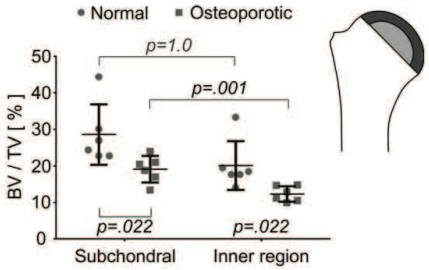

FIGURE 5. Humeral head bone density (BV/TV) of the normal and osteoporotic group in the subchondral (dark gray) and the inner region (light gray) has shown significant differences in the osteoporotic but not in the normal group. The bone density of the osteoporotic group in both regions is significantly lower than that in the normal group. Plots indicate average values with standard deviation. BV/TV = bone volume to total volume.

Cortical Dimensions of the Proximal Humerus

Thickness of the Subchondral Plate

The thickness of the subchondral plate supporting the articular cartilage was measured at defined locations in both groups, but revealed no statistically significant differences between the osteoporotic and normal group or the different locations within both groups (Figures 6 and 7).

Thickness of the Metaphyseal Cortex

The thickness of the cortical wall was measured medially and laterally at 9 points each. Only on the medial side the 4 most distal measuring sites exhibited significant differences between the 2 groups (Figures 7 and 8).

DISCUSSION

Osteoporosis is seen as a systemic condition, which affects the bone metabolism of the entire body.[1] As such it is often assumed that the bone stock and/or quality reduction process is more or less equally affecting all regions of the skeleton. Our results demonstrate that this is not the case in the human proximal humerus and that certain topographical regions are more prevalent to bone reduction than others. Comparable findings have been reported for the human distal humerus,[16] distal radius,[17] and for the proximal femur.[22–24] The fact that bone material reduction occurs in a nonuniform way in different regions with cancellous bone has implications for the fracture risk potential and subsequent treatment of osteoporotic humeral head fractures and our results may also help to predict regions in osteoporotic humeri, which are likely more suitable for anchoring of osteosynthesis materials in cases of fracture than others.

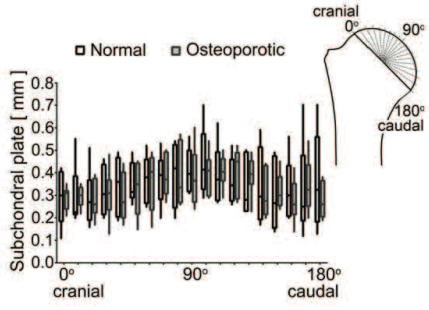

FIGURE 6. The thickness of the subchondral plate did not show any significant differences between the normal and osteoporotic group or between the different locations.

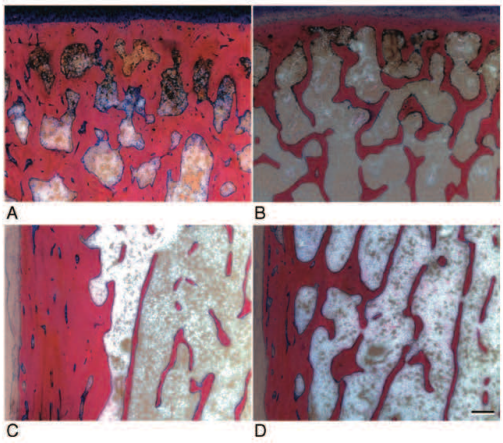

FIGURE 7. Examples of compact bone morphology in normal bone (A, C) and osteoporotic bone (B, D). A and B show a decrease of subchondral plate thickness and C and D show the decrease of cortical bone thickness in the lateral metaphyseal region. (Scale bar 500 μm).

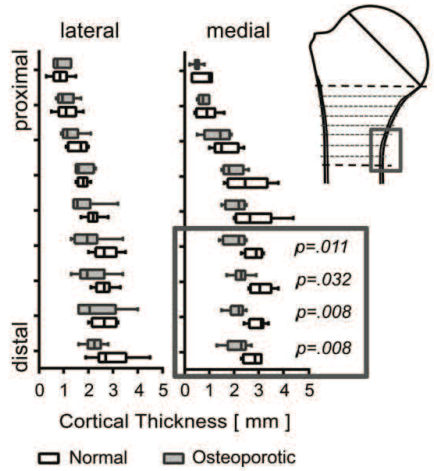

FIGURE 8. The investigation of cortical thickness at the lateral and medial sides of the metaphyseal region exhibited considerable differences between the different locations in both groups. Only for the most distal locations of the medial cortex (highlighted by dark gray boxes) the thickness values from the normal and osteoporotic group showed significant differences.

Our results also show that the humeri of normal individuals exhibit significant regional cancellous bone density variations and that these distribution patterns are changed under osteoporotic conditions.

The cancellous bone of the humeral head had the highest bone density in regions close to the subchondral plate. Closer to the anatomical neck the bone material density decreased and this effect was becoming more and more pronounced in osteoporosis. The regionally distinct and increasing degree of osteoporotic cancellous bone reduction is best reflected by the significant bone material decrease in the 2 medial metaphyseal regions. These 2 regions exhibit more bone loss than the corresponding osteoporotic humeral head, which also shows significant bone reduction when compared to a normal humeral head. It is interesting to note that a significant difference between the bone density values of the head and these 2 regions were only observed in the osteoporotic group whereas no differences were detected in the normal group. It is worth noting that in osteoporotic patients this region often fails to withstand the compressive stresses acting on the typically 1 superiorly placed fragment of the fractured head and that this caused deterioration of the stability of a surgically treated humeral head.[25] It is also worth to note that this region is already showing a tendency towards lower bone density values in normal patients.

In normal patients the humeral head has a relatively uniform cancellous bone density, which is significantly reduced in the central and especially subcapital regions in the osteoporotic group. The osteoporotic bone reduction process obviously affects certain regions more severe than others among them especially the cancellous bone at the level of the anatomical neck. This weakening of the humeral head stability is well reflected by the characteristic shape of frequently occurring humeral head fragments in osteoporotic patients.[18]

In the same context it was of interest to check whether the subchondral bone plate, which consists of the subchondral bone and the overlying mineralized cartilage, was reduced in thickness under osteoporotic conditions. This clearly was not the case in our investigation and it looks as if the humeral subchondral plate thickness is a parameter which is not or much less affected by osteoporosis. At present we can only speculate on the reasons for this observation. It has however been observed at other locations of the skeleton that cancellous bone may be much earlier affected by osteoporosis than cortical bone[26] and it could well be that there is another difference for the subchondral plate beneath an articular joint and the shaft cortical bone. Here it has to be noted that the subchondral plate is consisting not only of bone but also of mineralized cartilage[20] and that the composition may vary considerably between individual joints.

Since the stability of the shaft of a long bone is well determined by the thickness of the cortical bone, it was most interesting to see how the transition zone, where the load-bearing function is shifted from the cancellous bone of the humeral head to the shafts cortical bone, would be altered in osteoporosis. Interestingly, the only significant difference we could determine was seen in the medial and distal cortical bone covering the medial metaphyseal regions. This was surprising because in the femoral neck region Zebaze & Seemann[27] could demonstrate significant changes of cortical thickness between normal and osteoporotic individuals. As mentioned before, in proximal humerus fractures the mechanical properties of the medial metaphyseal region are of paramount importance for the stability of a locked Plate[25] or a intramedullary nail osteosynthesis.[28] All other measuring points and this means also the entire lateral side of the humerus did not show a significant difference in cortical bone thickness when osteoporotic and normal humeri were compared.

Although our investigation is only using the humeri and radii from 12 donors, subdivided into 2 equally sized groups of normal and osteoporotic individuals, we could observe significant differences in bone material distribution and cortical thickness in various regions of the proximal humerus. This however is only achievable because the histomorphometric determination of bone material distribution (i.e. bone area per field of view) was made in large resin embedded sections of undecalcified bone which allows for high imaging resolution. The latter is mandatory for the reliable determination of thin bone structures. These thin cancellous or cortical structures cannot be reliably detected with other methods such as μ-CT or clinical CT because the current voxel sizes coincide with partial volume effects which affect predominantly regions with very low bone density and few fine structures. It however can be argued that we only investigated 1 section and not the entire volume of a proximal humerus. This is owed to the complexity of the measuring process and the geometrical determination of the regions and points of interest. Since all proximal humeri are of different size and shape, our approach aims to standardize the choice of randomly selected regions of interest. Using reproducibly determined regions of interest for morphometric bone, material distribution assessment is an important advantage of our study design. Moreover, it is a necessary precondition for the statistical analyses we performed.

Clinically, our results render the medial metaphyseal region as not very sufficient for implant (i.e. screw) anchoring in osteoporotic patients. In these patients it would probably be more successful to use longer screws aiming at regions where more bone stock is present.

However, our results are based on single sections in the frontal plane of proximal humeri obtained from a limited number of donors. Thus the surgeon has to consider other out-of-plane regions which may potentially provide sufficient implant anchoring capacity.

Our results show that the various regions of the proximal humerus exhibit different bone material distributions in normal and osteoporotic individuals. Osteoporotic individuals show more pronounced differences than normal individuals in various regions of the proximal humerus, inhomogeneously affected by bone loss. Especially the medial metaphyseal region experiences a particularly high bone loss and thus biomechanical weakening. This may influence the prevailing fracture patterns and also interferes with osteosynthesis stability.

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ORIGINAL RESEARCH

High-Resolution Tomography-Based Quantification of Cortical Porosity and Cortical Thickness at the Surgical Neck of the Humerus During Aging

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Abstract Fractures of the proximal humerus are highly related to age and osteoporotic bone remodeling. Previous studies have highlighted the cortex as a major side of the bone loss, but the microstructural changes of the humerus have not been evaluated entirely. Sixty-four ($n = 64$) humeri of a representative collective (18–100 years) were scanned with high-resolution peripheral quantitative computed tomography (82 µm). Bone mineral density (BMD), trabecular bone volume fraction (Tb.BV/TV), cortical thickness (Ct.Th), and cortical porosity (Ct.Po) were determined with respect to four age groups. The BMD ($r = -0.42$), Ct.Th ($r = 0.57$), and Tb.BV/TV ($r = 0.68$) showed an age group-related decrease, while the Ct.Po increased ($r = -0.55$). The oldest group (80–100 years) revealed an extensively higher Ct.Po of +87% compared to the youngest group (18–44 years), while the Ct.Th and Tb.BV/TV were significantly lower by −35 and −49% ($p < 0.05$). The main cortical bone loss occurred after 65 years with the Ct.Th (−34%) and Tb.BV/TV (−40%) being clearly lower and the Ct.Po (+93%) clearly higher compared to the youngest group. In summary, osteoporosis leads to an age-related higher Ct.Po and reduced Ct.Th at the humeral cortex of the surgical neck. The bone loss of the cortex predominantly occurs around the age of 65 years and is very likely to reduce the mechanical strength and highly increases the fracture risk.

Keywords Fracture · Cortical porosity · Cortical thickness · DXA · HR-pQCT

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Introduction

Fractures of the proximal humerus are the third most common fracture in the elderly [1–3]. Most of them occur during a low energy trauma and are related to osteoporotic changes of the bone [2, 4]. Osteoporosis is characterized by loss of bone mass and deterioration of bone microarchitecture, leading to an increase of fracture risk. Previous studies have mainly been focused on the trabecular bone due to the most obvious change of its structure in the course of the osteoporosis disease. Nevertheless, the cortical bone represents the major mass of the skeletal system and recent studies on the radius, femur, and tibia have demonstrated that the predominant bone loss is cortical and not trabecular [5–7]. For these anatomical locations, the development, progression, and regional distribution of the cortical and trabecular bone have already been evaluated in various studies [6, 8–13]. The results clearly demonstrate that the cortical bone, especially its porosity and thickness, has significant impact on the loss of bone mass and mechanical stability [5, 14, 15].

Zebaze et al. even assumed that the cortical porosity (Ct.Po) is underestimated, as the cortical bone is completely lost along the endocortical surface and is thus hard to determine [11, 16]. Furthermore, they demonstrated that even in patients with a normal bone mineral density (BMD), 60% had a high porosity at the cortical bone [11].

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Those findings suggest that Ct.Po is a crucial factor accounting for bone fragility and fracture risk in elderly patients [7]. Although there is steadily increasing evidence that the cortex plays an important role in the osteoporotic changes and therefore fracture risk, little data are available for the proximal humerus, one of the most common sites of age- and osteoporotic-related fractures. Few studies have analyzed the trabecular bone remodeling at the proximal humerus and none of them have addressed the issue of Ct.Po [8, 17].

Therefore, the aim of this study was to assess the cortical bone remodeling processes at the proximal humerus. The main focus was to investigate the microstructural changes, such as Ct.Po and cortical thickness (Ct.Th), and their dependence on patient age and BMD.

Materials and Methods

Specimens

Sixty-four fresh-frozen (−20 °C) proximal human cadaveric humeri with a representative age and BMD were enrolled in this study. Specimens had been collected post-mortem with appropriate consent of the donors during their lifetime or of their relatives (Platinum Medical, USA; Department of Anatomy, LMU, Munich, Germany; and Department of Pathology, University of Bern, Switzerland). The study was approved by the Institutional Review Board and specimens were handled according to the legal law of Switzerland. Radiographs were taken from all humeri prior to processing in order to exclude unreported bone alterations.

Similarly to Zebaze et al. who evaluated cortical and trabecular bone of the radius and femur, the total collective was divided into four groups [11]: Group I = 18–44 years, Group II = 45–64 years, Group III = 65–79 years, and Group VI = 80–100 years. Individuals younger than 44 years (Group I) served as a baseline group for comparisons to the other groups.

HR-pQCT Measurements

All specimens were scanned by means of high-resolution peripheral quantitative computed tomography (HR-pQCT). The HR-pQCT imaging system (XtremeCT, Scanco Medical, Brüttisellen, Switzerland) was equipped with a 70-lmfocal spot. The X-ray tube was set at 60 kVp and 900 µA and the image matrix size was of 1536 × 1536 at nominal 82 µm isotropic resolution. The integration time was set to 300 ms. A Scanco phantom was scanned daily for quality control.

Images were stored in three-dimensional arrays with a voxel size of 82 µm. For scanning, the proximal humerus was fixed in the central part of the tube with the lesser tubercle facing the 12-o'clock position. Starting from its proximal end, the scan of each humerus was performed for a minimum of the first 100 mm, resulting in approximately 1500 microtomographic slices.

Image Analysis and Regions of Interest (in HR-pQCT)

Image processing and analysis were performed using the software package provided by the scanner manufacturer (Image Processing Language, Scanco Medical, Brüttisellen, Switzerland). A Gaussian filter with a σ of 0.7 and support of 1 voxel was primarily used to suppress noise. For binary segmentation, a uniform threshold of 11% of the maximal grayscale value was selected for all samples. This value represents the peak of bone tissue in the gray value distribution histogram.

Volume of interests (VOIs) for each specimen was semi-automatically segmented into trabecular and cortical bone using the ranges of 301–512 and 512–1500 mg hydroxyapatite (HA)/cm^3, respectively [18]. The threshold values were optimized in accordance with the density histograms of the specimens.

Bone Mineral Density, Cortical and Trabecular Bone Analysis

Calculation of structural indices from HR-pQCT was performed as previously described and validated in several studies [14, 18–20]. Briefly, the bone volume (BV) was calculated using a tetrahedron meshing technique generated with the marching cubes method and total volume (TV) being identical to the defined VOI. From the trabecular BV and TV, the mean trabecular bone volume fraction [Tb.BV/TV (%)] was determined. Segmentation of Ct.Po (%) was achieved using an extended cortical analysis with the first including the creation of a cortical mask. This process initially requires a segmented image of the whole bone. This is done through application of a filter to the grayscale image followed by a fixed threshold binarization. The resulting segmented image and the periosteal contour generated previously were then used to create an endosteal contour through a series of dilations, erosions, and the application of a connectivity filter. The cortical compartment was identified by subtracting the endosteal contour from the periosteal contour. The Ct.Th (mm) is determined as the mean cortical volume divided by the outer bone surface.

Evaluation of the Ct.Po, Ct.Th, and Tb.BV/TV was performed at the surgical neck as the most common

fractured zone of the humerus (Fig. 1a). For a better comparability with recent studies, the BMD of the humerus was performed at the humeral head, similar as described before [21]. The volumetric BMD (mg HA/cm^3) was derived from the humeral head including the trabecular and cortical bone. The VOI included 150 sections cranial and caudal from the center of the humeral head, corresponding to a length of about 25 mm in z-axis (Fig. 1b).

Statistics and Analysis

Statistical analysis was performed with GraphPad Prism 5 (GraphPad Software, Inc., La Jolla, California, USA). Data for the Ct.Po, Ct.Th, BMD, and Tb.BV/TV are presented in absolute values or as percentage differences [with 95% confidence interval (CI)]. All variables of interest were checked for normal distribution. Linear regression was used to examine the correlation between age or BMD with Ct.Po, Ct.Th, BMD, or Tb.BV/TV. The analysis was performed for the whole collective, as well as for the male and female groups (expressed as r, Spearman's ρ coefficient, two-tailed). Then, all variables of interest from the different age groups were tested for normal distribution. Comparison between the age groups was performed using one-way ANOVA, when normally distributed. In cases of homogeneity, the Bonferroni correction was used and in all the other cases the Games Howell post hoc test was applied. Related to the cross-sectional study design, the results should be considered as an estimation of age-related changes.

Results

Characteristics of the Specimens

Sixty-four specimens (30 males/34 females) with a mean donor age of 69.6 ± 19.7 years [mean ± standard deviation, range 19–98 years] were analyzed. In 34 cases the left side and in 30 cases the right side were evaluated. The dominant side was unknown for all specimens. Age and gender of the groups are given in Table 1 and correlation of age with the BMD is depicted in Fig. 2. Classification of the groups was as follows: Group I, serving as the baseline group, included eight humeri ($n = 8$) from donors between 18 and 44 years with mean age of 30 years. Group II included ten humeri ($n = 10$) between 45 and 64 years with mean age of 55 years. Group III included 25 humeri ($n = 25$) between 65 and 79 years with mean age of 73 years and Group VI included 21 humeri ($n = 21$) between 80 and 100 years with a mean age of 88 years.

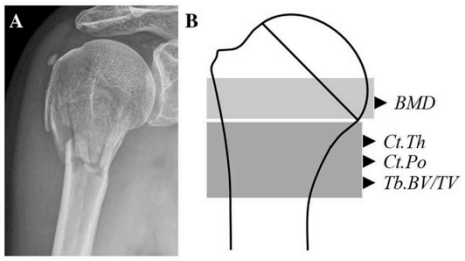

Fig. 1 **a** Clinical radiograph of a proximal humerus fracture involving the surgical neck as a major fracture sites in elderly. **b** Regions with analyzed BMD (humeral head) as well as Ct.Po, Ct.Th, and Tb.BV/TV (surgical neck) by means of HR-pQCT (resolution 82 µm)

Bone Mineral Density (BMD)

The mean BMD of the whole collective determined at the humeral head was 139 ± 50 mg HA/cm^3 (range 63–297 mg HA/cm^3). The mean BMD of Groups I–IV as well as the differences between the groups is given in Table 1 and Fig. 3. Compared to the baseline Group I, the BMD in Group II (45–64 years) was significantly lower by 16 mg HA/cm^3 (CI −63 to 32; −8%), in Group III (65–79 years) by 62 mg HA/cm^3 (CI −78 to −47; −33%), and in Group IV (80–100 years) by 65 mg HA/cm^3 (CI −82 to −49; −35%) ($p < 0.007$). All age groups (45–100 years) showed a lower BMD of −55 mg HA/cm^3 (CI −68 to −43; −29%) compared to the baseline Group I (18–44 years; Figs. 4, 5).

BMD was reduced between 45 and 64 years (Group II) by 8%, between 65 and 79 years (Group III) by additional 27%, and between 80 and 100 years (Group IV) by a further 3%. The highest BMD reduction was proportionally observed after the age of 65 years in Group III (65–79 years).

Cortical Porosity (Ct.Po)

The mean Ct.Po at the surgical neck of the whole collective was 23 ± 10% (range 7–54%). Age only moderately predicted the Ct.Po with $r = -0.35$, whereas the BMD was a better predictor for the Ct.Po $r = -0.55$ (Fig. 2). The mean Ct.Po of Groups I–IV as well as the differences between the groups is given in Table 1 and Fig. 3. Compared to the baseline Group I, the Ct.Po in Group II (45–64 years) was 4% higher (CI −3 to 11; +32%), in Group III (65–79 years) 13% higher (CI 8 to 18; +93%), and in Group IV (80–100 years) 12% higher (CI 8 to 15; +87%) ($p = 0.019$). All age groups (45–100 years) showed an increase of 11% (CI 8 to 14; +80%) compared to the baseline Group I (18–44 years) (Figs. 4, 5).

Table 1 Data representing absolute values for the BMD and age-related changes in cortical and trabecular bone for the different age groups [mean (95% CI)]

Groups	BMD (mg HA/cm^3)	Ct.Th (mm)	Ct.Po (%)	Tb.BV/TV (%)	Age (years)
18–44 ($m = 4$; $f = 4$)	188 (148, 227)	1.85 (1.39, 2.38)	14 (10, 17)	35 (27, 44)	30 (23, 37)
45–64 ($m = 6$; $f = 4$)	172 (124, 220)	1.54 (1.19, 1.89)	18 (11, 25)	32 (24, 40)	55 (49, 60)
65–79 ($m = 10$; $f = 15$)	125 (110, 141)	1.22 (1.07, 1.37)	26 (22, 31)	24 (21, 27)	73 (71, 75)
80–100 ($m = 10$; $f = 11$)	122 (106, 138)	1.20 (1.04, 1.36)	26 (22, 29)	23 (20, 26)	88 (86, 90)
45–100 ($f = 26$; $m = 30$)	132 (120, 145)	1.27 (1.16, 1.38)	25 (22, 27)	25 (0.23, 0.27)	75 (72, 79)

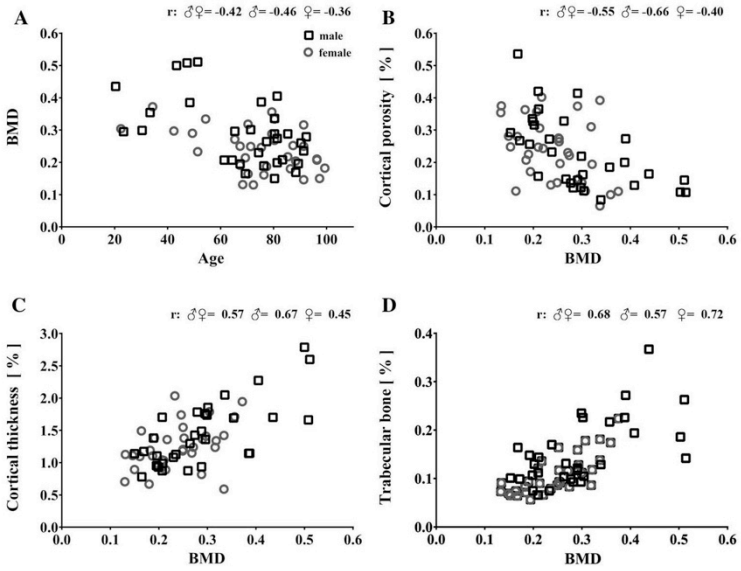

Fig. 2 Bone mineral density (BMD) with significant correlation ($p \leq 0.001$) to **a** age, cortical porosity (**b**), cortical thickness (**c**), and trabecular bone (**d**). p values determined for the whole collective

Ct.Po was increased between 45 and 64 years (Group II) by 4%, between 65 and 79 years (Group III) by additional 8%, and was 1% less between 80 and 100 years (Group IV). The highest increase in Ct.Po was proportionally observed after the age of 65 years in Group III (65–79 years).

Cortical Thickness (Ct.Th)

The mean Ct.Th of the whole collective was 1.34 ± 0.44 mm (range 0.60–2.79 mm). Age predicted the Ct.Th only moderately with $r = 0.44$, whereas the BMD was a better predictor for the Ct.Th with $r = 0.57$ (Fig. 2). The mean Ct.Th of Groups I–IV as well as the differences between the groups is given in Table 1 and Fig. 3. Compared to the baseline Group I, the Ct.Th in Group II (45–64 years) was lower by 0.31 mm (CI −0.66 to 0.40; −17%), in Group III (65–79 years) by 0.63 mm (CI −0.78 to 0.48; −34%), and in Group IV (80–100 years) by 0.65 mm (CI −0.81 to 0.49; −35%) ($p < 0.001$). All age groups (45–100 years) showed a reduction of −0.58 mm (CI −0.69 to −0.48; −31%) compared to the baseline Group I (18–44 years) (Figs. 4, 5).

Ct.Th was decreased between 45 and 64 years (Group II) by 17%, between 65 and 79 years (Group III) by additional 21%, and between 80 and 100 years (Group IV) by additional 2%. The highest reduction in Ct.Th was proportionally observed after the age of 65 years in Group III (65–79 years).

Trabecular Bone Volume Fraction (Tb.BV/TV)

The mean Tb.BV/TV of all specimens was $13 \pm 6\%$ (range 6–37%). Age moderately predicted the Tb.BV/TV

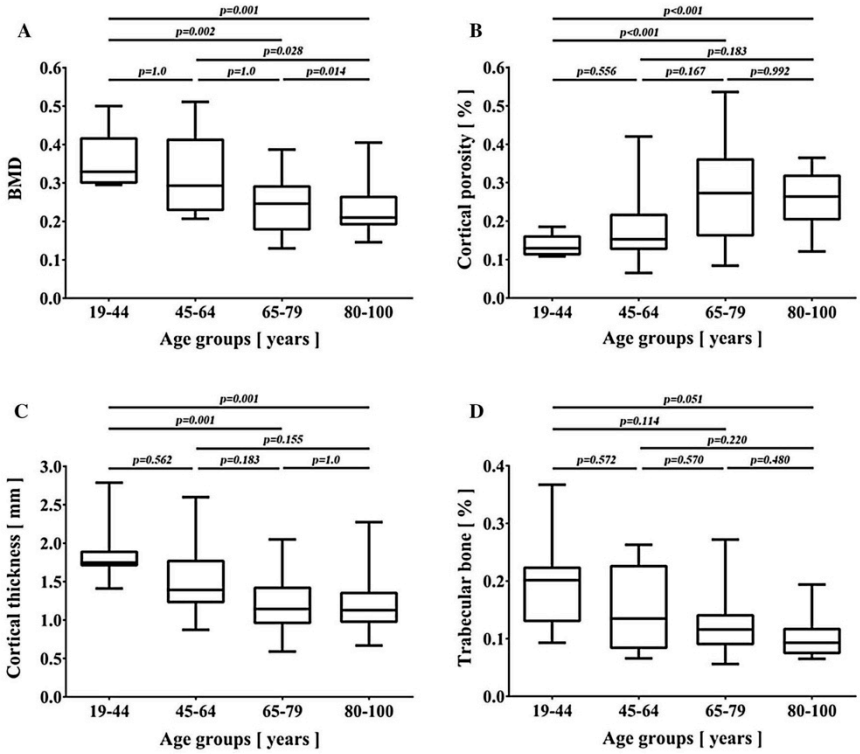

Fig. 3 Bone parameters for the different age groups: **a** BMD, **b** cortical porosity (Ct.Po), **c** cortical thickness (Ct.Th), and **d** trabecular bone (Tb.BV/TV). All parameters show a clear difference between the age groups 18–44 and 80–100 years

with $r = 0.40$, whereas the BMD was a good predictor for the Tb.BV/TV $r = 0.68$ (Fig. 2). The mean Tb.BV/TV of Groups I–IV as well as the differences between the groups is given in Table 1 and Fig. 3. Compared to the baseline Group I, the Tb.BV/TV in Group II (45–64 years) was 5% lower (CI −10 to 2; −24%), in Group III (65–79 years) 8% lower (CI −10 to −6; −40%), and in Group IV (80–100 years) 10% lower (CI −11 to −8; −49%) ($p = 0.019$). All age groups (45–100 years) showed a reduction of −8% (CI −9 to 7; −8%) compared to the baseline Group I (18–44 years) (Figs. 4, 5).

Discussion

This study is the first HR-pQCT study that describes the microstructural changes of the cortical bone at the proximal humerus. Previous studies almost exclusively focused on the trabecular bone [9], whereas more recent investigations on the radius, tibia, and femur have clearly identified the cortical bone as mainly contributing to the bone loss [11, 16, 22]. In accordance to those studies, the major findings regarding the surgical neck of the proximal humerus show that (1) Ct.Po increases during aging, (2) Ct.Th concurrently decreases, and (3) the highest microstructural changes at the cortex occur around the age of 65 years.

In this cross-sectional study, Ct.Po at the surgical neck increased with the age from 14 to 26%. These numbers are similar to a population-based HR-pQCT study of MacDonald et al. and Nishiyama et al. who found an increase in porosity from 5–6 to 14–16% for the distal radius and from 9 to 21–28% for the tibia [6, 23]. Burghardt et al. reported about an increase of Ct.Po in pre- and postmenopausal women of 88% for the distal radius and 99% for the tibia [20] and Shanbhogue et al. described an annual increase in Ct.Po between 0.4 and 7.1% for the radius and between 1.4 and 3.5% for the tibia [24].

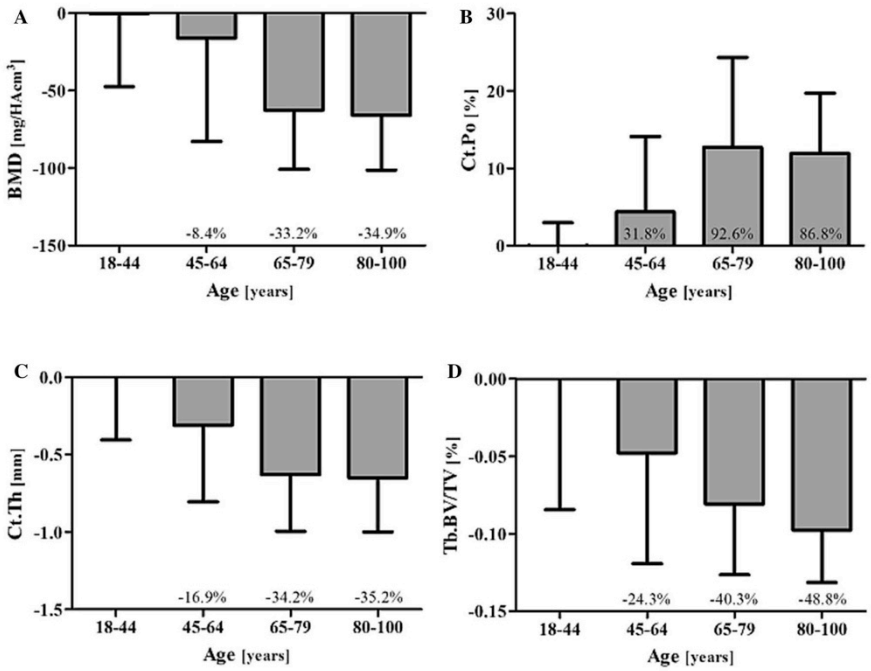

Fig. 4 Difference in cortical and trabecular bone for the age groups relative to the baseline group (18–44 years): **a** BMD of the humeral head and **b** cortical porosity (Ct.Po), **c** cortical thickness (Ct.Th), and **d** trabecular bone (Tb.BV/TV) at the surgical neck. Major cortical bone loss occurs between 45 and 79 years as depicted for the Ct.Po (**b**) and the Ct.Th (**c**)

Concurrent to the increased porosity, the Ct.Th at the radius and tibia was reduced [6, 20, 24], which was similarly observed in this study for the humerus. This is in good agreement with a histomorphological study where we could demonstrate that osteoporotic bone loss also affects the Ct.Th of the subchondral bone plate at the metaphyseal region of the humerus [25]. The loss of Ct.Th at the humerus is also in line with studies evaluating clinical radiographs that found a clear relation to the bone quality. Meema et al. reported a Ct.Th below 6 mm on plain radiographs to be strongly indicative of osteoporosis [26]. Tingart et al. as well as Mater et al. reported a significant correlation of the Ct.Th with age and BMD [21, 27]. The loss of Ct.Th at the humerus matches well with HR-pQCT studies on other bones, reporting a reduction between 21 and 24% for the distal radius, 17–19% for the tibia, and 19–22% for the femur with increasing age, compared to 31% in this study [20, 28, 29].

The decrease of trabecular bone mass during osteoporosis has extensively been described for the femoral neck and distal radius [30–32]. Chen et al. reported about a decrease of 20% for the femoral neck and Khosla et al. about a 27% decrease for the distal radius [32, 33]. Our data revealed a trabecular bone loss at the humerus of 41% which is comparable to Barvenick et al. reporting about 25% [8]. Although it is undisputed that trabecular bone is important for the mechanical bone strength, it has to be noticed that 80% of the fragility fractures in the elderly involve the appendicular skeleton and the cortical bone loss at those locations accounts for 70% [11, 34]. Biomechanical studies on paired cadaveric femurs demonstrated that removing the trabecular bone only reduced the load at fracture by 7% [35]. In contrast, Diab and Vashishth demonstrated that a 4% rise in porosity increases crack propagation by 84% [36] and Martin et al. showed than an increase from 4 to 10% halves the peak stress that can be tolerated before the bone fractures [37]. Those data underline the importance of the cortical bone integrity and show the influence of increased Ct.Po on the resistance of the bone. This is highly relevant and supported by a clinical study on women with osteopenia, where increased Ct.Po was associated with forearm fractures [5].

We found an increased porosity of about 90% at the surgical neck in patients older than 65 years, thus helping

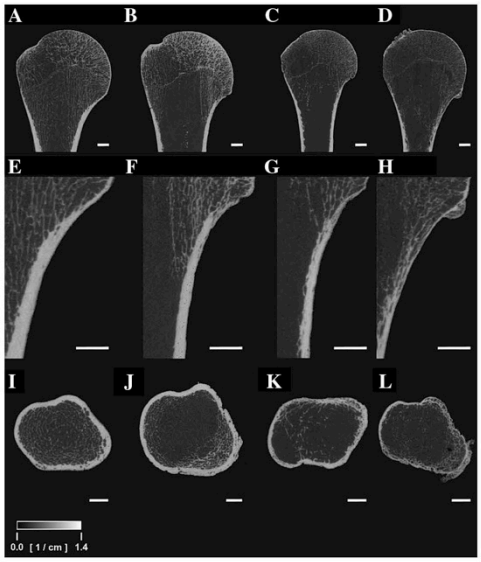

Fig. 5 Difference in cortical and trabecular bone at the surgical neck of the humerus for representative specimens of the four different age groups: <44 years (images **a**, **e**, **i**), 45–64 years (**b**, **f**, **j**), 65–79 years (**c**, **g**, **k**), and 80–100 years (**d**, **h**, **l**). **a–d** Overview of the specimens in the frontal plane. **e–h** Changes of the cortical thickness, porosity, and trabecular density at the surgical neck. **i–l** Transversal cross sections from the surgical neck indicating that changes predominantly occur at the medial side (all *scale bars* 5 mm)

to understand the high fracture risk at this bone site in the elderly. Moreover, in this age group the cortical bone is further weakened by a concurrent reduction of Ct.Th by about 35%. Pistoia et al. could show in the distal radius that the cortical bone carries the major load and a reduction in thickness had the greatest impact on bone strength, whereas reducing the trabecular structure affected the strength to a much lesser degree [38]. Similarly, the vertebral bone cortex accounts for about 30–60% of the bone mass but carries about 45–75% of the axial load [39]. Thus, cortical changes with a reduced thickness and increased porosity are likely to weaken the resistance of the humerus and increase the fracture risk. Although other factors including the geometry and material properties determine the bone strength, our findings contribute to a better understand of the highly increased incidence of humeral fractures in the elderly.

Overall, age and bone loss are inevitably linked, but the occurrence and bone site of the main bone loss have still not been elucidated. In this study, the main humeral bone loss in terms of increased Ct.Po and decreased thickness was noted around the age of 65 years. Our results correspond well to data reported by Zebaze et al. for the radius and femur. Contrary to prevailing views, they reported that in the first 15 years after menopause the bone loss at peripheral sites contributes only to an extent to total bone loss lifelong [11]. They further highlighted that this cortical bone loss is not solely driven by a fall in estrogen concentration but is indicated for both genders [7]. In accordance, Burghardt et al. reported an increased porosity in men and women [20] and Sundh et al. reported an increased Ct.Po in elderly men who sustained a fracture independently of its location [15]. Those results match well with our data of the humerus showing the highest cortical bone loss around the age of 65 years, which is further supported by the highly increased incidence of humeral fractures after this age [1, 3].

This study has certain limitations which are mainly related to the fact that while an in vivo measurement of the proximal humerus would allow large cohort studies, this is currently not possible with HR-pQCT. Although a considerable number of specimens were scanned, a larger sample number would enhance the results and enable a gender analysis that was not possible due to the limited donors. Furthermore, the number of donors was too low to determine predefined thresholds for BMD. Therefore, a continuous number series of BMDs was determined to define four categorical groups, as previously described by Zebaze et al. Besides, the cross-sectional design does not allow a definite statement about the bone remodeling processes but is rather an analysis of age-related changes. Secondly, we had no detailed information of the donors regarding the life style, medication, dominant side, or activity that might have affected the bone measurements. Thirdly, the measurement of the cortical bone is challenging in osteoporotic individuals as the bone loss occurs at the endosteal surface and the borders between cortical bone and trabecular bone are not always clear for definition despite the use of a semiautomatic technique. However, this rather results in an underestimation of the Ct.Po and would probably even result in higher microstructural changes and fracture risk than reported in this study. Fourthly, despite the fact that HR-pQCT is a high-resolution technique, it is still limited to the size of pores captured by the maximum resolution, which however does not necessarily reflect the true porosity on an ultrastructural level.

In summary, the current study demonstrates that besides a reduction in the trabecular bone, the cortex of the proximal humerus is clearly affected by osteoporotic changes. We observed a high Ct.Po and a concurrent reduced Ct.Th with aging and BMD loss, which started after 45 years, reaching a maximum around 65 years. This suggests a reduced bone strength at the surgical neck which is very likely to contribute to osteoporotic fractures in low energy

trauma events. Further research should evaluate the impact of the microstructural changes on the biomechanical strength and whether antiresorptive treatment can influence the remodeling processes at the humeral bone.

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Compliance with Ethical Standards

Conflict of interest Tobias Helfen, Christoph M. Sprecher, Ursula Eberli, Boyko Gueorguiev, Peter E. Müller, Robert G. Richards, and Florian Schmidutz declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent All specimens were collected post-mortem with appropriate consent of the donors during their lifetime or of their relatives and were handled according to the highest ethical standards.

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Originalien

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Charakterisierung des schwer verletzten Fahrradfahrers

Eine Auswertung der Hauptverletzungen und Behandlungsschwerpunkte von 2817 Patienten

Hintergrund und Fragestellung

In nationalen und internationalen Straßenverkehrsstatistiken kommt den Fahrradfahrern als eigenständige Verkehrsteilnehmergruppe eine besondere Bedeutung zu. Auch in der Medizin wurden bereits viele Arbeiten, die sich mit diesem Kollektiv befassten, publiziert. Arbeiten zum Gesamtverletzungsmuster bei definierter Verletzungsschwere liegen jedoch nur unzureichend vor. In den medizinischen Datenbanken sind v. a. Arbeiten zu isoliert verletzten Regionen im Kollektiv der Fahrradfahrer zu finden. Darüber hinaus besteht sehr häufig eine Studienschwäche aufgrund einer heterogenen Verletzungsschwere der jeweiligen Studienkollektive. Aus der bestehenden Literatur sind dennoch charakteristische Verletzungsmuster, epidemiologische Aspekte, Behandlungsschwerpunkte und Outcomeergebnisse erkennbar [7, 8, 11, 12]. Ziel der vorliegenden Arbeit war daher zum einen die Gesamterfassung aller Verletzungen sowie daraus resultierend die Charakterisierung von Verletzungsschwerpunkten, zum anderen die Generierung eines repräsentativen und mit dem Status „schwer verletzt" weitgehend homogen evaluierbaren Kollektiv verunfallter Fahrradfahrer.

Material und Methoden

Als Datenbasis für die retrospektive Analyse diente das Traumaregister der DGU (TR-DGU). Aus dem Gesamtkollektiv des seit 1993 geführten Registers wurden die Daten aller beteiligten 145 deutschen Kliniken im Zeitraum 2002–2010 ausgewertet. Ab 2002 erfolgte eine separate Erfassung der Fahrradfahrer als eigenständiges Kollektiv. Das TR-DGU erfasst standardisiert Daten zu definierten Zeitpunkten (Demografie, Präklinik, Schockraum, Intensivstation/Überwachungsstation, Entlassung), die eine Dokumentation der Diagnosen mit Klassifikationen der Verletzungsschwere „Injury Severity Score" (ISS) [5] und „Abbreviated Injury Scale" (AIS) [3], der Interventionen und Operation, der Outcomeparameter und -scores und Zeitangaben der einzelnen Behandlungsabschnitte der schwer verletzten Patienten umfasst (http://www.traumaregister.de).

Zwischen Januar 2002 und Mai 2012 (124 Monate) wurden insgesamt 2817 schwer verletzte Fahrradfahrer registriert. Die Einschlusskriterien waren ein ISS ≥9 und die gleichzeitig notwendige intensivmedizinische Behandlung bzw. Überwachungsbehandlung (ICU/IMC). Primärer Endpunkt der Untersuchung war die Evaluation des Gesamtverletzungsmusters und der daraus resultierenden Verletzungsschwerpunkte. Sekundäre Endpunkte waren epidemiologische Aspekte, Unfallumstände sowie die Evaluation von Behandlungsschwerpunkten und das Patientenoutcome. Entsprechend des Dokumentationsalgorithmus des Traumaregisters erfassten wir die Parameter in 3 Phasen:

- Phase A: „Präklinik" (Geschlecht, Alter, Unfalltag, Unfalluhrzeit, initialer GCS, initialer systolischer Blutdruck (RR_{syst}), Status der Analgosedierung, der Indikation zur präklinischen Intubation und Beatmung zur Anlage einer Thoraxdrainage, des infundierten Volumens und des Beginns der Katecholamintherapie),
- Phase B: „Schockraum" (Erfassung des Verletzungsmusters nach CT-Aufnahme, kristalloide Volumengabe, Bluttransfusion oder Massentransfusion),
- Phase C: „Intensivstation" (Beatmungstage, Dauer des Intensiv- und Gesamtkrankenhausaufenthalts, Krankenhausmortalität sowie das Entlassungsmanagement).

Für diese Studie war die Zustimmung einer Ethikkommission nicht notwendig, da die Behandlung bereits zu einem früheren Zeitpunkt erfolgte, die Studie also nicht zu Änderungen in der Patientenbe-

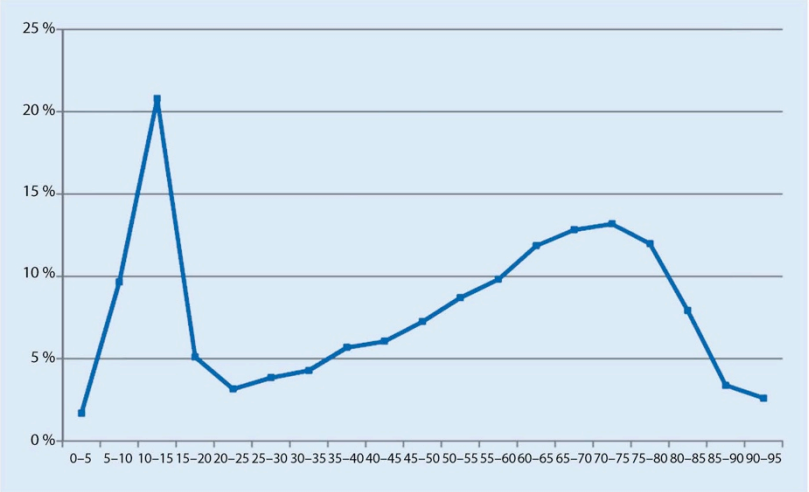

Abb. 1 ◀ Grafische Darstellung der Altersverteilung schwer verletzter Fahrradfahrer in 5-Jahres-Kategorien

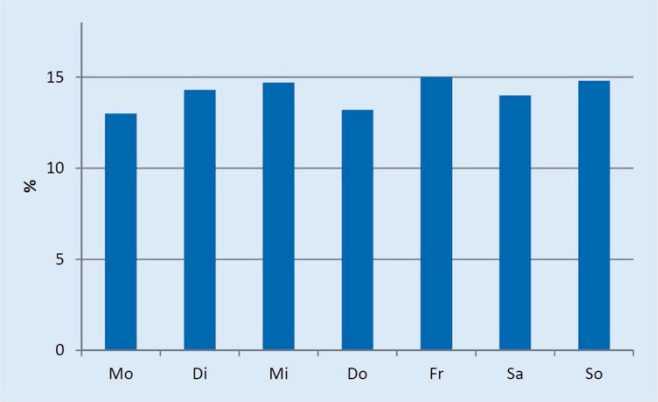

Abb. 2 ▲ Unfall-Wochenstatistik schwer verletzter Fahrradfahrer (Anteile in %)

handlung führte. Die Studie wurde vom Review Board der TraumaregisterDGU geprüft und zugelassen (2012–008).

Statistische Auswertung

Die weitere statistische Auswertung erfolgte mit SPSS (SPSS Inc., Version 15.0), wobei quantitative Variablen mit Mittelwerte und Standardabweichung (±) dargestellt werden. Bei Variablen, insbesondere mit schiefer Verteilung, wird zusätzlich der Median angeben. Häufigkeiten werden in Prozent dargestellt.

Ergebnisse

Epidemiologie

Insgesamt wurden 2817 schwer verletzte Fahrradfahrer eingeschlossen. Das durchschnittliche Alter betrug 50,3 ± 20,9 Jahre (Median 53 Jahre. 68,9 % (n = 1940) der Fahrradfahrer waren männlich. Der durchschnittliche ISS betrug 23,7 ± 12,6 (Median 21). Die Altersverteilung ergab einen ersten Peak (21,3 %) um das 10.–15. Lebensjahr mit einem folgenden deutlichen Rückgang der Unfälle bis zu einem Alter von etwa 20 Jahren. Im weiteren Verlauf stieg die Inzidenz schwer verletzter Fahrradfahrer konstant bis zu einem weiteren, jedoch deutlich weniger ausgeprägten Peak um das 70.–75. Lebensjahr 13,7 %. (◘ Abb. 1).

Allgemeine Unfallumstände

Die Prävalenz der Unfälle mit schwer verletzten Fahrradfahrern war auf die Wochentage verteilt nahezu identisch und bewegte sich stets zwischen 13 und 15 % (◘ Abb. 2). Bei Tageslicht ereigneten sich 71,4 % der Fahrradunfälle. Die Hauptsaison für Unfälle lag Im Zeitraum April bis September. In diesen Monaten ereigneten sich 73,0 % aller Fahrradunfälle.

Verletzungsmuster

Die 3 meistbetroffenen AIS-Regionen (≥3) waren der Kopf mit 71,9 % (n = 2025), der Thorax mit 44,9 % (n = 1264) und die oberen Extremitäten mit 33,6 % (947). Die Hauptverletzungen, die zu einen ISS ≥9 führten, waren Kopf- und Nackenverletzungen (68,2 %), weit gefolgt von Verletzungen der Brust (38 %) sowie der Extremitäten und des Beckengürtels (20,7 %; ◘ Tab. 1 und 2; ◘ Abb. 3). In 21,1 % der Fälle (n = 594) lag das

Zusammenfassung · Abstract

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Charakterisierung des schwer verletzten Fahrradfahrers. Eine Auswertung der Hauptverletzungen und Behandlungsschwerpunkte von 2817 Patienten

Zusammenfassung

Hintergrund. In Straßenverkehrsstatistiken kommt den Fahrradfahrern als Verkehrsteilnehmergruppe eine besondere Bedeutung zu. Auch in der Medizin wurden bereits viele Arbeiten um dieses Kollektiv publiziert. Meist werden einzelne verletzte Regionen bei heterogener Gesamtverletzungsschwere analysiert. Verletzungsmuster, epidemiologische Aspekte, Behandlungsschwerpunkte und das Outcome scheinen daraus resultierend charakteristisch verteilt zu sein. Ziel der vorliegenden Arbeit war die Gesamterfassung der Verletzungen sowie die Charakterisierung von Verletzungsschwerpunkten in einem standardisierten und repräsentativen Kollektiv schwer verletzter Fahrradfahrer.

Methoden. Es wurden Daten des Traumaregisters der DGU® über den Zeitraum 2002–2010 ausgewertet. Insgesamt wurden 2817 schwer verletzte (ISS ≥ 9 mit zusätzlicher intensivmedizinischer oder Intensivüberwachungstherapie) Fahrradfahrer eingeschlossen. Primärer Endpunkt der Untersuchung war die Evaluation des Gesamtverletzungsmusters und der Verletzungsschwerpunkte. Des Weiteren wurden Parameter wie epidemiologische Aspekte, Unfallumstände sowie Behandlungsschwerpunkte und das Outcome untersucht.

Ergebnisse. Das mittlere Alter lag bei 50,3 ± 20,9 Jahren. 68,9 % (n = 1940) der Fahrradfahrer waren männlich. Der mittlere ISS betrug 23,7 ± 12,6. Die 3 meistbetroffenen AIS-Regionen waren der Kopf mit 71,9 % (n = 2025), gefolgt vom Thorax mit 44,9 % (n = 1264) und den oberen Extremitäten 33,6 % (947). In 68,2 % der Fälle wurde ein ISS ≥ 9 isoliert durch das Schädel-Hirn-Trauma erreicht, in 21,1 % der eingeschlossenen Fälle lagen Monoverletzungen vor. Es resultierten eine charakteristische Altersverteilung und Prävalenz der Unfälle in Bezug auf den Unfallzeitpunkt.

Schlussfolgerung. Die vorliegende Arbeit untersuchte das bislang größte Kollektiv schwer verletzter Fahrradfahrer nach medizinischer Definition. Das Schädel-Hirn-Trauma konnte hier klar als Hauptverletzung charakterisiert werden, zudem wurde gezeigt, dass es sich bei jedem 5. Fall um eine Monoverletzung handelt, die zum Status „schwer verletzt" führt.

Schlüsselwörter
Fahrradfahrer · ISS · SHT · Polytrauma · Traumaregister

Characterization of the seriously injured cyclist. An evaluation of the injury and treatment focus areas of 2817 patients

Abstract

Background. Transport statistics classify bicyclists in a separate road user collective. For medical reasons, this differentiation is applied as well. Much literature is published in this field. Nevertheless there is a lack of literature regarding the overall injury patterns in a defined injury severity collective. Most literature is about isolated injured regions in combination with a heterogeneous injury severity. Further parameters, such as injury patterns, epidemiological aspects, treatment focal points and characteristic outcomes, have also been studied. The aim of the present study was to evaluate and characterize injury patterns in a standardized and representative collective of severely injured bicyclists.
Methods
We analysed data from the Traumaregister DGU® from 2002 to 2010. In total, 2817 severely injured (ISS ≥ 9 and additional intensive/intermediate care unit) bicyclists were included. The primary endpoint was evaluation of injury patterns and injury focal points. In addition to that we analysed parameters like epidemiological aspects, circumstances of accident, treatment focal points and outcome.

Results. The mean age was 50.3 ± 20.9 years. Males accounted for 68.9 % (n = 1940). The mean ISS was 23.7 ± 12.6. The mean AIS regions were the head 71.9 % (n = 2025), the chest with 44.9 % (n = 1264) and the upper extremities 33.6 % (947). In 68.2 % of all cases an ISS ≥ 9 was achieved by a traumatic brain injury; 21.1 % of all cases were mono-injuries. A characteristic distribution of age and a characteristic prevalence of the accidents in relation to the weekday and the month could be shown.

Conclusion. The present study analysed the largest ever published collective of severely injured bicyclists. Traumatic brain injury could clearly be shown as the main injury in this collective. Moreover, one of five cases achieved the state "severely injured" due to mono-injury.

Keywords
Bicyclists · ISS · TBI · Polytrauma · Trauma registry

Schädel-Hirn-Trauma in Form einer Monoverletzung vor.

Präklinik (A)

Der mittlere initiale Glasgow Coma Scale (GCS) betrug 10,6 ± 4,6 (Median 13) Punkte. Ein GCS ≤8 trat bei 32,6 % (n = 918) der Patienten auf. Der initiale systolische Blutdruck ($RR_{syst.}$) betrug 125 ± 35 mmHg. In dieser Phase befanden sich 14,9 % (n = 420) der Fahrradfahrer in einem hämodynamischen Schock ($RR_{syst.}$ ≤ 90 mmHg). Eine Analgosedierung wurde in 72,9 % (n = 1406) etabliert, die Indikation zur präklinischen Intubation und Beatmung wurde in 48,3 % (n = 1360) der Fälle gestellt. 4,3 % (n = 121) der Patienten erhielten präklinisch eine Thoraxdrainage. Die Therapie der Hämodynamik erfolgte in 87,0 % (n = 2451) aller Fälle mit gemittelt 955 ml Kristalloiden. Eine Katecholamintherapie wurde in 7,9 % (n = 223) der Fälle in dieser Phase begonnen. Bei 3,8 % (n = 107) der Fahrradfahrer lag in dieser Phase ein Herz-Kreislauf-Stillstand vor. Die präklinische Behandlungsdauer bis zur Ankunft in der Klinik betrug 64,8 ± 37,7 min (Median 58 min). 33,6 % (n =

Tab. 1 Verteilung der Verletzungen die zu einem ISS ≥ 9 geführt haben

Region	Prävalenz (%)
Kopf/Nacken	68,2
Gesicht	5,7
Brustkorb	38
Abdomen	8,8
Extremitäten und Becken	20,7
Äußere Verletzungen	1

Tab. 2 Verteilung des AIS-Regionen ≥ 3

Region	Prävalenz (%)
Kopf	71,9
Gesicht	18,8
Nacken	0,6
Thorax	44,9
Abdomen	13,3
Wirbelsäule	22,6
Obere Extremitäten	33,6
Untere Extremitäten	24,5
Becken	13,4

947) der Fahrradfahrer wurden mittels Rettungshubschrauber (RTH) transportiert.

Schockraum (B)

Bei Eintreffen im Schockraum befanden sich noch 9,6 % (n = 270) der Fahrradfahrer im persistenden bzw. zu diesem Zeitpunkt im hämodynamischen Schock. Der $RR_{syst.}$ der anderen Patienten war mit 126 mmHg stabil. In dieser Phase wurden, gemittelt über alle Patienten, weitere 1728 ml Kristalloide infundiert. Zusätzlich war in dieser Phase bei 16,4 % (n = 462) der Patienten eine Bluttransfusion indiziert. Massentransfusionen (≥10 Erythrozytenkonzentrate) waren in 3,7 % (n = 104) der Fälle notwendig.

Intensivstation (C)

Die Anzahl der Beatmungstage betrug 5,6 ± 0,1 Tage (Median 2 Tage). Die Aufenthaltsdauer auf der Intensiv-/Überwachungsstation betrug im Mittel 9,5 ± 12,2 Tage (Median 4 Tage). Die 24-h-Mortalität lag bei 7,7 % (n = 217), die Krankenhausgesamtmortalität bei 14,8 % (n = 417). Die Krankenhausgesamtverweildauer betrug 21,0 ± 23,9 Tage (Median 15 Tage). Ziele nach Entlassung aus der Akutversorgung waren: nach Hause 40 % (n = 1227), in Reha-Einrichtungen 30,9 % (n = 870), in ein anderes Krankenhaus 13,1 % (n = 369) und 1,1 % in eine andere Institutione.

Diskussion

Das Kollektiv der Fahrradfahrer ist sowohl in Straßenverkehrsstatistiken als auch in der Medizin als eigenständige Verkehrsteilnehmergruppe zu betrachten. Trotz der Relevanz der Kenntnisse von Verletzungsmustern und -schwerpunkten in diesem Kollektiv liegen hierzu wenige wissenschaftliche Arbeiten vor. Ziel der vorliegenden Arbeit war daher die Gesamterfassung der Verletzungen sowie die Charakterisierung von Verletzungsschwerpunkten in einem repräsentativen Kollektiv schwer verletzter Fahrradfahrer.

Mit einer Anzahl eingeschlossener Patienten von 2817 handelt es sich um das größte jemals publizierte, unter medizinischen Gesichtspunkten als „schwer verletzt" definierte Kollektiv im Zusammenhang mit Fahrradunfällen. Allgemeine Verkehrsstatistiken (Statistisches Bundesamt, Allgemeiner Deutscher Fahrrad-Club [ADFC]) führen deutlich mehr Betroffene in ihren Statistiken. Hier fehlten jedoch die medizinischen Hintergründe und Definitionen. Zudem wurde mit der Wahl der Einschlusskriterien: ISS ≥ 9 und die gleichzeitig notwendige intensivmedizinische/Intensivüberwachungsbehandlung ein hohes Maß an Standardisierung erreicht [2]. Der mittlere ISS von 23,7 ± 12,6 repräsentiert den Status „schwer verletzt" adäquat [4].

Mit einem mittleren Alter von 50,3 ± 20,9 Jahren liegen schwer verletzte Fahrradfahrer deutlich über dem mittleren Alter der Straßenverkehrsteilnehmer Auto oder Motorrad [13]. Demgegenüber steht interessanterweise ein dramatischer Peak der Unfallprävalenz zwischen dem 10. und 15. Lebensjahr [17]. Dies kann durch die zunehmende Teilnahme der Kinder dieses Alters am Straßenverkehr erklärt sein. Der Rückgang der Unfallzahlen bis zu einem Alter von 20 Jahren kann ebenso erklärt werden. Es scheint in diesem Alter zu einem Umstieg vom Fahrrad aufs Motorrad und später auf das Auto zu kommen. Darüber hinaus scheint das Fahrrad gerade bei der älteren Bevölkerung ein beliebtes, jedoch auch unfallträchtiges Fortbewegungsmittel zu sein. Ein kontinuierlicher Anstieg bis zum Alter von 70–75 Jahren, ebenso wie der Abfall danach, sind charakteristisch. Die Sicherheit und die Kondition lassen bei älteren Menschen nach und das Risiko für Unfälle scheint hierdurch zu steigen. Aufgrund eingeschränkter Mobilität im Alter nimmt die Zahl der Fahrradfahrer ab diesem Zeitpunkt ab. Berücksichtigt man die Altersverteilung, so können Kinder und Senioren als Hochrisikogruppe benannt werden [6].

Im Zeitraum von April bis September ereigneten sich nahezu 75 % aller Unfälle. Die nahezu gleiche Inzidenz von Fahrradunfällen an jedem Wochentag zeigt, dass das Fahrrad als tägliches Fortbewegungsmittel genutzt wird. Erst Auswertungen des Kollektivs Motorradfahrer deuten auf einen dramatischen Anstieg der Unfälle zum Wochenende hin.

Als primärer Endpunkt der Studie konnte ein charakteristisches Verletzungsmuster des schwer verletzten Fahrradfahrers nachgewiesen werden. Die mit Abstand am Häufigsten zum Status „schwer verletzt" führende Region war die Kopf- und Nackenregion. Deutlich weniger ausgeprägt folgten Verletzungen des Thorax und der oberen Extremitäten. Ein kritischer GCS (≤8) in einem Drittel der Fälle unterstreicht die Relevanz des Schädel-Hirn-Traumas beim schwer verletzten Fahrradfahrer. Der Kopf scheint die Schlüsselregion zu sein, die den Schweregrad der Verletzung bei Fahrradfahrern bestimmt [10]. Zudem liegt bei jedem 5. schwer verletzten Fahrradfahrer ein Schädel-Hirn-Trauma als Monoverletzung vor, was ein weiteres Charakteristikum darstellt. Bei nahezu der Hälfte aller Patienten wurde

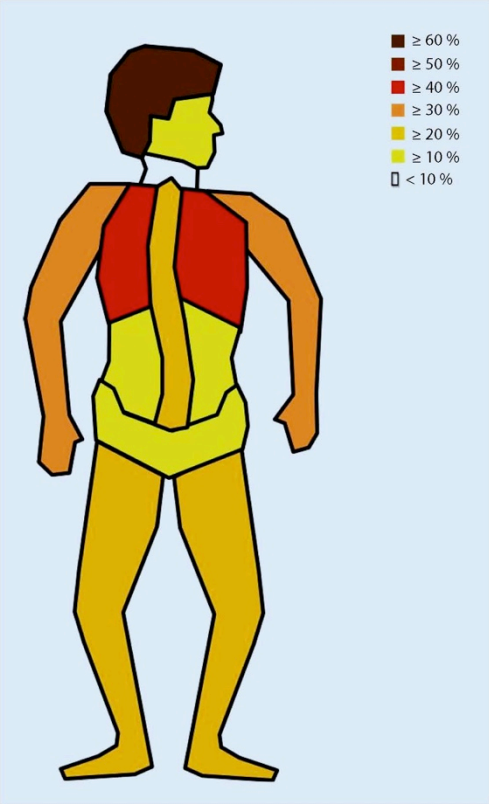

Abb. 3 ◀ Grafische Darstellung der Verletzungen entsprechend ihrer Häufigkeit

eine präklinische Narkose eingeleitet, wobei der Anteil der Patienten mit einem intubationspflichtigen GCS unter dem der eingeleiteten Narkosen lag. Hier könnten Begleitverletzungen wie Thorax- oder Extremitätenverletzungen eine Rolle spielen. Eine dezidierte Indikation zur Narkoseeinleitung wurde nicht erfasst (**Abb. 3**). Die mit 4,3 % sehr selten gestellte Indikation zur Thoraxdrainage stuft die Therapierelevanz des schweren Thoraxtraumas als zweithäufigste Verletzung zurück, wenngleich auch initial nichttherapiepflichtige Thoraxtraumen relevant Einfluss auf die Gesamtverletzungsschwere haben können.

Hämodynamische Beeinträchtigungen sind sowohl durch isoliert auftretende Schädel-Hirn-Traumen aber auch durch begleitende Thorax- und Extremitätenverletzungen erklärbar. Die Kombination aus Schädel-Hirn-Trauma und Hypotonie reduziert aufgrund konsekutiv ansteigendem Hirndruck und der Bildung eines Hirnödems das Outcome. Sekundärschäden können hier durch frühzeitige Katecholamingabe therapiert werden [9]. Sowohl kardiozirkulatorische Dysregulationen nach schwerem Schädel-Hirn-Trauma als auch Blutverlust können hier Ursachen sein [14]. Die Datenerhebung lässt eine detailliertere Differenzierung der Ursache hämodynamischer Instabilität nicht zu. Die Gabe von 955 ml Kristalloiden bei 87 % aller Patienten entspricht am ehesten der Bestückung der im Advanced Trauma Life Support (ATLS®) geforderten 2 Zugänge [16]. Der Anteil an Herz-Kreislauf-Stillständen sowie die Indikation zur Katecholamintherapie waren nicht wesentlich, verglichen mit anderen Kollektiven.

Die Nutzung des RTH als Transportmittel in einem Drittel der Fälle erscheint bemerkenswert. Sie liegt deutlich höher als der TR-DGU 10-Jahres-Durchschnitt (22 %). Die Dauer der präklinischen Phase mit 64,8 ± 37,7 min liegt unter der durchschnittlichen Rettungszeit des TR-DGU (71 min im Jahr 2014) und lässt sich durch die häufig deutlich weniger komplexe technische Rettung erklären. Insgesamt spiegeln diese beiden Ergebnisse den präklinischen Ablauf charakteristisch wieder, bei dem ein nichtaufwendig zu rettender, schwer verletzter Patient in eine Klinik der Maximalversorgung transportiert wird [15].

Die Daten aus „Phase C" können als Vergleichswerte für folgende Studien anderer Straßenverkehrskollektive herangezogen werden. Für eine Beurteilung der Beatmungs- und Intensivtage fehlen derzeit vergleichbare Arbeiten. Die Gesamtkrankenhausmortalität ist jedoch durchaus vergleichbar und liegt deutlich über der anderer Kollektive, wie z. B. den Kraftradfahrern [1]. Es stellt sich die Frage nach den Ursachen höherer Mortalität der Fahrradfahrer verglichen mit anderen Verkehrsteilnehmern. Faktoren wie Protektionssysteme, Alter oder Begleiterkrankungen könnten eine Rolle spielen. Kinder und ältere Menschen scheinen deutlich häufiger betroffen zu sein, das Tragen eines Helmes ist als positiver prognostischer Faktur nachgewiesen und wird von Fachgesellschaften empfohlen [18].

Einen Gesamteindruck über die Mortalität aller Fahrradfahrer kann durch die Studie nicht geleistet werden. Hierin liegt eine Schwäche. Das Kollektiv derer, die die Klinik nicht lebend erreichen, spielt eine relevante Rolle und wird im Traumaregister nicht erfasst. Laut ADFC starben alleine im Jahr 2014 405 Menschen bei insgesamt 78.653 Fahrradunfällen. In der vorliegenden Arbeit verstarben 417 Patienten in einem Zeitraum von 9 Jahren. Hier besteht eine deutliche Differenz zwischen erfassten und insgesamt getöteten Menschen. Eine Verknüpfung der Daten wäre wünschenswert. Als „schwer verletzt" zählt jedoch in den Verkehrsstatis-

tiken jeder, der nach einem Verkehrsunfall 24 h hospitalisiert wurde. Hier muss zunächst eine einheitliche Definition erfolgen und wird derzeit bereits diskutiert.

Fazit für die Praxis

- **Bei schwer verletzten Fahrradfahrern können charakteristische Verletzungsmuster und -schwerpunkte erwartet werden.**
- **Das schwere Schädel-Hirn-Trauma stellt klar die dominierende Hauptverletzung dar.**
- **Des Weiteren triggern Thoraxtraumen und Verletzungen der oberen Extremitäten den Status „schwer verletzt".**
- **Bei jedem 5. schwer verletzten Fahrradfahrer liegt das Schädel-Hirn-Trauma als Monoverletzung vor.**
- **Kinder um das 10.–15. Lebensjahr und Senioren um das 60.–80. Lebensjahr sind Risikogruppen.**

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Einhaltung ethischer Richtlinien

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Dieser Beitrag beinhaltet keine von den Autoren durchgeführten Studien an Menschen oder Tieren.

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Fachnachrichten

Ärztliche Mitteilungspflicht nach Gewalt aufgehoben

Mitteilung nach §294a SGB V für Fälle von Misshandlung und sexueller Gewalt gegen Erwachsene nur noch mit Einverständnis der Patienten*innen oder Betroffenen

Die ärztliche Mitteilungspflicht an Krankenkassen wird für Fälle physischer und psychischer Misshandlung und sexueller Gewalt gegen Erwachsene aufgehoben, bzw. an die Einwilligung der Patient*in gebunden. Die neue Regelung tritt am 11.4.2017 in Kraft (Bekanntgabe am 10.4.17, Bundesgesetzblatt).

Zahlreiche Verbände, u.a. die Gesundheitsministerkonferenz, der Deutsche Ärztetag und der Berufsverband der Frauenärzte, forderten die Abschaffung der Mitteilungspflicht gegenüber den Krankenkassen in Anbetracht möglicher negativer Folgen für Betroffene und für Gesundheitsfachkräfte: fehlende Vertraulichkeit in der Beziehung zwischen Ärzt*in und Patient*in, erneute oder eskalierende Gewalthandlungen, Gefährdung des Genesungs- und Behandlungserfolgs sowie das Verhindern von Intervention und Unterstützung.
Statt *„Ich muss Ihre Krankenkasse informieren, dass diese Verletzungen von Ihrem Ehemann verursacht wurden."* gilt zukünftig uneingeschränkt: *„Ich unterliege der Schweigepflicht. Ohne ihr Einverständnis werde ich niemanden darüber informieren, von wem Sie verletzt wurden. Sie können offen mit mir sprechen."*.

Diese Klarheit betont die Schweigepflicht von Ärzt*innen. Sie ist entscheidend für eine gelingende Intervention bei häuslicher und sexualisierter Gewalt und für eine adäquate gesundheitliche Versorgung und Unterstützung der Betroffenen.

Quelle: S.I.G.N.A.L. e.V. Berlin, www.signal-intervention.de

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ORIGINAL ARTICLE

Management of prehospital shoulder dislocation: feasibility and need of reduction

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Abstract
Purpose Dislocation of the shoulder is rare in the prehospital setting. The medical specialities of the emergency physicians are heterogeneous, and the level of experience is different. Aim of this study was to evaluate the feasibility, sufficiency, and need of prehospital reduction.
Methods Over 12 months, 16 rescue stations in Germany and Austria documented cases. Points of examination were: incidence of reduction, influence of pathological findings, therapy and effectiveness of reduction.
Results We included 70 patients. A reduction was undertaken in $n = 47$ (66.6 %). In $n = 70$ (100 %) perfusion was without pathological finding after reduction, all $n = 7$ (10 %) neurological pathologies declined after reduction. There was no significance in total implementation of prehospital reduction between surgeons and anaesthetists. $N = 63$ (90 %) of all patients received an immobilisation of the shoulder. $N = 68$ (97 %) of all patients were transported to a hospital. Time to arrival in hospital was in $n = 50$ (71.4 %) $\leq$10 min, in $n = 17$ (24.2 %) $\leq$20 min and in $n = 3$ (4.4 %) $\leq$30 min.
Conclusion Implementation of reduction is independent of pathological neurological or vascular findings. Knowledge and skill is enough to perform a reduction quiet effectively in all emergency physicians. No specific technique can be recommended for prehospital use, the importance of being skilled is more important than one method. Early reduction was performed most rapidly in surgeons, but as well in the recommended time by other medical disciplines. On documented timings to admission hospital waiver of reduction is doubt. Therefore, a reduction in the prehospital setting is possible, but not obligatory.

Keywords Sholder dislocation · Prehospital · Treatment · Reposition · Feasibility

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Purpose

Dislocation of the shoulder is the most frequent dislocation treated in emergency medicine. The overall incidence is 1.7 % [1], with complications as high as 26 % having been reported [2]. Literature has tended to focus on reduction methods and complications [3], whereas little is written concerning the feasibility of reduction, especially in the prehospital setting. Only a few case reports about prehospital reduction of shoulder dislocation could be found in PUBMED, while some papers deal with prehospital anaesthesia in shoulder dislocation [4, 5]. For emergency physicians it is important to be familiar with reduction methods and complications associated with shoulder dislocations, because patients may present in the prehospital setting with problems after dislocation. Recognition of complications is important to the prognosis of a patient who has sustained a complication. A delay in recognition and treatment of complications can have a long-term impact on a patient's functional outcome. Two skills seem to be indispensable to treat a prehospital shoulder dislocation: surgical expertise and an adequate pain therapy. Additionally, x-ray is an important step missing in the prehospital setting. Among German and Austrian emergency physicians, the most common medical specialities in prehospital emergency medicine are: surgery, anaesthesiology and internal medicine. In general, all emergency physicians are sufficiently trained in shoulder

dislocation, but practise is limited due to the small incidence of shoulder dislocation. The aim of the present study was to evaluate the feasibility of shoulder reduction in daily prehospital practise. The following questions should be answered: how often does prehospital reduction of a dislocated shoulder take place? Is the indication for reduction dependent on pathological findings? How effective is a reduction under prehospital circumstances performed by the heterogeneous specialized emergency physicians? Considering these results: is there a general recommendation for prehospital reduction under certain conditions? Is an adequate treatment and reduction given independent of the specialty of the emergency physician? Are there advantages in one medical specialisation?

Methods

In the course of a large anonymous survey of rescue stations with a rescue helicopter or an ambulance car accompanied by an emergency physician, we evaluated the current treatment for prehospital shoulder dislocations. For a period of 3 months we recruited 16 study centres in Germany and Austria ("Appendix"). The study began following the recruitment of study centres. This prospective multi-centre study included all prehospital treated patients with dislocations of the shoulder. Inclusion criteria consisted of a clinically manifested shoulder dislocation, and an age $\geq$16. Documentation of findings and treatment was made after treatment. The following parameters were recorded: age, sex, accident type, Glasgow coma scale (GCS), visual analogue scale (VAS), injury details (isolate injury vs. multiple injuries; primary event vs. relapses; conditions of perfusion, neurology and soft tissue); reduction steps, after treatment and finally, the emergency physicians' background. For a total of 12 months, from May 2011 to May 2012, we included a total of 70 patients with prehospital dislocated shoulder. For this study an ethical approval was not needed because treatment took place before, therefore the study did not lead to changes of the participants' treatment.

Data are presented as mean with standard deviation ($\pm$SD) for continuous variables and as number of cases with percentages for categorical variables. Statistical measures are derived from cases with valid data only; no imputation of missing values was performed. Statistical comparisons were made with the non-parametric Mann–Whitney *U* test or the Chi-squared test, respectively. A p value <0.05 was considered statistically significant. However, due to the large sample size even minor and clinically non-relevant differences could become significant, thus interpretation should mainly be based on the observed difference. Data were analyzed by the SPSS statistical software package (Version 18.0, IBM Inc., Armonk NY, USA).

Results

In total 70 patients with dislocated shoulder were treated. $N = 49$ (70 %) were male, $n = 21$ (30 %) were female ($p < 0.001$). The mean age was 40.2 ± 19.3. $N = 35$ (50 %) of shoulder dislocations occurring in sport, $n = 12$ (16.7 %) at work and $n = 23$ (33.3 %) others. In $n = 33$ (46.7 %) patients, an emergency physician was alarmed further in time by the paramedic-equivalent in the participating countries for adequate pain therapy with medication. Distribution of medical specialities in emergency physicians was: $n = 30$ (42.8 %) surgeons (S), $n = 28$ (40 %) anaesthesiologists (*A*), $n = 5$ (7.2 %) internist (*I*), $n = 7$ (10 %) others/unknown (*O*).

Initial GCS was 14.0 ± 0.4, initial pain score was 8.2 ± 1.6 points. $N = 58$ (83.3 %) shoulder dislocations were mono-injuries, $n = 12$ (16.7 %) multi-injuries. Rate of recurrent dislocations was $n = 14$ (20 %). The mean number of recurrent dislocation events was 2 ± 1.4. In $n = 70$ (100 %) perfusion of the affected extremity was without pathological findings, whereas in $n = 7$ (10 %) investigation showed neurological pathologies. In $n = 5$ (6 %) impaired soft tissue could be found in the dislocation area.

A reduction or a trial of reduction was undertaken in 47 (66.6 %) of all cases. The following techniques for reduction were applied: $N = 28$ (60 %) Hippocrates, $n = 12$ (25.5 %) scapular manipulation, $n = 5$ (7 %) self-reduction, $n = 2$ (4.2 %) Arlt. The Matsen, Hennepin or Stimson techniques were not applied in any of the cases. In $n = 70$ (100 %) perfusion was without pathological finding after reduction, and all $n = 7$ (10 %) neurological pathologies declined after reduction. In $n = 2$ (4.2 %) cases, no pain medication was administered. Three different types of therapy with pain medication were administered: a 1-drug therapy (single use of Fentanyl), a 2-drug therapy (Midazolam as sedative, Ketamine or Fentanyl as anaesthetic) and a 3-drug therapy (Midazolam as sedative, Ketamine and Fentanyl as anaesthetic). The distribution and types of medication are shown in Figs. 1, 2, 3, 4. Significances in therapy with medication are shown in Table 1. The 2-drug therapy Ketamine group demonstrated the only significance between surgeons and internists, as well as anaesthesiologists and internists. There was no significance in total implementation of prehospital reduction between (*S*) and (*A*). The number of reductions in other groups was too low for proper calculation. Surgeons required 1–2 trials until reposition was successful, while anaesthetists required 1–4 trials. There was significance in the 1st trials group (Table 2). Effectiveness of trials tailed significant off after 2 trails ($p < 0.002$). Concerning the $n = 7$ (10 %) dislocations with neurological pathologies, the following individual

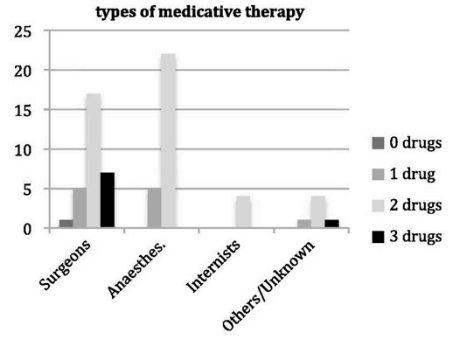

Fig. 1 Distribution of therapy with medication related to medical specialty

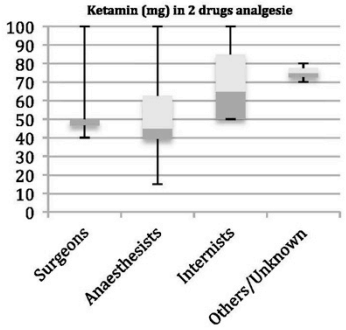

Fig. 2 Distribution of Ketamine dose related to medical specialty

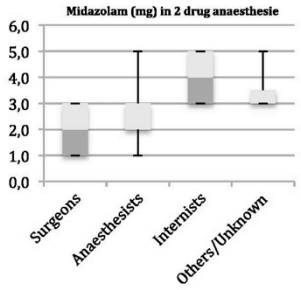

Fig. 3 Distribution of Midazolam dose related to medical specialty

observations were made: in $n = 4$ (5.7 %) cases a reduction was implemented, while in 3 (4.3 %) cases no reduction occurred.

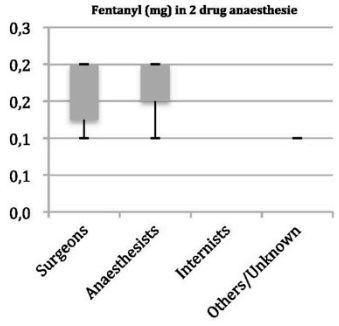

Fig. 4 Distribution of Fentanyl dose related to medical specialty

Table 1 Significances in therapy with medication

p values	1-drug therapy	2-drug therapy		
	Fentanyl	Midazolam	Ketamin	Fentanyl
(S) vs. (A)	0.15	0.92	0.19	1.0
(S) vs. (I)		0.12	*<0.01*	
(S) vs. (O)		0.08	0.15	0.22
(A) vs. (I)		0.33	*0.04*	
(A) vs. (O)		0.34	0.18	0.1
(I) vs. (O)		0.8	0.55	

Italic values represent significant *p* value ($p < 0.05$)

Table 2 Reduction trials surgeons vs. anaesthetists

(%)	Surgeons	Anesthesists	*p* values
Total trials	46.8	36.2	0.4
1st trial	72.3	35.3	*0.03*
2nd trials	27.3	35.3	0.73
3rd trials	–	17.6	–
4th trials	–	11.7	–

Italic value represent significant *p* value ($p < 0.05$)

$N = 63$ (90 %) of all patients received an immobilisation of the affected shoulder. $N = 68$ (97 %) of all patients were transported to a hospital. Hospital arrival time was in $n = 50$ (71.4 %) ≤10 min, in $n = 17$ (24.2 %) ≤20 min, and in $n = 3$ (4.4 %) ≤30 min.

Discussion

Treatment of prehospital shoulder dislocations is affected by unfavourable factors. The incidence is low when averaged over all prehospital emergencies, a routine treatment is lacking, and only a few emergency physicians have

clinical expertise, as not only surgeons but other medical disciplines are involved in emergency medicine as well. These observations lead to the question of whether prehospital treatment of a dislocated shoulder is sufficient, and absolutely necessary. In this prospective study we examined the treatment, performance and therapeutic success of shoulder reduction, as it is evident that this investigation is necessary. A comprehensive literature search (MEDLINE) was performed with the keywords: "prehospital", "shoulder", "dislocation" and "treatment". We identified 3 papers, 1 case report and 2 papers concerning interscalene brachial plexus, though there was no clinical study available.

Our collective of $n = 70$ patients is representative [6], as the gender distribution, mean age and recurrent dislocation rate resemble other publications [7]. Sport as a main mechanism of shoulder dislocation, as reported in clinical studies, is in correlation with our prehospital findings [8]. A major point of discussion involves the protocol of alerting emergency physicians. There is no paramedic system in Germany and Austria, therefore an emergency physician is needed for special indications, such as pain therapy, and has to be called by the paramedic-equivalent in these countries. A number of 46.7 % demonstrated pain of dislocation events, thus an initial pain therapy is needed. The collective of emergency physicians' is ambivalent. A ratio of nearly 1:1 surgeons versus anaesthetists offers a good basis for comparison. The number of participating internists and other/unknown physicians was weak for comparison concerning the collectives, thus only patient data collected by the last two physician groups were included.

From the initial findings, we can assume that shoulder dislocation is a painful mono-injury. Most patients are not critically injured, but many local complications may affect recognition and prevention, highlighting the point that prompt recognition and follow-up are essential [3]. This fact is a key element for prehospital treatment and should be achieved. Axillary artery injuries can occur with shoulder dislocations. In our study there were no cases of affected perfusion under dislocation. Most reports discuss isolated cases of axillary artery involvement as a rare complication [9, 10]. Numerous nerve structures innervate the shoulder and the axilla, and so complications here are much higher than vascular injuries. Other studies found nerve lesions associated with injuries of the shoulder between 21 and 36 % of the time [2, 11]. Nerve lesions demonstrated in our study were below cited values. Nevertheless, nerve lesions are a risk, and further complications include fractures.

Recommended time to reduction is not clearly defined in literature in both the clinical and prehospital settings. A widespread time is between 30 and 120 min [12]. A percentage of 66.6 % indicates knowledge of the methods of reduction and the awareness of complications, as well as the need to reduce early over all medical specialities of emergency physicians. The most favoured reduction method was the Hippocrates. Unfortunately this method is still recommended in some texts [13], and historically it is the most public method. The scapular manipulation is a comparatively more careful technique, and thus is recommended. The patient is placed prone on the table, which might lead to difficulties in the ambulance vehicle [14]. The Arlt method is one of the methods that are better described and are more effective [15]. Some methods may take 20–30 min before reduction occurs, which includes the scapular manipulation method. Duration of a method or spatial conditions is in turn a limiting factor in prehospital setting and can lead to preferences in the choice of technique [16, 17].

No reduction resulted in new neurological or vascular pathologies, and all pre-existing pathological neurological findings declined under reduction. It is a clear argument for the effectiveness of prehospital reduction over all medical specialties. Medical therapy was performed by administering 1–3 drug therapies. In general, no substantial differences between emergency physician groups versus a combination of drugs could be shown. This issue is the subject of controversial debate. Some operators feel that chemical sedation/analgesia should, either always or in the majority of cases, be given [18, 19]. Other studies, using a variety of techniques, have however shown the standard use of drugs to be unnecessary [20, 21]. Intra-articular nerve blocks have been used, though there is a theoretical risk of joint infection [22].

Implementation of reduction was, from the investigation, not significantly different between surgeons and anaesthetists. The number of reduction trials was less in surgeons as a collective. The effectiveness of reduction tailed off after 2 trials. These facts are clearly explainable as being related to the level of skill [23]. Error rate statements could not be investigated due to a low number of cases. As the results show faster and more successful reduction in the group of patients treated by surgeons, we may conclude that a skill education or practise should be recommended for the internists and anaesthesiologists in an appropriate sequence of relevant skill training. Training dummies does not exist, cadaver-labs will be necessary.

Immobilisation is part of the standard procedure in treatment of shoulder dislocation. A total of 90 % of our patients were immobilized, and 97 % were transported to hospital, which indicates a proper treatment according to the guidelines [24, 25].

All patients arrived to the hospital in 30 min or less which is an important fact. Participating rescue centres were chosen considering different geographical variations (urban, rural, mountains, coast). In all cases and in all different geographical variations, a prompt admission to hospital could be guaranteed. Regarding recommendations for reduction time from 30–120 min, there are no hard criteria

for a mandatory reduction in prehospital setting. The user has to ensure and to verify the indication. Reduction of the shoulder dislocation has benefit after a sport accident, but it can be risky in a 60-year-old low active female patient. The study design was not able to examine any fractures by prehospital manipulation, activity level or metabolic bone disorders that were not included.

Conclusion

In general there is no inhibition for emergency physicians to reduce dislocated shoulders in the prehospital setting. Implementation of reduction is independent of pathological neurological or vascular findings. Despite the different medical specialties of emergency physicians, knowledge and skill is enough to perform an effective reduction under prehospital circumstances. A prehospital reduction can be recommended not only for surgeons, and success rates are very good. Pain medication was administered in all cases properly, though it is not the main focus of treatment and remains under debate. There are different techniques with advantages and disadvantages. Although no specific technique can be recommended for prehospital use, the importance of being skilled is more important than the method of choice. The main goal of treatment is the early reduction, which was performed most rapidly and successfully in surgeons, but as well in time and success by anaesthetists. The recommended number of prehospital trails is two. A reduction of hospital arrival time is doubtful. Therefore, a reduction in the prehospital setting is possible, but not obligatory. Prehospital indication has to be ensured carefully.

Conflict of interest Tobias Helfen, Ben Ockert, Peter Pozder, Markus Regauer and Florian Haasters declare that they have no conflict of interest.

Compliance with ethical requirements Approval by the ethical committee has been obtained. (507-14 Ludwig-Maximilians University Munich).

Appendix

Emergency doctor's vehicle, Bavarian Red Cross Neustadt, Germany.
Emergency doctor's vehicle, German Red Cross Bad Bergzabern, Germany.
Emergency doctor's vehicle, German Red Cross Merzig-Wadern, Germany.
Rescue helicopter ADAC Air Rescue Ochsenfurt, Germany.
Rescue helicopter, SHS Air Rescue Kaltenbach, Austria.
Emergency doctor's vehicle, Professional fire brigade Hamburg, Germany.
Emergency doctor's vehicles, Professional fire brigade Bonn, Germany.
Emergency doctor's vehicles, Professional fire brigade München, Germany.
Emergency doctor's vehicles, Professional fire brigade Münster, Germany.
Rescue helicopter, Federal Ministry of the Interior Hamburg and Eutin, Germany.
Rescue helicopters Heli-Ambulance Team Sölden and Zell am See, Austria.

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MAGNETIC RESONANCE

Structured reporting of MRI of the shoulder – improvement of report quality?

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Abstract

Objectives To evaluate the effect of structured reports (SRs) in comparison to non-structured narrative free text (NRs) shoulder MRI reports and potential effects of both types of reporting on completeness, readability, linguistic quality and referring surgeons' satisfaction.

Methods Thirty patients after trauma or with suspected degenerative changes of the shoulder were included in this study (2012–2015). All patients underwent shoulder MRI for further assessment and possible surgical planning. NRs were generated during clinical routine. Corresponding SRs were created using a dedicated template. All 60 reports were evaluated by two experienced orthopaedic shoulder surgeons using a questionnaire that included eight questions.

Results Eighty per cent of the SRs were fully complete without any missing key features whereas only 45% of the NRs were fully complete ($p < 0.001$). The extraction of information was regarded to be easy in 92% of the SRs and 63% of the NRs. The overall quality of the SRs was rated better than that of the NRs ($p < 0.001$).

Conclusions Structured reporting of shoulder MRI improves the readability as well as the linguistic quality of radiological reports, and potentially leads to a higher satisfaction of referring physicians.

Key Points

- *Structured MRI reports of the shoulder improve readability.*
- *Structured reporting facilitates information extraction.*
- *Referring physicians prefer structured reports to narrative free text reports.*
- *Structured MRI reports of the shoulder can reduce radiologist re-consultations.*

Sebastian Gassenmaier and Marco Armbruster contributed equally to this work.

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Keywords Radiology · MRI · Quality improvement · Medical informatics · Shoulder

Abbreviations

CI 95%	Confidence interval
MSK	Musculoskeletal
NRs	Narrative free text reports
SRs	Structured reports
std	Standard deviation

Introduction

Radiological reports constitute the primary means of communication between radiologists and referring physicians and its main goal is to deliver imaging examination results in an accurate and easily understood manner. Despite the exciting innovations of modern imaging techniques, radiological reporting has remained static for a long time [1]. The majority of radiology reports are still acquired in a free text reporting technique using speech recognition. On the other hand, the necessity of implementing more structure into radiological reports has been discussed for a very long time not only in radiology but also in many other fields of medicine [2–5].

However, scientific findings are not unambiguous and there are contradictory studies about this topic. It was shown previously that free text reporting delivers some inconsistencies regarding usage of specific terms and usage of terms expressing uncertainty [6, 7]. This is why the Radiological Society of North America (RSNA) founded the RadLex initiative [8]. Additionally, e.g. Naik et al. [9] and Bosmans et al. [10] respectively stated that clinicians clearly prefer structured and itemized reports. However, opinions on this topic among radiologists vary strongly. Some studies are in favour of structured reports (SRs) [9, 10], whereas in other studies, structured reporting is criticized as too rigid, constraining and time-consuming [11, 12].

The SRs used in computed tomography (CT) of the pancreas and CT body scans have demonstrated the ability to improve the methodology of extracting information and the clarity and content of the reports [13, 14]. Furthermore, Larson et al. were able to show the feasibility of introducing structured reporting into a clinical system with acceptance of both radiologists and referring physicians [15]. However, despite all discussed advantages, structured reporting is still very uncommon, although it is ready for implementation into clinical systems [16]. One reason could be due to a potential decrease in accuracy and completeness through SRs [12]; another reason is that radiologists are just not used to this new technique of reporting and therefore prefer the well-known type of free text reporting.

Although many studies have already highlighted the advantages and disadvantages of structured reporting in oncologic reporting, there is only little known about the role of SRs in the area of musculoskeletal (MSK) imaging [17]. Thus, this study investigated the effect of structured reporting on MRI images of the shoulder. The latter is a complex radiological task due to the necessary consideration of many anatomical structures and the correct specifications of numerous classifications (e.g. Ellman [18], Zanetti et al. [19], Thomazeau et al. [20], Goutallier et al. [21]).

Therefore, the aim of the study was to evaluate the effect of structured reports (SRs) in comparison to non-structured narrative free text (NRs) shoulder MRI reports and potential effects of both types of reporting on completeness, readability, linguistic quality and referring surgeons' satisfaction.

Materials and methods

Institutional review

This retrospective study was approved by the institutional review board. Informed consent was waived by the local review board because of the retrospective design of this study.

Inclusion and exclusion criteria

Inclusion criteria for this study were shoulder dislocations or instabilities, rotator cuff lesions and impingement syndromes. Patients with a history of cancer diseases, previous operations of the shoulder or inflammatory arthropathy were excluded. Additionally, NRs had to contain a findings section as well as an impression section.

Patients

The study was performed retrospectively with a database of 1004 patients who underwent MRI examinations of the shoulder at our hospital between 2012 and 2015. By means of our inclusion and exclusion criteria, 30 patients out of 367 who fitted these criteria were randomly selected. The most frequent reason for requesting the MRI scan was shoulder dislocation (11 cases) and suspicion of rotator cuff tears (14 cases). In five cases, MRI was performed because of an impingement syndrome (Table 1).

Table 1 Patient demographics and sample characteristics of the current study

Characteristics	Values
Number of patients	30
Age (mean ± std)	47.0 ± 17.9
Age (range; years)	18–83
Male gender (%)	70%
Reason for MRI request[a]	Dislocation: $N = 11$ Rupture of rotator cuff: $N = 14$ Impingement: $N = 5$

std standard deviation

[a] Most requests are related to rupture of rotator cuff

Study design

We compared two different kinds of reporting styles. The first group consisted of NRs obtained during clinical routine and were taken from our internal radiology information system. These reports were created by seven different radiology consultants with at least 5 years of experience in MSK imaging. The second group of reports contained SRs of the same examinations. These reports were created by two radiologists with 2 and 4 years of experience in MSK imaging, respectively. The two radiologists were blinded to the NRs.

We purposely used retrospective NRs for comparison with prospective SRs. The NRs were created with high standards necessary for clinical work processes and were written by highly experienced consultants. Because of this, highly qualitative NRs can be assumed even without study conditions. Another reason why we decided to take retrospective reports is the broad spectrum of indications for imaging. The aim of the study was to represent a very heterogeneous group of patients to show that structured reporting can be applied to a broad spectrum of pathologies. Another factor relating to the use of retrospective NRs is a possible observer bias in this study. The non-structured reports are much more affected by the study bias than the SRs are as a result of the method of reporting. The radiologists might change the structure and the appearance of the NRs under study conditions compared to the NRs created without study conditions. However, the structured reports were created using an online-based platform. By using this platform, the radiologists are guided by fields provided by the software through the template and they should address the same points in every report. Because of this, the radiologists cannot change the method of reporting and the appearance of the report as it could be done by producing prospective NRs. This makes the SRs far more reproducible and less dependent on the reporting radiologist. As the method of reporting is the same every time, we decided to accept the bias of producing prospective SRs as reporting under study conditions does not vary much from the routine reporting.

Structured reporting system

Online-based freeware (http://www.smart-radiology.com) was used for the generation of the SRs. This software offers a dedicated template for MRI of the shoulder with clickable decision trees (Fig. 1). The template is separated into a findings and an impression section. The findings section consists of previous examinations, clinical information, image quality, side of the examined shoulder, glenohumeral joint, acromioclavicular joint, subacromial space and other findings. Each section opens up with a mouse click and displays further items for selection on the next level. Each subitem consists of several subsequent levels, e.g. as shown for the supraspinatus muscle in Fig. 1. The detailed description of a full thickness tear is built up in the following way: The user can name the fibre bundles (ventral, mid, dorsal) affected and the localization of the tear in the coronal plane (insertion, proximal of insertion or musculotendinous transition) as well as in the sagittal plane and classify it according to Bateman [22] and Davidson and Burkhart [23]. By selecting the different subitems, the software concomitantly generates semantic sentences from predefined text phrases stored in the software's database (Figs. 2 and 3). These sentences do not have to be edited any more by humans. However, it is possible to enter further information manually using the keyboard at any time if necessary (this feature was not used in the study). The impression section is structured into trauma-related changes, degenerative changes, signs of subacromial impingement and other findings. The user can not only choose an automatic adoption from the findings but can also add an impression manually. Furthermore, the software features additional information about different pathologies and their corresponding images, explanations of classifications and expert comments (see electronic supplementary material for an example of an SR and an NR).

Analysis of reports

A questionnaire for evaluation was established which dealt with the completeness, linguistic and overall quality of the reports among other issues (Table 2). The NRs and the corresponding SRs were compared and reviewed independently by two orthopaedic surgeons with 10 and 6 years of expertise in shoulder surgery.

The first question dealt with the key factor of the referring physician. Moreover, we analysed if a decision regarding surgery vs. non-operative therapy is possible. A further question referred to the missing key facts of the reports. The following contents were defined as key features: clear information about presence/absence of tears or lesions, exact location of tears or lesions, muscle atrophies, bone structure, subacromial impingement and degenerative changes [17]. The reviewers were additionally asked to analyse the effort of information extraction. Another element of our research examined the trust in the

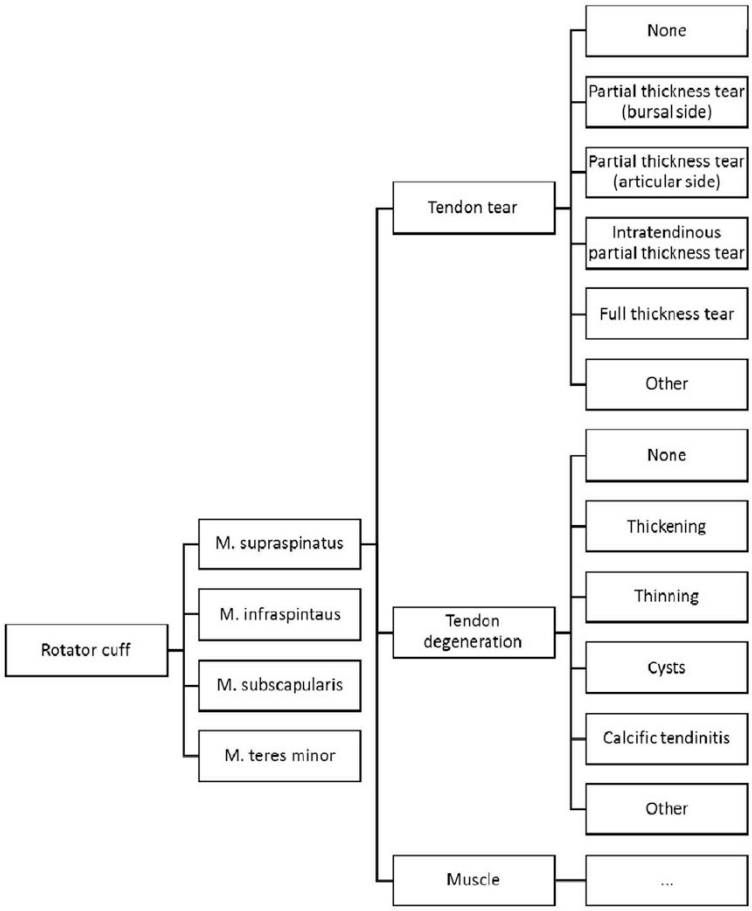

Fig. 1 Example of clickable decision tree of the structured reporting software. The rotator cuff is one of the subitems of the glenohumeral joint, divided into the four muscles of the rotator cuff. Each muscle can be further described regarding a possible tendon tear or degeneration and the muscle texture. The user selects one of these subitems and the software generates the text of the report concomitantly

information given. The last two questions covered the linguistic and overall quality of the reports with a Likert scale ranging from 1 (insufficient) to 6 (excellent). The overall quality was measured with a point-based system. The reviewers could rate the reports with up to 6 points. Two points for the complete answering of the key question (1 point if further consultation is needed), two points for the completeness (2 points for 0–1 missing key features, 1 point for 2 missing key features, 0 points for more than 2 missing key features), one point for easy extraction of information and one point for a very good or excellent (5–6 on a Likert scale) linguistic quality.

Statistical methods

We used statistical software (IBM SPSS Statistics, Version 23; Armonk, New York. Microsoft Excel 2016; Redmond, Washington) for analysis. The level of significance was set at $p = 0.05$. A Wilcoxon signed-rank test for paired data and a McNemar test for binominal data were used to test for significance. The agreement of the two observers was tested with Cohen's kappa test.

Results

The response rates of the reviewers were 100% (120 questionnaires). Each reviewer filled in 30 questionnaires about SRs and 30 questionnaires about NRs (altogether 60 structured cases and 60 non-structured cases). The results are given in percentage and in number of cases.

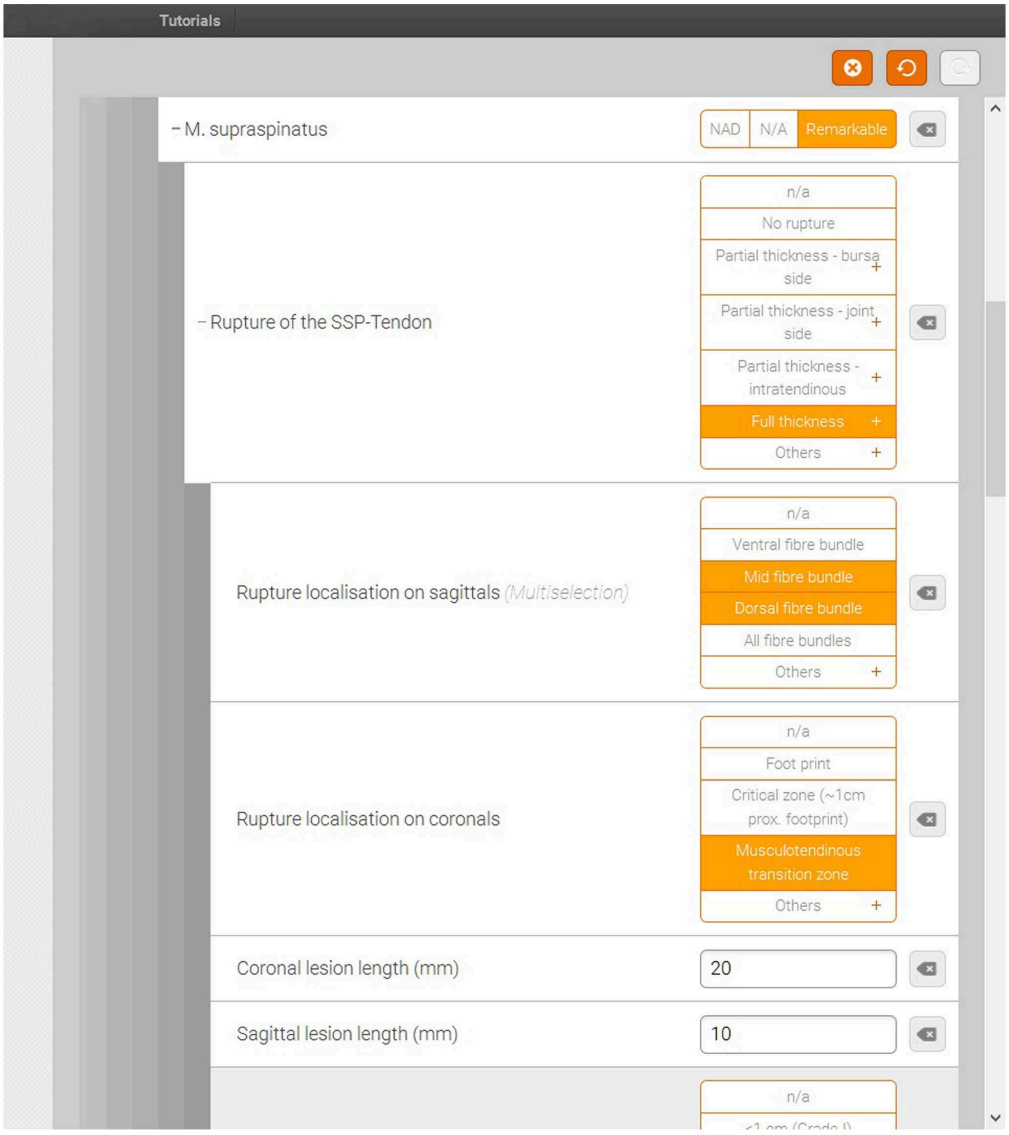

Fig. 2 Screenshot of the decision tree of the reporting software. The user can select from the possibilities of ruptures of the supraspinatus tendon (SSP) displayed and specify it regarding the exact localization and length of the rupture. Additionally, classifications of Bateman, Davidson and Burkhart, and Patte are available

Patient data

Mean age of the patients was 47.0 years with a standard deviation (std) of 17.9 years. The median age was 46 years with a range from 18 to 83 years. Out of 30 patients, 21 were male (70%) (Table 1). The agreement between the two reviewers was substantial (Cohen's kappa of 0.625) [24].

Findings

Left shoulder:

Glenohumeral joint: Rotator cuff: *M. supraspinatus:* Full thickness rupture of the middle and dorsal fibre bundles of the SSP tendon at the musculotendinous transition with a coronal length of 20 mm and a sagittal length of 10 mm (Grade II Bateman classification) (Type II Davidson and Burkhart classification) with retraction of the tendon between apex and glenoid (Type II Patte classification).

Impression

1. Traumatic changes: Full thickness rupture of the SSP tendon.

Fig. 3 Screenshot of the findings section of the reporting software. The figure shows the structured report corresponding to the selections of Fig. 2

Key questions

A total of 97% (58 cases) of the SRs answered the key questions of the referring clinicians vs. 93% (56) of the NRs ($p = 0.625$). Most SRs enabled decision-making between surgery and conservative therapy (92%; 55), whereas only 75% (45) of the NRs could provide such information ($p = 0.013$). Further consultation with radiologists was needed in 8% (5) of the SRs (NRs: 25%; 15). Additionally, there was a significant difference regarding the information for surgical planning: The number of reports that needed further clarification with a radiologist was reduced from 33% (20) (NRs) to 13% (8) at SRs ($p = 0.008$).

Missing key features

Overall 20% (12) of the SRs were incomplete vs. 55% (33) of the NRs ($p < 0.001$). An average of seven key features was missing in all SRs compared to 24 missing key features in all NRs. Among the SRs most missing key features were related to clear information about presence/absence of tears or lesions and information about bone structure (each 36% of all missing key features). The key feature most often missed in NRs was clear information about the presence/absence of tears or lesions (25% of all missing key features) followed by information about muscle atrophies (21%) and bone structures (21%). The higher level of information contained in SRs is also displayed by the length of the reports. The mean number of words in the SRs was 260 ± 51 (95% confidence interval (CI), 241–279) whereas the NRs consisted of 166 ± 52 words (CI 147–186). However, the impression section of the SRs was insignificantly shorter than the impression section of the NRs. The SRs' impression section had a mean of 38 ± 16 words (CI 33–45) versus the NR's impression section consisted of 43 ± 20 words (CI 35–50) ($p = 0.241$).

Readability

The reviewers could easily extract the information in 92% (55) of the SRs. In 8% (5) of the SRs they had to invest some effort. An easy extraction of information could only be achieved in 63% (38) of the NRs. In 30% (18) of the latter, the reviewers needed some effort and in 3% (2) they evaluated the process as time-consuming ($p < 0.001$). In two cases the question could not be evaluated.

Quality of reports

The reviewers trusted the information given in 93% (56) of the SRs and had doubts about some minor issues which were not further described by the reviewers in 3% (2). The reviewers had no doubts in 70% (42) of the NRs. However, they were unsure about some minor issues in 25% (15) and had major doubts about the correctness of the reports in 5% (3) ($p < 0.001$). The linguistic quality of the SRs was rated 5.7 ± 0.56 with a CI of 5.55–5.85 (range 4–6; Likert scale with 1–6; 1, insufficient; 6, excellent) vs. 5.42 ± 0.65 (range 4–6; CI 5.25–5.58) of the NRs ($p = 0.006$) (Fig. 4). The overall quality of the SRs was evaluated at 5.65 ± 0.55 (range 4–6; CI 5.51–5.79) and that of the NRs at 4.9 ± 0.99 (range 1–6; CI 4.65–5.15) ($p < 0.001$) (Fig. 5).

Discussion

The results of our survey are in line with previous studies. The layout of the SRs is more appealing and information is more clearly arranged than in the NRs. The preference of clinicians and general practitioners for SRs has been described in the past [10, 25, 26]. Our reviewers' evaluation pointed out very clearly that SRs are much easier to understand and it is possible to extract the necessary information more rapidly than from NRs. Regarding clarity and improved content, our study

Table 2 Questionnaire for evaluation

1. Key question of referring physician answered?
a) ☐ Yes
b) ☐ No
c) ☐ Not in total, needs further consultation with radiologist/clarification

2. Decision regarding surgery vs. conservative therapy possible?
a) ☐ Yes
b) ☐ No
c) ☐ Needs further consultation with radiologist/clarification

3. In case of surgery: Info for surgical planning
a) ☐ Adequate
b) ☐ Inadequate
c) ☐ Needs further consultation with radiologist/clarification

4. Missing key features?
a) ☐ Clear information about presence/absence of tears or lesions
b) ☐ Exact location of tears or lesions
c) ☐ Muscle atrophies
d) ☐ Bone structure
e) ☐ Subacromial impingement
f) ☐ Degenerative changes
g) ☐ Others: _____

5. Effort of information extraction
a) ☐ Easy
b) ☐ Some effort
c) ☐ Time-consuming

6. Trust in the given information?
a) ☐ No doubts about correctness of report
b) ☐ Some minor issues
c) ☐ Major doubts about correctness of report

7. How would you rate the linguistic quality of the report (1=insufficient; 6=excellent):

☐ ☐ ☐ ☐ ☐ ☐
1 2 3 4 5 6

8. How would you rate the overall report (1=insufficient; 6=excellent):

☐ ☐ ☐ ☐ ☐ ☐
1 2 3 4 5 6

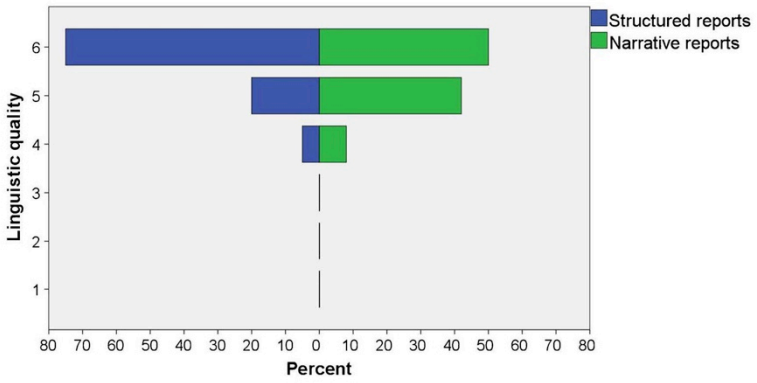

Fig. 4 Distribution of the linguistic quality of the reports. The readers evaluated the structured and the narrative reports on a Likert scale (range 1–6; 1 = insufficient, 6 = excellent). The structured reports were rated better (5.7 ± 0.56) than the narrative reports (5.42 ± 0.65) ($p = 0.006$)

is in line with several other surveys [13, 14, 27, 28]. Additionally, the clear structure of radiology reports can play an important part in research in the future. The clinical course of patients can be monitored more easily (e.g. size of tumours) if all relevant information regarding a keyword is found in one paragraph and not hidden or spread over the whole report. Thereby, structured reporting facilitates research in retrospective studies [29].

However, there are also contradictory scientific findings concerning structured reporting. Whereas Sistrom and Honeyman-Buck [30] did not find a difference between SRs and NRs regarding efficiency and accuracy, Johnson et al. [12] were able to demonstrate a decrease in accuracy and completeness by using structured reporting. In addition to the advantages of the uniform structure, this kind of layout may have a downside as it can be too rigid and constraining [11, 12]. Additionally, entrenched habits between reporters and referrers that are well known to each other may influence the style and detail of narrative reports and therefore constitute a possible bias in this study. However, as a result of frequent rotations of radiologists and orthopaedic physicians as well as the work with various external referrers, radiologists oftentimes are not well known to referring physicians and vice versa.

Another remarkable result is the linguistic quality of the SRs. The SRs were rated better than the NRs. One could assume that computer software is not able to produce a higher linguistic level than a human being. In previous research on linguistic quality, the lack of agreement between radiologists regarding the use of specific phrases, e.g. describing diagnostic certainty, has been striking [6, 7] as well as the rate of omission and missense errors [31]. This is why the RSNA founded the RadLex initiative to establish a common trunk of phrases and terms [8]. An advantage of structured reporting is the standardization of the terms, definitions and grammatical structures used. It has been shown that structured reporting can decrease misspellings and grammatical, missense and omission errors in reports [32].

The majority of radiology reports are currently written in prose, even the structured ones [33]. However, many academic radiology departments are currently testing structured reporting [34]. An important issue in this context is the difference between the structured reporting systems. Structured

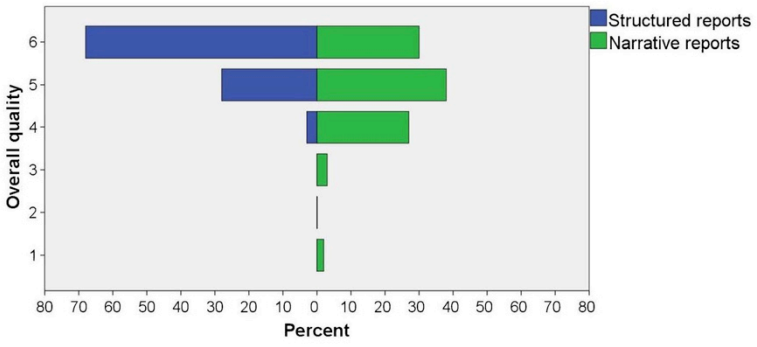

Fig. 5 Distribution of the overall linguistic quality of the reports. The readers evaluated the structured and the narrative reports on a Likert scale (range 1–6; 1 = insufficient, 6 = excellent). The structured reports were rated better (5.65 ± 0.55) than the narrative reports (4.9 ± 0.99) ($p < 0.001$)

reporting differs from itemized, checklist-based reporting to prose with default sections [35, 36]. The RSNA is trying to solve this problem by creating standard templates for structured reporting (RadReport) [37]. In summary, modern structured reporting systems are ready to be implemented into clinical work processes [16]. Examples of successful reporting standards in the field of radiology are the Breast Imaging Reporting and Data System (BI-RADS) [38], Liver Imaging Reporting and Data System (LI-RADS) [39] and Prostate Imaging Reporting and Data System (PI-RADS) [40]. These examples show that structured reporting is spreading in radiology and can already be embedded in the reporting infrastructure of hospitals [15].

Limitations

Only two clinicians were involved in the review of SRs vs. NRs. However, we tried to minimise this confinement by the strict independence of our reviewers and their voluntary participation. We also did not announce any expectations we would like to be fulfilled. The circumscribed inclusion and exclusion criteria might have an effect on the outcome. We took this issue into consideration by establishing a questionnaire that, in addition to very detailed questions, also includes very general points, such as linguistic quality. We did not investigate the accuracy of the reports because of the lack of a gold standard. As a result of the variety of the inclusion criteria and the different requests combined with inter-reader variability it was not possible to define such a standard. However, as this is an important issue, further studies are clearly necessary to investigate the effect of SRs on diagnostic accuracy in MSK imaging. Furthermore, we did not measure the time needed for producing the SRs. It was not possible to determine the time needed for creating the NRs because of their retrospective nature. Additionally, the SRs also reduce the time needed for consultation with clinicians owing to less misunderstandings. Therefore, it is not possible to calculate exactly if structured reporting is slower or not.

This study demonstrates that structured reporting has the ability to improve report quality and readability of radiological reports and is accompanied by a chance for more rapid extraction of information and can therefore potentially lead to a higher satisfaction of referring physicians.

Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Professor Wieland H. Sommer.

Conflict of interest The authors of this manuscript declare relationships with the following companies: QMedify GmbH. Wieland H. Sommer and Marco Armbruster are co-founders of the website www.smart-radiology.com (by Smart Reporting GmbH), an online platform for structured reporting.

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No complex statistical methods were necessary for this paper.

Informed consent Written informed consent was waived by the institutional review board.

Ethical approval Institutional review board approval was obtained.

Methodology
- retrospective
- diagnostic study
- performed at one institution

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Complications of locked plating for proximal humeral fractures—are we getting any better?

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Background: Complication rates reported after locking plate fixation of proximal humeral fractures still range up to 40%. Whether modifications of surgical techniques, use of primary shoulder arthroplasty, or a fracture-specific management resulted in decreased complication rates during recent years remains unclear. Therefore, the aim of this long-term observation study was to analyze the incidence of complications and revision surgery after locked plating.
Methods: Between February 2002 and December 2013, 788 patients (aged 67.4 ± 17.3 years) with displaced proximal humeral fractures were treated with locking plate, primary hemiarthroplasty (HA), or reverse shoulder arthroplasty (RSA). Standardized follow-up included radiographs at 1 day, 6 weeks, and 3, 6, and 12 months. Complications and unplanned revision surgery were prospectively recorded over the complete follow-up.
Results: Of 788 patients, 646 (82%) were treated with locking plate, 82 (10.4%) with HA, and 60 (7.6%) with RSA. Mean follow-up was 14.8 ± 3.8 months. The mean complication rate associated with locked plating was 12.8%, and revision surgery was necessary in 11.6%. Within the last 5 years, the loss of fixation rate markedly decreased from 14.3% to 4.8%; simultaneously, an increased use of RSA was observed.
Conclusion: The overall complication rate of locking plate osteosynthesis for proximal humeral fractures has been decreasing considerably within the last years. Among others, this might be due to an increased use of primary RSA for complex fracture types. In addition to a precise surgical technique, choosing the adequate treatment for each individual fracture to avoid complications and revision surgery is of utmost importance.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: proximal humeral fracture; locked plating; primary arthroplasty; long-term; outcome; complication, revision

This study was conducted according to the Declaration of Helsinki and was approved by the Ethical Committee (No. 156-12) of Ludwig-Maximilians-Universität, Munich, Germany.

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Proximal humeral fractures are the seventh most common fracture in adults and the third most in patients older than 65 years.[19] Most proximal humeral fractures are attributable to low-energy trauma in elderly patients.[3,17] Therefore, these fractures show a steady increase in incidence as the elderly population expands.[17,19] Most proximal humeral fractures are nondisplaced or mildly displaced and result in appropriate

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functional outcome after nonsurgical treatment.[13,14] Approximately 15% to 20% of all fractures are displaced and treated operatively according to the Neer criteria.[8,14] Various surgical treatment options are described and still discussed controversially. However, open reduction and internal fixation (ORIF) with locked plating is the most popular treatment of choice.[26]

Although anatomically precontoured locking plates have been routinely used for more than 1 decade, significant complications related to surgical treatment are still described.[18] Typical complications of locked humeral plating include secondary varus displacement, with or without concomitant cutting out of screws into the glenohumeral joint, avascular necrosis (AVN) of the humeral head, varus malunion, subacromial impingement, hematoma, or infection. The rate of complications described varies widely between 3% and 54%.[21,24,27] This wide range of reported complications might be due to different study setups (design, follow-up, patient number), different patient populations (age, gender, fracture type and pattern, vascular supply), patient specifics (osteoporosis, other comorbidities, compliance), and the surgeon's personal experience and preference.

Taking these variables into account, whether there is any improvement of our complication rate after locked plate fixation for proximal humeral fractures over the last decade remains unclear. However, we hypothesize that the complication and revision rate has decreased due to a deeper insight into this fracture entity, the identification of risk factors for failure,[4,5] the use of primary arthroplasty,[15] and the overall learning curve. The aim of the study was to evaluate the complication and revision rate after locked plate fixation of proximal humeral fractures under an invariable institutional study setup over 12 years.

Materials and methods

The study included all patients with unstable proximal humeral fractures according to the criteria by Neer[14] who were treated between February 2002 and December 2013 with ORIF using a PHILOS (Synthes, Oberdorf, Switzerland) or NCB-PH (Zimmer, Warsaw, IN, USA) locking plate, with a primary hemiarthroplasty (HA) using the Aequalis Fracture Shoulder (Tornier, Warsaw, IN, USA), or reversed shoulder arthroplasty (RSA) using the Aequalis Reversed Fracture system (Tornier). Patients were prospectively observed from the time of operation and longitudinally followed up. Informed consent was obtained from all patients.

Perioperative data, including patient characteristics and fracture-specific features were recorded at the in-patient stay. Standard shoulder radiographs were taken routinely at day 1, week 6, and at months 3, 6, and 12 postoperatively to verify fracture alignment and healing. In any case of postoperative complication or if revision surgery was necessary, additional radiographs were obtained until the final treatment had been accomplished. Fractures were classified according to the Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association and the Neer classification.[10,11,13]

The following complications were recorded: loss of fixation, infection, hematoma, or nerve injuries. Loss of fixation was defined as a decreased head-shaft angulation of >10° in the anteroposterior or lateral plane according to the measuring technique described previously.[1] Any unplanned revision surgery was analyzed. The abovementioned follow-up was accomplished in 76.4% of all patients included.

Operative technique

An experienced senior trauma surgeon performed the operations, as published previously.[16] Surgery was performed under general anesthesia with the patient in the beach chair position on a radiolucent table. An interscalene block was used as standard perioperative analgesia unless the patient refused it. All patients received prophylactic intravenous antibiotics before the procedure. ORIF was conducted via a deltoid-pectoral approach. The rotator cuff was evaluated for full-thickness tears, and predominant tuberosities were sutured to the plate using nonresorbable FiberWire No. 5 (Arthrex, Naples, FL, USA). Screws were meticulously placed in the subchondral layer not penetrating the articular surface (Fig. 2). No bone grafts or cement augmentation were used to support the fixation. Accurate fracture reduction and correct position of screws were checked during the surgical procedure by use of multiplane fluoroscopy in at least 3 views.

The postoperative rehabilitation protocol consisted of supervised passive and active assisted range of motion starting from postoperative day 1. Abduction and elevation up to 60°, without forced external rotation, were allowed for the first 6 weeks; thereafter, active exercises with full range of motion were started. HA and RSA (Fig. 4) were performed as published elsewhere.[7,15]

Statistics

Continuous variables are described by means, standard deviation, and percentage of total numbers. Statistical analyses and graphs were performed with SPSS 20 software (IBM Corp, Armonk, NY, USA) and Excel 2011 (Microsoft Corp, Redmond, WA, USA). The χ^2 test of independence was used to test for statistically different distributions of categoric variables.

Results

Demographic data

The study included 788 patients (67.8% women) with displaced proximal humeral fractures. Mean age at surgery was 67.4 ± 17.3 years. The mean age of the population from 2002 to 2004 was 67.2 ± 15.8 years, with 59.3% women, and from 2009 to 2011 was 68.6 ± 14.9 years, with 52.6% women. These differences were statistically not significant ($P = .21$ and $P = .55$, respectively). None of the patients had an open or a pathologic fracture. During the observation period, the number of patients treated operatively increased, although undulations were noticed. Between 2006 and 2008, patient numbers reached a lower plateau. Since 2009, a steadily increasing number of patients with proximal humeral fracture and subsequent surgical treatment were recorded (Fig. 1).

The overall fracture patterns according to the Neer classification were 2-part in 38.3%, 3-part in 39.8%, 4-part in 9.8%,

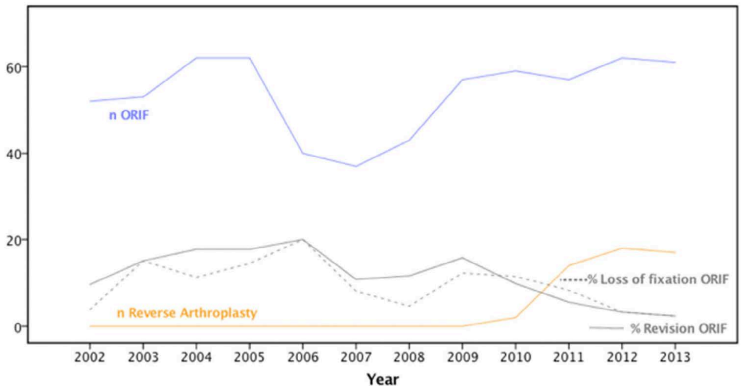

Figure 1 Line graph illustrates the number of locked plate osteosyntheses, the rate of loss of fixation (%), and the rate of unplanned revisions due to implant related complications after open reduction and internal fixation (*ORIF*) per year (%). The rate of loss of fixation markedly decreased from 14.3% in 2009 to 4.8% in 2013. This observation was accompanied by an increasing use of reverse shoulder arthroplasty.

and type VI fractures with head split in 8.4%, with fracture dislocation in 3.7%. Comparing the first and the last 3 years, a homogeneous distribution of 2-part fractures could be observed with 73 of 107 and 91 of 170, respectively ($P = .22$). Three-part fractures were significantly more frequent (83 of 97 vs. 93 of 168, $P = .03$) within the first 3 years, whereas 4-part fractures as well as fracture dislocations and head-split fractures were significantly more often observed (8 of 172 vs. 36 of 225 [$P = .001$] and 12 of 168 vs. 41 of 220 [$P = .004$]; Table I and Supplementary Fig. S1) in the last 3 years.

A total of 646 patients (82.0%) were treated by ORIF with locking plate osteosynthesis, 82 (10.4%) by use of HA, and 60 (7.6%) with RSA. The number of patients treated with ORIF and locked plating followed the number of overall patients included. After a decrease between 2006 and 2008, the number patients treated with locked plating increased from 2009 to 2013. Simultaneously, an increased use of RSA was observed within these 5 years (Fig. 1).

Complications and revisions

The overall complication rate of locked plating was 21.4%. Within the observed complications, loss of fixation was most common and found in 83 patients (12.8%) (Fig. 3). Within the last 5 years, the loss of fixation rate markedly decreased from 14.3% to 4.8% in 2013. Hematoma/infection occurred in 19 patients (2.9%), nerve injuries in 6 (0.9%), and frozen shoulder in 30 (4.6%). An unplanned surgical revision was necessary in 75 patients (11.6%).

Within the first 3 years (2002-2004), we observed 41 of 180 patients with any kind of complication, whereas 22 of 239 patients presented with complications within the last 3 years (2011-2013). This difference was statistically significant ($P = .00002$). Loss of fixation occurred in 23 of 180 patients within the first 3 years and in 14 of 247 patients within the last 3 years. This difference was statistically significant ($P = .006$). Furthermore, revision rates significantly differed ($P = .00004$) between the first 3 years (24 of 156) and the last 3 years (8 of 253; Table I and Supplementary Fig. S2).

Discussion

This study represents the first longitudinal long-term analysis of complications after locked plating for proximal humeral fractures in a large patient cohort. The main result is that the overall complication rate and the number of unplanned surgical revisions markedly decreased during the last 12 years (Fig. 1). The overall decline of complications was mainly due to a decreased rate of loss of fixation. The most striking improvement in terms of loss of fixation and revision rate was recorded simultaneously to an increased use of primary RSA for treating proximal humeral fractures. Therefore, we assume that the implementation of RSA for complex fracture situations in the elderly patient may avoid typical complications of locked plating.

Study population

The characteristics of our study population can be well compared to the patient demographics of other large cohort analyses of proximal humeral fractures treated with locked plating, such as performed by Südkamp et al.[25] The fracture types were distributed as summarized in recent review articles.[24,28] Although the number of patients per year undulated slightly, the mean age and the fracture types showed comparable distributions (Table I, Supplementary Fig. S1). We therefore conclude that changes in the complication rate are not due to a change to less complex fractures patterns or changes in the patient cohorts treated within recent years.

Table I Demographic data, fracture types, types of complications, and revision rates

Variable*	Total	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
	(N = 788)	(n = 55)	(n = 56)	(n = 69)	(n = 71)	(n = 47)	(n = 42)	(n = 54)	(n = 63)	(n = 70)	(n = 76)	(n = 98)	(n = 87)
Age (y)	67.4 ± 17.3	69.1 ± 15.1	68.0 ± 15.6	64.4 ± 16.8	62.4 ± 15.7	70.6 ± 13.9	71.7 ± 12.8	65.3 ± 15.7	64.5 ± 17.8	62.4 ± 18.6	67.3 ± 15.5	69.5 ± 14.9	68.9 ± 14.2
Female	534/67.8	37/71.2	40/74.1	36/58.1	35/56.5	31/73.8	26/81.3	28/59.6	37/64.9	43/68.3	45/67.2	69/68.3	57/64.8
Fracture type													
2-part	302/38.3	22/40.0	23/41.1	28/40.6	28/39.4	18/38.3	16/38.1	23/42.6	23/36.5	30/42.9	27/35.5	32/32.7	32/36.8
3-part	314/39.8	26/47.3	25/44.6	32/46.4	31/43.7	20/42.6	18/42.9	19/35.2	24/38.1	26/37.1	28/36.8	36/36.7	29/33.3
4-part	77/9.8	3/5.4	3/5.4	2/2.9	4/5.6	5/10.6	3/7.1	8/14.8	6/9.5	7/10.0	10/13.2	14/14.3	12/13.8
Dislocation	29/3.7	1/1.8	1/1.8	1/1.4	2/2.8	1/2.1	1/2.4	2/3.7	4/6.4	2/2.9	5/6.6	5/5.1	4/4.6
Head split	66/8.4	3/5.5	4/7.1	6/8.7	6/8.5	3/6.4	4/9.5	2/3.7	6/9.5	5/7.1	6/7.9	11/11.2	10/11.5
ORIF locking plate	646/82.0	51/92.7	52/92.9	62/89.9	62/87.3	41/87.2	38/90.5	43/79.6	56/88.9	60/85.8	54/71.1	64/65.3	63/72.4
Reversed arthroplasty	60/7.6	0	0	0	0	0	0	0	0	5/7.1	15/19.7	21/21.4	19/21.8
Hemiarthroplasty	82/10.4	4/7.3	4/7.1	7/10.1	9/12.7	6/12.8	4/9.5	11/20.4	7/11.1	5/7.1	7/9.2	13/13.3	5/5.8
Total complications locking plate	138/21.4	13/25.5	15/28.8	15/24.2	16/25.8	12/29.3	8/21.1	11/25.6	13/23.2	13/21.7	9/16.7	8/12.5	5/7.9
Loss of fixation	83/12.8	4/7.8	10/19.2	9/14.5	11/17.7	10/24.4	5/13.1	4/9.3	8/14.3	8/13.3	7/12.9	4/6.2	3/4.8
Hematoma or infection	19/2.9	3/5.8	2/3.8	3/4.8	1/1.6	0	1/2.6	3/6.9	2/3.6	2/3.3	1/1.9	1/1.6	0
Nerve injury	6/0.9	2/3.9	0/0.0	1/1.6	1/1.6	0	1/2.6	0	1/1.8	0	0	0	0
Frozen shoulder	30/4.6	4/7.8	3/5.8	2/3.2	3/4.8	2/4.9	1/2.6	4/9.3	2/3.6	3/5.0	1/1.9	3/4.9	2/3.2
Revision locking plate	75/11.6	5/9.8	8/15.4	11/17.7	11/17.7	8/19.5	4/10.5	5/11.6	9/16.1	6/10.0	3/5.6	3/4.7	2/3.2

ORIF, open reduction and internal fixation.
* Continuous data are presented as mean ± standard deviation and categoric data as number/%.

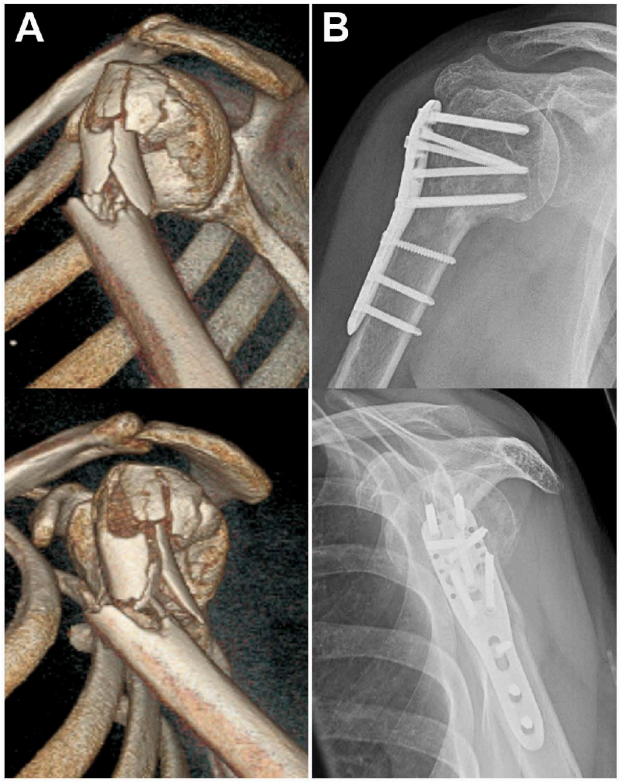

Figure 2 **(A)** Three-dimensional computed tomography scan shows a comminuted proximal humeral fracture (AO11-B2) in a 65-year-old woman. **(B)** Complete bony healing 6 months after open reduction and internal fixation with a PHILOS locking plate (Synthes, Oberdorf, Switzerland) and FiberWire (Arthrex, Naples, FL, USA) sutures of the tuberosities.

Complications and reoperations

In our study, loss of fixation was identified as the most common complication (Table I). This finding goes well in line with Sproul et al.[24] In their review of 12 studies of locking plate osteosynthesis for proximal humeral fractures, the authors found that varus malunion due to loss of fixation occurred in 16.3%. The authors indicated that this complication is of utmost importance because it may lead to screw cutout into the humeral joint and reoperations. Thanasas et al[28] further researched the main reasons for reoperations after locked plating of proximal humeral fractures, and found loss of fixation and cutout were the most common reasons for unplanned revisions. Furthermore, previous studies from our group identified the adverse events of loss of fixation and reoperation were risk factors for poor long-term functional outcome.[16]

Interestingly, the rate of loss of fixation differs widely between studies. Solberg et al[23] reported 25 varus malunions in 70 older patients (35.7%), whereas Lee et al[9] found only 11.1% varus dislocations in their study of patients with of an average age of 64 years. Both studies were published in the same year. In 2012, Acklin et al[1] observed only 7.2% of implant-related complications. In contrast, Kralinger et al[6] very recently reported mechanical failure after locking plate fixation in 35% in a study population of 150 patients.

Summarizing these findings from literature, whether there is any improvement in reducing the rate of loss of fixation within the last decade remains unclear. Our analysis represents a longitudinal observation to clarify this question. Although the number of patients treated with ORIF and the distribution of fracture types remained equal over the last years, the rate of total complications, loss of fixation, and reoperations significantly decreased (Fig. 1, Table I and Supplementary Fig. S2). Presumably, reasons for this observation are multifactorial. Improvements in surgical technique, intraoperative management, and the surgeon's individual

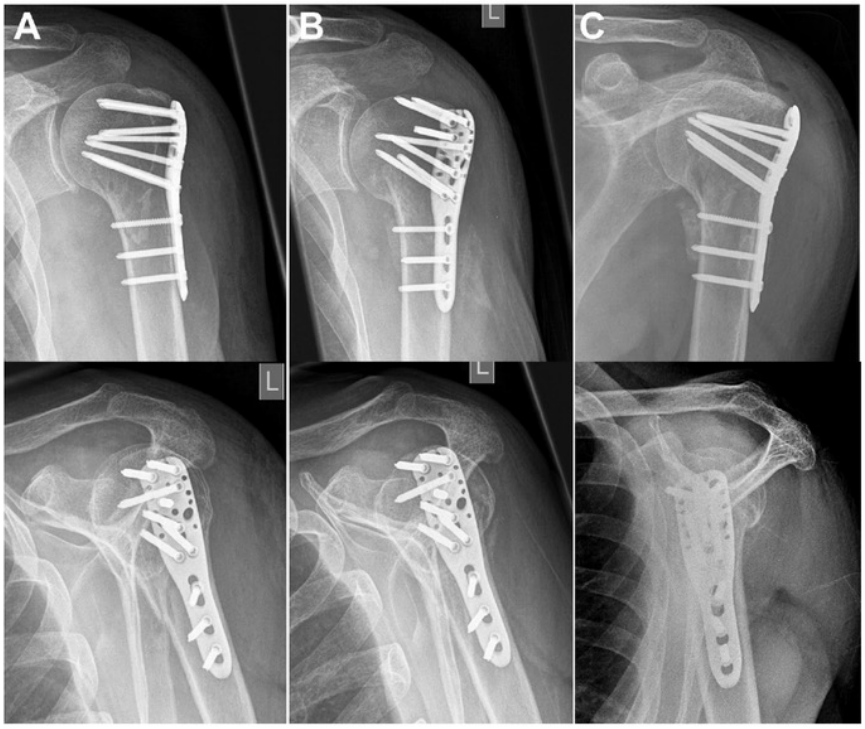

Figure 3 **(A)** Initial radiographs in anteroposterior and lateral views after open reduction and internal fixation of a proximal humeral fracture (AO11-A3) with a PHILOS locking plate (Synthes, Oberdorf, Switzerland) showing anatomic reduction and correct positions of the plate and screws. **(B)** Loss of fixation with varus dislocation of the head was noticed 6 weeks after the operation. **(C)** Bony healing after 6 months. The proximal screws have been removed at 3 months after the initial surgery.

learning curve are known to be important parameters for a good outcome. Furthermore, we assume that the implementation of specialized departments dedicated to shoulder surgery, the knowledge about risk factors for failure, and the capability to apply alternative techniques, such as RSA or HA, for complex fractures highly contribute to a decrease of complications and reoperations. Beside individual learning curves, we subsume these aspects in an institutional learning process.

Surgical technique of locked plating

Varus collapse is most likely caused by deforming forces acting on the proximal humeral fragment. The rotator cuff tendons are a primary displacing force generator along with additional compressive glenohumeral forces from loading the extremity.[22] The addition of tension-relieving sutures from the plate to the rotator cuff tendons is possible with most plate designs, such as used in this study. They theoretically offer the advantage of transferring deforming forces directly to the plate–screw construct, thereby neutralizing their deforming tendencies.[22] Many surgeons therefore routinely apply neutralizing sutures to prevent screw cutout.[12] However, tension-relieving rotator cuff sutures added to locking plate fixation did not improve stability of the construct in biomechanical models,[22,29] and comparative clinical studies are missing.

In addition to tension-relieving sutures, other strategies have been developed to enhance the mechanical stability of locking plate fixation of proximal humeral fractures. Schliemann et al[20] reviewed that medial support screws, filling of bone voids, screw-tip augmentation with bone cement, and the application of bone grafts are currently the most frequently performed methods. We conclude that the mentioned strategies appear to have a positive effect on achieving and maintaining a stable reduction even of complex fractures, but further clinical studies with a higher level of evidence are required to clarify the indications for cement augmentation, bone grafting, or implementation of bone substitutes.

Figure 4 **(A)** Radiographs show a proximal humeral fracture with a head-split and risk factors for a humeral head ischemia (short medial head extension and widely disrupted medial hinge) in an active 82-year-old woman. **(B)** Postoperative radiographs after performing primary reversed shoulder arthroplasty (Aequalis Reversed Fracture; Tornier, Bloomington, IN, USA).

Primary arthroplasty for humeral fractures

Because treatment of complex 3- and 4-part fractures of the proximal humerus in elderly patients can be associated with high rates of complications, primary shoulder arthroplasty is gaining more popularity.[15,23,30] Recently published data from our group revealed functional outcome after treating complex fracture situation with primary RSA was comparable in a matched-pair analysis to locked plating of fractures without risk factors.[15] Within this analysis, we could not identify infections, dislocations, vascular or neural disorders, and surgical revision in any patient. We therefore consider RSA as an appropriate alternative to treat complex proximal humeral fractures in the elderly.

The present analysis further demonstrates that RSA was more often used than HA. This tendency goes well in line with the findings of a recently published randomized controlled trial of Gulotta et al[2] showing that RSA provided better functional outcomes than HA for acute proximal humeral fractures in a patient cohort with a mean age of 74 years. These findings are further supported by a recent meta-analysis of Wang et al.[30] Compared with HA, RSA was associated with a lower rate of total complications, higher functional outcome parameters, and a higher rate of tuberosity integration. Both treatments were comparable in revision operations, mortality, subjective satisfaction, and active external rotation. The present evidence from this meta-analysis suggested that RSA was a more advantaged method for the treatment of complex proximal humeral fractures.[30]

Limitations

The evidence of the present study is limited due to a missing control group. We focused our analysis on the major complication of locked plating and the loss of fixation and did not research complications, such as AVN. Nevertheless, loss of fixation is the most relevant complication of locked plating in proximal humeral fractures, and humeral head ischemia

is mainly dependent on the fracture pattern and morphology.[5] In addition, the effect of AVN on the functional outcome is controversially discussed. Finally, complications of primary shoulder arthroplasty were not analyzed or compared with complications after locked plating. However, a large number of the included RSA cohort has been discussed in recent publications of our group.[15]

Conclusions

Loss of fixation is the most important complication after locked plating of proximal humeral fractures. During the last 12 years, this complication and the incidence of unplanned surgical revisions have markedly decreased. We conclude that the institutional experience gained during this time led to an improvement of our surgical technique and to deeper understanding of the risk factors for failure. Furthermore, careful analysis of the individual characteristics of the patients and fractures resulted in a sophisticated management of these fractures. Respecting the limitation of locked plating, the increased use of primary RSA for complex fractures in the elderly may be responsible for the reduction of complications and surgical revisions.

Disclaimer

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Appendix
Supplementary material

Supplementary data to this article can be found online at doi:10.1016/j.jse.2016.02.015.

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Timing of surgery for open reduction and internal fixation of displaced proximal humeral fractures

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KEYWORDS

proximal humerus fracture
locked plating
angular stable plating
timing of surgery
delay of intervention
osteosynthesis
complication
outcome

ABSTRACT

Background: Open reduction and internal fixation is one established method for treatment of displaced fractures of the proximal humerus. However, the timing of surgery and its effect on complications have not yet been investigated in the literature. Hence, aim of this study was to analyze the occurrence of complication following locked plating of proximal humeral fractures when surgery was delayed in comparison to early intervention.

Methods: Between February 2002 and November 2010, 497 patients with displaced proximal humeral fractures were treated by open reduction and locked plating. 329 patients were available for follow-up with a minimum of 12 months after surgery. Outcome analysis included radiographic evidence of loss of fixation (>10° of secondary displacement), screw-cutout and avascular head necrosis. Outcomes were analyzed with regards to age, gender and fracture pattern and were compared between time intervals in which the primary surgery had been conducted; early intervention (<48h), timely scheduled for surgery (3-5 days) and delayed intervention (>5 days).

Results: Of 329 patients (68.4% women; median age at time of surgery: 69.9 years, 95% Confidence Interval (CI) 68.2, 71.2) the median time between fracture incident and surgical intervention was 3.2 days (95%CI: 3.1, 3.3). Surgery was performed in a 2-part fracture at a median of 3.3 days (95%CI: 3.2, 3.4) after trauma, in a 3-part fracture after 3.3 days (95%CI: 3.1, 3.4), in a 4-part fracture 2.9 days (95%CI: 2.8, 3.0), in head split type fracture 2.2 days (95%CI: 2.0, 2.4) and in dislocation type fracture 0.8 days after trauma (95%CI: 0.7, 0.9, p = 0.40). Loss of fixation was observed in 12.8% (n = 42 patients), of which in 4.9% (n = 16) screw cutout was evident and in 6.8% of cases (n = 20) avascular head necrosis was diagnosed. Patients in which complication was observed were treated at median 2.5 days after trauma (95% CI, 1.8, 3.2), in comparison, patients without evidence of complications were treated at a median of 3.2 days (95% CI, 2.8-3.8, p = 0.35). The odds ratio regarding occurrence of complications for patients treated <48 hours was 0,924, for patients in which surgery was performed 3-5 days after the incident the odds ratio was 0,836 and in patients treated > 5 days the odds ratio was 1,637.

Conclusions: Loss of fixation following open reduction and internal fixation of proximal humeral fractures was not more frequently observed when surgery was performed 3-5 days after the incident in comparison to early intervention (<48h). However, a delay of intervention > 5 days is related to significant increase of complications. Thus, if open reduction and internal fixation is indicated, reconstruction of the proximal humerus should be performed within 5 days of the fracture event. In head split and dislocated fracture types anatomic reconstruction completed within 48h from the incident may be beneficial with regards to risk of avascular necrosis.

Introduction

Proximal humeral fractures represent about 5% of all fractures of the human body [1]. Due to a demographic change, the number of proximal humeral fractures is predicted to rise within the next years [2]. While non-displaced fractures may be treated non-operatively with good functional results, displaced and comminuted fractures indicate for surgery [3]. In the last decade open reduction and internal fixation by use of locking plates has become one established surgical treatment, however, complication rates following locked plating account for 20% including loss of fixation, screw cutout, and avascular necrosis of the humeral head [4-8].

Several studies aim to identify risk factors related to the occurrence of complications, including age, female gender and comorbidities. With regards to operative treatment of proximal humeral fractures an increase of complications is associated with delay of surgery, such as surgical-site infection, peripheral

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thrombosis events and pneumonia [9]. However, besides patient immanent factors, fracture healing is also related to fracture morphology, disruption of the medial hinge and may depend on perfusion of the humeral head (i.e. intact blood supply) [10,11]. In terms of preservation of blood supply early reconstruction of the humeral head may be beneficial. However, to our knowledge, timing of surgery has not yet been analyzed for open reduction and internal fixation of displaced proximal humeral fractures in this context. As delayed surgical treatment could jeopardize vital bone structures, thereby negatively influencing the healing process, we hypothesize that an early intervention (<48 hours after trauma) may be advantageous in osteosynthesis.

The aim of the study therefore was to investigate the relationship between timing of surgery and complications associated to fracture healing following open reduction and internal fixation of proximal humeral fractures. In addition, we analyzed factors contributing to the time spent awaiting surgery.

Material and Methods

This study was conducted by approval of the local ethical review board (No.: 156-12). After giving their informed consent, patients were prospectively enrolled into the study and longitudinally followed up from the time of the operation, in consistency with the declaration of Helsinki. Medical records comprised demographic information, the effective date and time of the fracture incident, the fracture pattern as well as the documented date and time of the surgical procedure were included in a database.

Between February 2002 and November 2010, 497 patients with displaced proximal humeral fractures (Neer criteria) were included [12,13]. All fractures were treated by means of open reduction and internal fixation = ORIF. Exclusion criteria included open fractures, fractures resulting from primary or metastatic neoplasia, fractures with concomitant traumatic nerve deficiency. Patients were also excluded if locked plating was not the primary treatment (revision from other osteosynthesis). In addition, patients diagnosed with dementia or following apoplectic insults were also excluded from this study.

Surgical procedure

For ORIF surgical reconstruction of the humeral head was performed using locking plates (PHILOS®, Synthes DePuy GmbH, Oberdorf, Switzerland or NCB-PH®, Zimmer GmbH, Winterthur, Switzerland). Surgery was conducted by one of seven experienced trauma surgeons in upright beach chair position on a radiolucent table. Every patient received prophylactic intravenous antibiotics (Cefuroxime®) as a 1.5g single-shot and general anesthesia in combination with an interscalene block for postoperative pain control. Using a standardized deltopectoral approach, surgical reconstruction was achieved by restoring the humeral offset and anatomic reduction of fragments. Neither bone grafts nor bone cement or cement augmentation were used to support fixation in this study. The rotator cuff was evaluated for rotator cuff tears and tuberosity sutures (FiberWire No. 5®; Arthrex, Naples, FL, USA) were used predominantly. Screws were carefully driven into the subchondral layer, thereby not penetrating the articular surface of the humeral head. To ensure correct screw position and accurate fracture reduction, every step was verified by multi-plane fluoroscopy intraoperatively. When necessary, a screw was repositioned to obtain the intended distance and location of the screw tip relative to the subchondral bone and layer.

The post-surgical rehabilitation protocol allowed passive and active-assisted motion exercises, supervised by a physical therapist, beginning immediately on day one after surgery. Abduction and elevation was limited to 60°, without forced external rotation for the first 6 weeks, followed by active exercises with full range of motion and increasing strength exercises.

Follow-up and outcome measures

At every follow-up examination, patients were both interviewed according to a standardized protocol and physically examined by a member of the orthopedic surgery staff. The standardized follow-up comprised clinical and radiographic examinations of the affected shoulder at three, six and 12 months after surgery as well as at final follow-up. The median follow up was 4.5 years (95% Confidence Interval (CI) 4.2, 4.9) after surgery with a minimal follow-up of 12 months. From 497 patients a complete follow-up could be obtained of 329 patients (225 women ≙ 68.4% and 104 men ≙ 31.6%; median age: 64.9 years; 95%CI: 63.4 – 66.5, follow-up rate: 66.2%).

Radiographic evaluation

Every patient underwent true anteroposterior (a.p.) and outlet view radiographs of the injured shoulder. The fracture pattern was determined according to the Neer classification. In most cases additional CT-scan was obtained for a comprehensive identification of the exact fracture type. Our clinical follow-up comprised x-rays in true a.p. and outlet-view at 3, 6, and 12 months after surgery to verify the bone healing process and identify complications. At final follow-up, x-rays were only performed if the patient reported of pain, or if a decrease in range of motion or a low functional result was identified with respect to ethical committee objections.

Radiographs were evaluated for any complications related to the fracture fixation: loss of fixation, secondary displacement >10°, screw cutout, osteonecrosis of the humeral head, nonunion, malunion or failure of the implant (loosening, breakage).

Statistical analysis

We described continuous variables by median and 95% confidence intervals (95% CI). Timing of surgery for different fracture patterns was compared using Kruskal-Wallis-Test. To calculate the median time period, with or without occurrence of complications, the Mann-Whitney-U-Test was used. To compare the risk of complications for surgery at different time intervals after trauma the odds ratio was calculated. Level of significance for all testing was set at $p < 0.05$. Statistical analysis was performed with SPSS version 23 (SPSS Inc., Chicago, IL, USA).

Results

Of the 329 patients (225 women ≙ 68.4% and 104 men ≙ 31.6%; median age: 64.9; 95%CI: 63.4 – 66.5) the median time period (Δ) between trauma incident and the surgical procedure (open reduction and internal fixation by use of locking plates, ORIF) was 3.2 days (95% CI: 2.7 - 3.6).

In 151 cases (45.9%) the surgery was performed within 48h from trauma, in 135 cases (41.0) between 48h and 4 days, and in 43 cases (13.1%) 5 days or later, respectively. There were no differences in age and gender between the groups (p=0.913; p=0.862, Table 1).

The fracture patterns according to Neer classification were as following: 2-part fracture = 126 patients (38.3%), 3-part fracture = 136 patients (41.3%), 4-part fracture = 43 patients (13.1%), head split type fracture = 11 patients (3.3%) and dislocation type fracture = 13 patients (4.0%). Regarding the timing of surgery with respect to fracture pattern there was no significant difference between the fracture types according to the Neer classification, however, there was strong tendency for dislocation type fractures to be operated on earlier (p=0,059, Table 2).

Table 1
Descriptive data of patients divided by the surgical timing intervals.

	<48h	48h – 5 days	> 5 days	p
n (%)	151 (45.9)	135 (41.0)	43 (13.1)	
median age (95%CI)	64.8 (62.3; 67.3)	65.0 (62.7; 67.3)	65.1 (61.1; 69.2)	0.913
female n (%)	103 (68.2)	97 (69.6)	28 (65.1)	0.862
2-part n (%)	54 (35.8)	53 (39.3)	19 (44.2)	0.578
3 part n (%)	63 (41.7)	55 (40.7)	18 (41.9)	0.983
4-part n (%)	19 (12.6)	19 (14.1)	5 (11.6)	0.891
head split n (%)	5 (3.3)	5 (3.7)	1 (2.3)	0.908
dislocation type fracture n (%)	10 (6.6)	3 (2.2)	0 (0)	0.059
Loss of fixation n (%)	19 (12.6)	15 (11.1)	8 (18.6)	0.438

Table 2
Fracture types and median delay of surgery.

	n(%)	Δ trauma – surgery (d) (95%CI)
2-part	126 (38.3)	3.3 (3.1, 3.5)
3-part	136 (41.3)	3.3 (3.2, 3.4)
4-part	43 (13.1)	2.9 (2.8, 3.0)
Head-split	11 (3.3)	2.2 (2.0, 2.4)
Dislocation type	13 (4.0)	0.8 (0.6, 1.0)
Overall	329	3.2 (2.7, 3.6)

p = 0.406, Kruskal-Wallis-Test.

Table 3
Cumulative odds ratio for complications in relation to timing of surgery (<48 hours, 48 hours to 5 days, > 5 days).

Δ trauma – surgery	cumulative odds ratio for complications
<48h	*0,924*
≥48h - 5 days	*0,836*
>5 days	*1,637*

Loss of fixation was observed in 12.8% (n = 42 patients) of patients, of which screw cut-out was seen in 4.9% (n=16) and avascular humeral head necrosis in 6.8% (n = 20 patients) of cases. The median time period (Δ) trauma – surgery was 2.5 days (95% CI: 1.8 – 3.2) for patients with post-surgical complications versus 3.2 days without complications (95% CI: 2.8 – 3.8, p = 0.271, Mann-Whitney-U-Test). For ORIF performed within 48h from the trauma incident in 19 cases (12.6%) and within 24h and 5 days 15 cases (11.1%) loss of fixation was observed subsequently. In comparison, when surgery was conducted >5 days after the incident loss of fixation was seen in 18.6% (n=8, p=0.438). The cumulative odds ratio (OR) for complication following early surgical intervention (< 48 hours) was OR = 0.924, between 48 hours to 5 days OR = 0.836, and >5 days OR = 1.637, (Table 3).

While the number of interventions decreases from the third day the proportional rate of complications rises for patients treated more than 5 days after trauma (Fig. 1).

Discussion

The incidence of proximal humeral fractures have increased substantially and the optimal treatment remains a topic of interest within the trauma society [14-20].

We believe that this is the first report on the relationship between surgical timing and complication associated to the osteosynthesis following open reduction and internal fixation of displaced proximal humeral fractures.

The main result of this study is that early surgical intervention (<48h) does not relate with a reduced rate of complications (loss of fixation, screw cutout and humeral head necrosis). Patients in which ORIF by means of locked plating was performed between 48h and 5 days after the trauma were not likelier to develop complications (OR=0.8) compared to patients undergone early intervention (<48h, OR= 0.9). In contrast, longer delay of surgical treatment (>5 days) was associated with a higher rate of loss of fixation and avascular necrosis (OR=1.6).

In this study loss of fixation was seen in 12.8% of cases, in which 4.9% (n=16) screw cutout was observed and in 6.4% of cases avascular necrosis (AVN) of the humeral head was evident. This is in line with other reports of similar complication rate [8,21,22]. Südkamp et.al showed a rate of 9.7% secondary displacement and 4% of AVN in their collective, thus secondary displacement with or without screw cutout is the most common adverse event following open reduction and internal fixation in proximal humeral fractures [6]. However, complications associated with the osteosynthesis may be a result of impaired fracture healing. As Perren described "the obvious element enabling repair is blood supply" [23]. Interestingly in a recent study, surgery conducted several

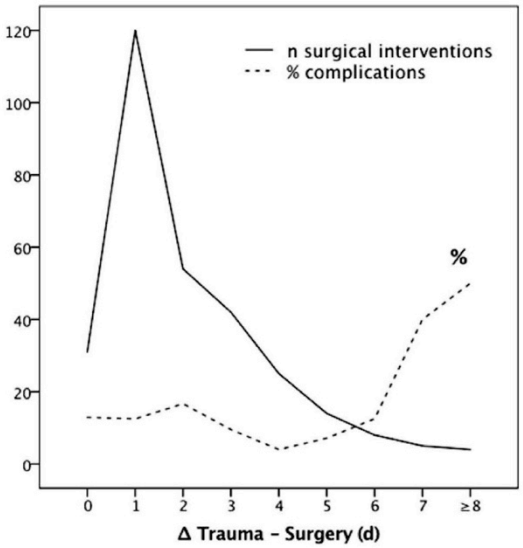

Fig. 1. Total number of ORIF and percentage of complications in relationship to surgical timing.

days after the fracture was associated to damaged blood vessels, resulting in an interruption of the increased blood flow and reducing the VEGF expression [24]. However, besides rare evidence from molecular studies, there is little data from which to judge the optimal timing for fracture treatment in the clinical scenario.

The relationship of surgical timing and postoperative complications has been extensively analyzed in patients with hip fractures where early surgical treatment (12-48 hours after trauma) has been shown to reduce the rate of loss of fixation in comparison to delayed surgical treatment (>48h) [22,25-30]. Papakostidis et al showed no significant influence on the occurrence of avascular necrosis of the proximal femur but a significant increase in cases of non-union for fractures treated more than 24 hours after injury [31].

In our study the median time between the fracture event and the surgical intervention was 3.2 days. This is comparable to other studies investigating on open reduction and internal fixation [8,21,32]. We observed a tendency for head-split fractures (2.2 days) and dislocation type fractures (0.8 days) to be operated on earlier. A reason for this result may be seen in the general guidance that a fracture with dislocation of the joint presents an emergency. Patients who underwent surgery more than 5 days after trauma were mostly transferred to our institution or were otherwise medically objected from timely intervention.

As avascular necrosis of the humeral head is influenced through the size and integrity of the medial hinge, medial extension, blood supply and fracture type, from the results of our study one might suggest that the timing of surgery seems to be not the important factor relating to complications [11,33]. One main influence on lack of statistical difference between early and late surgical intervention may be a difference in preoperative planning (indication, selection of treatment, anesthesiological work-up). Menendez et al. showed an increase in inpatient mortality, postoperative length of stay and non-routine discharge for patients with dislocated proximal humeral fractures treated more than 3 days after trauma [9]. However, the contribution of delayed surgery on complications associated to the osteosynthesis was not addressed in this study.

Regarding the incidence of complications for different fracture types in relation to timing of surgery one could see a higher rate of complications for head split and dislocation type fractures if surgery was performed more than 48 hours after trauma. In contrast, 3-part fractures showed lower rates of complications if treated after 48 hours, however fracture patterns were not represented equally in terms of volume. From the authors personal experience we recommend surgical intervention for articular fractures with glenohumeral dislocation as soon as possible. In turn, 3-part fractures may be treated later than 48 hours (<5 days) without increased risk of osteosynthesis-related complications when preoperative preparations is completed and the most experienced surgeon is available.

The results of this study have to be seen in the light of its limitations. Some proximal humeral fractures were treated soon after admission due to an in-house guideline for dislocation type fractures. These cases, when fractures occurred on the weekend or at night and when surgery had been performed by less experienced general trauma surgeons, are compared to operations that have been electively planned and performed by surgeons dedicated to shoulder surgery. Furthermore, in cases of head split type fractures in the elderly patient these surgeons may tend to indicate for reversed shoulder arthroplasty. Consequently, patients were not included into this study, which may have led to a selection bias.

In order to provide the best evidence of the relationship between timing of surgery for proximal humeral fracture and complications associated to the osteosynthesis, randomized controlled trials are necessary, but as with hip fractures, they are unlikely to be conducted because of ethical concerns.

Conclusion

If open reduction and internal fixation is indicated, reconstruction of the proximal humerus should be performed within 5 days of the fracture event. In head split and dislocated fracture types anatomic reconstruction completed within 48h from the incident may be beneficial with regards to risk of avascular necrosis. The optimal timing of surgery within 5 days from the fracture incident still remains unclear, as our results show no significant differences within this time interval. In case of unpreventable longer delay of surgery or late hospital admission, alternative patient specific therapeutic options (e.g., arthroplasty) should be taken into consideration.

Conflict of interest

The authors, their immediate family, and any foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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PLOS ONE

RESEARCH ARTICLE

Open reduction and internal fixation of displaced proximal humeral fractures. Does the surgeon's experience have an impact on outcomes?

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Abstract

Introduction

To evaluate outcomes following open reduction and internal fixation of displaced proximal humeral fractures with regards to the surgeon's experience.

Material and methods

Patients were included undergoing ORIF by use of locking plates for displaced two-part surgical neck type proximal humeral fractures. Reduction and functional outcomes were compared between procedures that were conducted by trauma surgeons [TS], senior (>2 years after board certified) trauma surgeons [STS] and trauma surgeons performing ≥50 shoulder surgeries per year [SS]. Quality of reduction was measured on postoperative x-rays. Functional outcomes were assessed by gender- and age-related Constant Score (nCS). Secondary outcome measures were complication and revision rates.

Results

Between 2002–2014 (12.5 years) n = 278 two-part surgical neck type humeral fractures (AO 11-A2, 11-A3) were included. Open reduction and internal fixation was performed with the following educational levels: [TS](n = 68, 25.7%), [STS](n = 110, 41.5%) and [SS](n = 77, 29.1%). Functional outcome (nCS) increased with each higher level of experience and was significantly superior in [SS] (93.3) vs. [TS] (79.6; p = 0.01) vs. [STS] (83.0; p = 0.05). [SS] (7.8%) had significantly less complications compared with [TS] (11.3%; p = 0.003) and [STS](11.7%; p = 0.01) moreover significantly less revision rates (3.9%) vs. [TS](8.2%) and [STS](7.4%) (p<0.001). Primary revision was necessary in 13 cases (4.7%) due to malreduction of the fracture.

Conclusion

Quality of reduction and functional outcomes following open reduction and internal fixation of displaced two-part surgical neck fractures are related to the surgeon's experience. In addition, complications and revision rates are less frequent if surgery is conducted by a trauma surgeon performing ≥50 shoulder surgeries per year.

Introduction

Treatment of displaced proximal humeral fractures can be challenging. Although conservative treatment leads to good results in mildly displaced fractures, outcomes following operative treatment of displaced fractures is heterogeneous. Open reduction and internal fixation is the most frequently performed operative procedure for treatment of displaced proximal humeral fractures [1]. Over the last decade, fracture fixation by use of locking implants has become an established treatment and results have improved in comparison to conventional fixation techniques [2]. However, complication rates following open reduction and internal fixation of displaced proximal humeral fractures still account for up to 30% and numerous studies investigated factors associated with poor outcome [3–6].

Several studies evaluated risk-factors of complications and unsuccessful functional outcomes after locked plating of proximal humeral fractures [7–9]. Comorbidities and the integrity of the medial hinge have been shown to significantly influence clinical outcome and should be assessed for indication preoperatively [7, 10]. Another important factor to avoid complication and achieve a good outcome may be the surgeon itself. Schnetzke et al. have shown, that satisfactory outcome of locked-plate fixation of proximal humeral fractures mainly depends on the quality of fracture reduction. Shoulder function is impaired and complications are more frequently seen, if fractures were reduced nonanatomically [11].

In the treatment of distal radius fractures and hip fractures it has been shown, that quality of fracture reduction and outcomes are related to the experience and practise of the treating surgeon. [12–14]. The role of surgical experience as an independent factor for the quality of reduction in the treatment of proximal humeral fractures remains largely unknown. In addition, the impact of the treating surgeon on functional outcomes and complications following proximal humeral fracture treatment is inadequately understood.

Therefore, the objective of our study was to evaluate the impact of surgeon experience in the treatment of displaced proximal humeral fractures. We hypothesized that in patients undergoing open reduction and internal fixation, fracture reduction would be anatomic and functional outcomes would be excellent, if the surgery was conducted by an experienced surgeon.

Materials and methods

For this ethical board approved study (LMU No.: 156–12), patients were retrospectively assessed from the institutional proximal humeral fracture database. All data were fully anonymized before evaluation. N = 1,411 Patients with a displaced proximal humeral fracture were treated by open reduction and locking plate fixation between February 2002 and September 2014 (12.5 years). The fracture pattern was determined according to the AO classification [15]. In most cases additional CT-scan was obtained for a comprehensive identification of the exact fracture type. Inclusion criteria were displaced two-part surgical neck type fractures of the

proximal humerus (AO 11-A2 and AO 11-A3) treated by locked plating. A total of n = 278 patients were identified and evaluated for this study.

Surgery was conducted in upright beach chair position on a radiolucent table. Every patient received prophylactic intravenous antibiotics as a single-shot and general anaesthesia. Using the deltopectoral approach, surgical reconstruction was achieved in all cases by open reduction and fractures were fixed by use of a locking plate (PHILOS, Synthes DePuy GmbH, Oberdorf, Switzerland). Neither bone grafts nor bone cement or cement augmentation was used to support the fixation in this study. Screws were carefully driven into the subchondral layer, thereby not penetrating the articular surface of the humeral head. To ensure correct screw position and accurate fracture reduction, every step was verified by multi-plane fluoroscopy intraoperatively. When necessary, a screw was repositioned to obtain the intended distance and location of the screw tip relative to the subchondral bone and layer [16, 17].

Surgical experience was determined based on the educational level of the operating surgeon at the time of surgery. With respect to the surgeon's experience, three subgroups were created:

1. board certified trauma surgeon [TS],
2. senior (>2 years after training) trauma surgeon [STS],
3. board certified trauma surgeon performing ≥50 shoulder surgeries per year [SS], including arthroscopic procedures, fracture treatment around the shoulder and shoulder arthroplasty

Quality of reduction was assessed in each patient from the postoperative true anteroposterior (AP) and outlet-view radiographs of the shoulder conducted within three days from surgery. The AP radiographs were retrospectively analysed by two blinded examiners for quality of fracture reduction (head-shaft displacement, head-shaft alignment) and integrity of the medial calcar hinge. The criteria were adopted from previous studies [10, 18]: A minor varus head-shaft alignment of <120° to 110° was considered to be an acceptable result of fracture reduction, a head-shaft alignment of <110° or >150° was rated as malreduction which is in agreement with previous studies [19–21]. Under these considerations of the quantitative determination of fracture reduction, patients were assigned in 3 groups according to Schnetzke et al. [11]: Overall anatomical fracture reduction, acceptable fracture reduction and malreduced fracture.

True anteroposterior (AP) and outlet-view radiographs of the shoulder were also taken at 6 weeks, 3, 6, and 12 months after surgery to verify the bone healing process and identify variances to the postoperative x-ray and complications. Complications included: Secondary displacement, plate dislocations out of the shaft, screw cut-out, avascular necrosis, infections or hematomas.

At every follow-up examination, patients were also interviewed according to a standardized protocol and physically examined by a member of the orthopaedic surgery staff. The standardized follow-up comprised clinical examinations of the affected shoulder at three, six and 12 months after surgery as well as at final follow-up. Functional outcome measure was the gender- and age-related (normalized) Constant Score [nCS] [22, 23].

Statistics

Continuous variables were described by median and 95% confidence intervals (95% CI). Descriptive statistics were expressed as mean ± standard deviation. Categorical data were expressed as percentages. Timing of surgery for different fracture patterns was compared using Kruskal-Wallis-Test. Comparisons between normally distributed continuous variables (level of experience) were performed with one-way ANOVA or the t-test and differences

among the categorical data were analyzed with chi-square test. Post-hoc analyses for pairwise comparisons were performed using the Bonferroni method for categorical data and the Tukey method for continuous variables. *P* values less than 0.05 were considered statistically significant. Statistical analysis was performed with SPSS version 23 (SPSS Inc., Chicago, IL, USA).

Results

Between 2002–2014 278 two-part surgical neck type fractures (11-A2 and AO 11-A3) underwent locking-plate osteosynthesis by 22 surgeons. [TS] treated n = 77 (27.7%), [STS] treated n = 116 (41.7%) and [SS] n = 85 (30.6%) patients. Group sizes were significant different in [TS] vs. [SS] p = 0.002 and [STS] vs. [SS] p = 0.004.

Overall anatomical and acceptable fracture reduction was achieved in n = 265 (95.3%) of the patients. Radiographic evaluation of early postoperative radiographs revealed that n = 248 (93.6%) of the patients had primary anatomic reduction, [TS] 87.9% [STS] 91.2% [SS] 96.5%, p<0.001 [SS] vs. others. In N = 17 (6.4%) cases minor head-shaft alignment was noticed with an overall acceptable reduction. In 13 cases (4.7%) fractures were malreduced and early revision osteosynthesis was performed. Between groups distribution was [TS] 6.8%, [STS] 5.5% and [SS]1.2%, p<0.001 [SS] vs. others. (Figs 1 and 2).

Fig 1. AO 11-A3 fractures before and after ORIF by locking plate. (A)+(B): fracture of a 69 years old female with postoperative anatomical fracture reduction = Inclusion criteria. (C)+(D): fracture of a 72 years old female with postoperative varus malreduction of the humeral head = Exclusion criteria.

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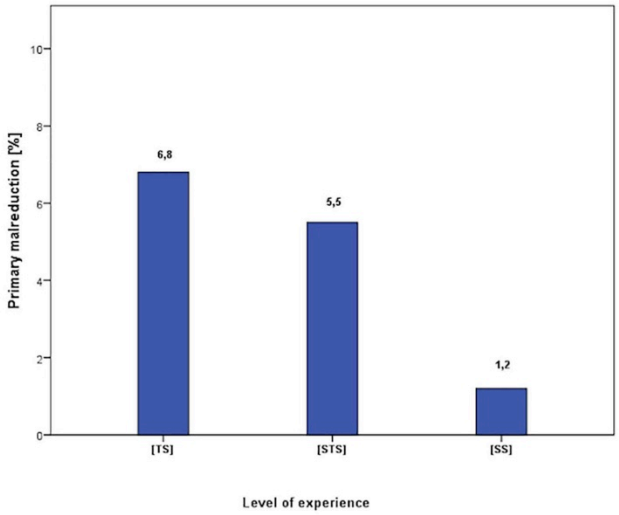

Fig 2. Distribution of primary malreduction and study exclusion rate.

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Of 265 patients with primary anatomic and overall acceptable fracture reduction, median age at time of surgery was 66.5±17.7 years, 95% Confidence Interval (CI) (65.2,69.5). N = 206 (77.6%) were female (p = 0.78). Distribution of age and gender was not significant between the groups (p = 0.32). The mean functional outcome (nCS) was 85.3±19.6, [TS] 79.6±22.2, [STS] 83.0 ±23.7, [SS] 93.3±13.5, [SS] group vs. others p = 0.01; p = 0.05, [TS] vs. [STS] p = 0.6. (Table 1, Fig 3) Complication resulted in the following distributions [TS] 11.3%, [STS] 11.7%, [SS] 7.8%, [SS] group vs. others p = 0.003; p = 0.01, [TS] vs. [STS] p = 0.83. Complications included loss of fixation with or without screw cut-out in n = 41 cases (15.5%, thereof: 5.8% [TS], 6.8% [STS], 2.2% [SS]). Avascular necrosis n = 4 (1.5%, thereof: 0.7% [TS], 0.7% [STS], 0% [SS]), posttraumatic frozen shoulder in n = 21 cases (7.9%, thereof: 3.2% [TS], 2.9% [STS], 1.4% [SS]) and hematoma in n = 9 cases (3.4%, thereof: 1.8% [TS], 1.4% [STS], 0.3% [SS]). Significance was only found in loss of fixation between [SS] and [STS] (p = 0.04) and [TS] (p = 0.01). There was no case of deep infection or nerve injury. Revision surgery was necessary in [TS] 7.4%, [STS] 8.2%, [SS] 3.9%, [SS], group vs. others p>0.001, [TS] vs. [STS] p = 0.23 (Table 2). We distinguished absolute and relative indications for revision. All of the [TS]

Table 1. Averaged functional outcome between the three groups nCS [Points]. [CS] was significant superior in [SS] compared to the other groups.

nCS [Points]	p-value
[TS] 79.6±22.2 vs. [STS] 83.0 ±23.7	0.6
[TS] 79.6±22.2 vs. [SS] 93.3±13.5	*0.01*
[STS] 83.3 ±25.6 vs. [SS] 93.3±13.5	*0.05*

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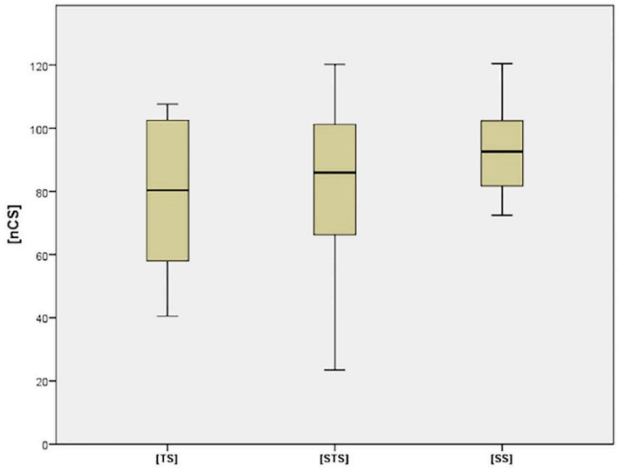

Fig 3. Distribution of the functional outcome (nCS).

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revisions were absolutely indicated due to screw cut-out or plate dislocation. In [STS] except for n = 2 (1,7%) moderate secondary displacements all others were absolutely indicated due to relevant secondary displacement, plate dislocations out of the shaft, screw cut-out or infection. All of the [SS] revisions were indicated relatively due to secondary displacement and were discussed critically with the patients. In total 73.7% of all revisions were absolutely indicated. None of the revised patients suffered from peri- or postoperative systemic or other critical harms. Except of n = 3 (15.8%) cases of frozen shoulder after revision surgery, all other patients' functional outcome benefited from surgery immediately.

Discussion

The main finding of this study is that quality of reduction and functional outcome following open reduction and internal fixation of a two-part surgical neck type proximal humeral fracture is related to the surgeon's experience. Surgeons with routine experience in shoulder surgeries (>50 cases per year) provide anatomic reduction more frequently, and patients achieve

Table 2. Averaged functional outcome between the three groups nCS [Points]. [CS] was significant superior in [SS] compared to the other groups.

Complications [%]	p-value
[TS] 11.3 vs. [STS] 11.7	0.83
[TS] 11.3 vs. [SS] 7.8	*0.003*
[STS] 11.7vs. [SS] 7.8	*0.01*
Revisions [%]	**p-value**
[TS] 7.4 vs. [STS] 8.2	0.23
[TS] 7.4 vs. [SS] 3.9	*>0.001*
[STS] 8.2 vs. [SS] 3.9	*>0.001*

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better functional outcomes. In turn, complications are less frequently observed compared to patients treated by surgeons with less experience in shoulder surgery.

In order to discover predictive factors for a successful treatment of proximal humeral fractures, currently, most studies investigate on a variety of patients- and fracture-specific variables i.e. age, bone quality, medial hinge disruption. [12–14]. However, when it comes to open reduction and internal fixation, the surgeon might be another variable of interest. Anatomic reduction has shown to be important in order to facilitate for a good outcome, and complications are less likely if the fracture was reduced anatomically [11]. However, fracture reduction is technically demanding and sometimes every surgeon struggles to achieve so. Gaining more experience in surgical treatment of proximal humeral fractures, thereby increasing the knowledge of typical problems, specific patterns and improving reduction skills, may lead to more accurate operative results. In comparison to distal radial fractures and hip fractures, however, the role of the surgeon's experience as a potential factor influencing the quality of reduction and the patients' outcome in proximal humeral fracture treatment was largely unknown, until now. [12–14].

Anatomic reduction was achieved by trauma surgeons [TS] in 87.9% of cases. In comparison, trauma surgeons with >2years experience following their training [STS] achieved anatomic reduction in 91.2%. Thus, more experienced surgeons provided anatomic reduction more often. However, the rate of complications was 11.3% [TS] vs. 11.7%. [STS]. One reason could be, that uncomplicated fracture healing may not only depend on anatomic reduction. Implant position, meticulous screw placement and respect to the periosteal sleeve tissue may also be important factors to avoid complications. Patients showed better functional outcomes if the surgery was conducted by a trauma surgeon performing >50 shoulder surgeries per year [SS]. In comparison, the shoulder function was inferior, when the fracture was treated by a surgeon performing shoulder surgeries less frequently, [SS] 93.3 points normalized Constant-Score vs. [TS] 79.6 points vs. [STS] 83.0 points. Some could argue, that other factors such as management of the long head of biceps tendon and of concomitant rotator cuff tear may influence the functional outcome in a relevant manner as well. However, we may not conclude whether anatomic reduction by itself, or other reasons are responsible for the functional outcome, yet, the functional outcome may be multifactorial. The present study is not able to provide a statement about a minimum number of shoulder surgeries to achieve the results of the [SS] group. Authors' opinion is not to need a fixed number of ORIF's of proximal humeral fractures per year, but rather an eye for appearing concomitant injuries as mentioned above. Not only to operate the bone but also to consider all aspects of the injury might be a key factor for better functional outcome.

We evaluated the impact of surgeon's experience at an educational based university hospital level 1 trauma centre, where surgeons have different experience with fracture treatment of the proximal humerus. For this study, we emphasised on homogeneity in order to reduce potential bias. Although every surgeon has an individual educational training, treatment protocols were institutionally standardized. Thus, we propose, that preoperative diagnostic, the intraoperative setting as well as implants were comparable and patients received the same rehabilitation protocol.

We excluded multisegmental three- and four-part fractures as well as head-split type fractures and fracture dislocation from this study. This was also done for the reasons of comparability. Patients with three- and four-part fracture and head-split type fractures are treated much more individually at our institution, including additive screws, suture cerclage or double plating. Furthermore, patients suffering from a fracture involving the tubercula receive different rehabilitation protocols compared to patients with a two-part fracture of the surgical neck at our institution. We suggest that complex fractures are technically even more demanding

and differences between surgeons may be even more distinguishing with respect to their experience. However, surgical neck fractures of the proximal humerus can be highly unstable and are commonly treated by fracture repair.

Besides its retrospective design, this study has several limitations. There was no control group, and a power analysis was not performed. The data are based on a register of surgically treated proximal humeral fractures. A nonoperative control group would be reasonable for further studies. Nevertheless, the study population was larger than that in comparable previous studies and was focused exclusively on proximal humerus fractures involving the surgical neck. Fractures were treated by open reduction and internal fixation with the use of locking plates. Therefore, no information can be given for closed reduction or other fixation techniques. Closed reduction and intramedullary nailing may be advantageous in the treatment of two-part surgical neck type fractures. However, locked plating is an established treatment for such fractures and is performed most frequently.

Conclusion

Surgeon's experience has impact on quality of reduction, rate of complication as well as on patient outcome following open reduction and internal fixation of two-part surgical neck type humeral fractures. Outcomes are in favour if the surgery is performed by a trauma surgeon performing >50 shoulder surgeries per year.

Author Contributions

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Therapie der akuten AC-Gelenk-Instabilität

Eine Metaanalyse arthroskopischer/minimal-invasiver vs. offener Verfahren

Die zur Verfügung stehenden operativen Verfahren zur Behandlung der akuten Akromioklavikular(AC)-Gelenkinstabilität sind vielfältig und variantenreich. Es sind über 150 verschiedene Operationstechniken zur Versorgung der AC-Gelenk-Verletzung beschrieben. Jedes dieser Verfahren bietet spezifische Vor- und Nachteile und keine dieser Techniken wird als Goldstandard akzeptiert. Die Vielfalt der beschriebenen operativen Verfahren erschwert einen Vergleich arthroskopischer mit konventionell-offenen Techniken. Ziel dieser systematischen, metaanalytischen Auswertung ist es daher, die Evidenz für ein arthroskopisches oder offenes Verfahren zur Behandlung der akuten AC-Gelenk-Instabilität zusammenzufassen.

Hintergrund

Zu mehreren grundsätzlichen Fragen im Management der AC-Gelenk-Verletzung wurde kürzlich in wichtigen Übersichtsarbeiten Stellung bezogen: Auf Grundlage der gängigen Rockwood-Klassifikation [1] wurde eine operative Behandlung für den horizontal instabilen Typ III (als IIIb bezeichnet) und die Typen IV und V empfohlen [2]. Außerdem wurde die akute AC-Gelenk-Verletzung als ≤3 Wochen zurückliegend definiert [3].

Dennoch steht der behandelnde Chirurg weiterhin dem Problem der Verfahrenswahl gegenüber. Unter der Vielfalt der Operationstechniken zeigten in den letzten Jahren insbesondere arthroskopische Verfahren zur Stabilisierung der korakoklavikulären (CC)-Bänder eine rasante Entwicklung [4–17]. Gründe für die große Popularität und die steigenden Anwenderzahlen dieser Operationsverfahren sind die minimale Invasivität, das einzeitige Versorgungskonzept sowie die simultane Identifikation und Behandlung glenohumeraler Begleitverletzungen [18–22].

Studiendesign und Untersuchungsmethoden

Zwei Reviewer führten unabhängig eine Literaturrecherche in den medizinischen Datenbanken MEDLINE und Embase durch, bei der Publikationen aus dem Zeitraum November 2004 bis November 2014 erfasst wurden. Folgende Suchbegriffe wurden definiert: „AC-Joint" OR „acromioclavicular joint" OR „acromioclavicular joint". Im nächsten Schritt wurde diese Datenbankrecherche um die folgenden zweiten Suchbegriffe erweitert: „dislocation" OR „rupture" OR „ruptures" OR „ruptured" OR „separation" AND „arthroscopic*" OR „arthroscopy" OR „minimally invasive" OR „open" OR „plate" OR „treatment" (Abb. 1). Danach erfolgte die inhaltliche Bewertung der ermittelten Studien durch die beiden Reviewer; zunächst anhand des Abstracts und nachfolgend durch die Volltextanalyse. Ausgeschlossen wurden Arbeiten, die im Untersuchungskollektiv nichtakute AC-Gelenk-Verletzungen (>3 Wochen) behandelten [23], Arbeiten zu Revisionsverfahren, biomechanische, anatomische und experimentelle Studien, andere Metaanalysen und Übersichtsartikel, Arbeiten, die offene gegen offene oder arthroskopische gegen arthroskopische Techniken oder konservative gegen operative Therapie verglichen, Arbeiten mit vorläufigen Ergebnissen und Studien mit dem Evidenzlevel V [24]. Zudem wurden die Quellenangaben der eingeschlossenen Artikel auf weiterführende Artikel hin evaluiert [25]. Der Einschluss einer Arbeit in die Metaanalyse wurde unter Berücksichtigung des vom Cochrane Handbook for Systematic Reviews of Interventions, Version 5.0.2 empfohlenen Bias-Tool vorgenommen.

Datenauswertung und Outcomeparameter

Die Daten wurden durch 2 unabhängig Reviewer (TH, FH) standardisiert erfasst. Auswertungskonflikte wurden im Konsensusverfahren gelöst. Die eingeschlossenen Studien wurden hinsichtlich des Operationsverfahrens und nach Evidenzlevel charakterisiert [24]. Aufgrund der Fragestellung erfolgte fortan eine Differenzierung der Auswertung in komparative Studien, die ein offenes mit einem arthroskopischen/minimal-invasiven Verfahren verglichen und in nicht-komparative Studien dieser beiden Techniken. Die in den Arbeiten gewählten primären und sekundären Outcomeparameter wurden evaluiert und entsprechend ihrer Verteilung und Häufigkeit untersucht (Tab. 1). Es ergaben sich folgende für die Metaanalyse geeignete Parameter (Tab. 1):

- funktionelles Ergebnis gemessen mit dem Constant-Score,

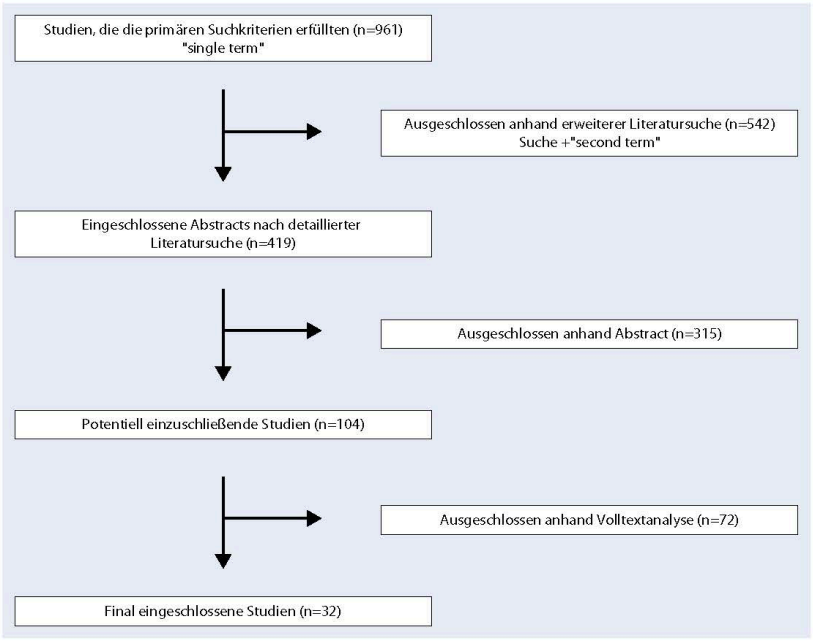

Abb. 1 ◀ Flussdiagramm für den Studieneinschluss

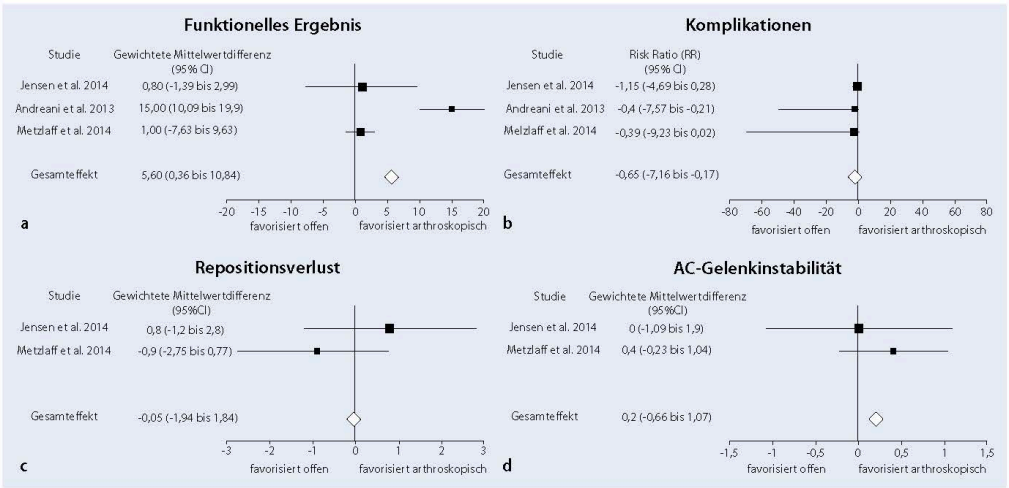

Abb. 2 ▲ Komparative Studien in Bezug auf **a** funktionelles Outcome gemessen anhand des Constant-Score, **b** Komplikationen, **c** Repositionsverlust quantifiziert im Röntgenbild mittels CC-Differenz, **d** AC-Gelenk-Instabilität. [9, 28, 29]. *CC* korakoklavikulär, *CI* Konfidenzintervall

- Komplikationen im Behandlungsverlauf,
- Repositionsverlust gemessen an der radiologisch ermittelten CC-Differenz und
- die AC-Gelenk-Instabilität gemessen am Taft-Score.

Statistische Auswertung

Dichotome Variablen wurden mittels gewichteter Mittelwertdifferenz für numerische Variablen oder als „risk ratio" (RR)

für kategorische Variablen ausgedrückt. Wenn die Standardabweichung nicht beschrieben war, wurde diese nach Ma et al. [26] kalkuliert. Wenn weder Mittelwert noch Standardabweichung aufgeführt waren, wurden diese nach Hozo et al. [27] berechnet. Metaregression und Subgruppenanalysen wurden nicht berücksichtigt. Das Signifikanzniveau lag bei $p \leq 0{,}05$.

Ergebnisse der Literatursuche

Anhand der Datenbankanalyse wurden nach primärer Suche 961 Artikel identifiziert. Unter Verwendung der erweiterten Suche wurden 542 Arbeiten ausgeschlossen. Nach Durchsicht der Abstracts dieser Studien wurden gemäß den definierten Kriterien 315 Arbeiten ausgeschlossen. Einer Volltextanalyse wurden 104 Artikel unterzogen, von denen 32 Arbeiten in die finale Analyse eingingen (**Abb. 1**). Drei Studien zu offenen vs. arthroskopischen/minimal-invasiven Verfahren hatten ein komparatives Design und waren daher für die nachfolgende Metaanalyse geeignet (**Tab. 2**). Für eine systematische Übersicht wurden 11 Arbeiten zu arthroskopischen und 18 zu offenen Operationsverfahren identifiziert (**Tab. 3** und **4**). Alle eingeschlossenen Arbeiten wurden auf ihren Evidenzlevel gemäß der etablierten Oxford-Klassifikation überprüft [24]. Für die komparativen Arbeiten wurde ein Evidenzlevel III, für alle anderen Arbeiten ein Evidenzlevel IV ermittelt. Höherwertig einzustufende Arbeiten konnten nicht identifiziert werden.

Komparative Studien

Die 3 eingeschlossenen komparativen Arbeiten zeigten eine akzeptable Homogenität in Bezug auf die demographischen Daten (**Tab. 2**). In Summe wurden 69 Patienten arthroskopisch/minimal-invasiv und 59 offen versorgt [9, 28, 29]. Das mittlere Alter der Kollektive betrug 35,7 ± 6,6 Jahre. Das mittlere Follow-up beider Kollektive wurde nur in einer Studie differenziert angegebenen. Alle offenen Verfahren verwendeten eine Hakenplatte (Fa. Synthes & AAP). Die Materialentfernung erfolgte in 2 Studien regelhaft und im Mittel nach 11,9 bzw. 12 Wochen, in einer Arbeit wurde eine Plattenentfernung bei nur 3 Patienten (33 %) durchgeführt [28]. In Bezug auf die arthroskopischen/minimal-invasiven Verfahren wurde in einer Arbeit ein doppelbündiges Fadenankersystem verwendet [9] und in zwei Arbeiten ein singuläres Faden-Suture-Button-System untersucht [28, 29]. In einer Studie [28] wurde zusätzlich eine temporäre transkutane K-

Zusammenfassung · Abstract

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Therapie der akuten AC-Gelenk-Instabilität. Eine Metaanalyse arthroskopischer/minimal-invasiver vs. offener Verfahren

Zusammenfassung

Hintergrund. Die operativen Verfahren zur Behandlung der akuten Akromioklavikular(AC)-Gelenk-Instabilität sind vielfältig. Neben den offenen Techniken finden zunehmend arthroskopisch gestützte Verfahren Anwendung. Jedes Vorgehen bietet spezifische Vor- und Nachteile, bisher hat sich jedoch keines als Goldstandard durchgesetzt.

Fragestellung. Ziel dieser systematischen, metaanalytischen Auswertung war es daher, die vorhandene Evidenz für arthroskopische und offene Operationstechniken zusammenzufassen.

Material und Methode. Entsprechend dem Cochrane Handbook for Systematic Reviews of Interventions wurde eine Literaturrecherche in den medizinischen Datenbanken MEDLINE und Embase über den Zeitraum der letzten 10 Jahre durchgeführt.

Ergebnisse. Von 961 Studien wurden 32 Arbeiten in diese Übersichtsarbeit aufgenommen. Drei Arbeiten eigneten sich für eine metaanalytische Auswertung. Die arthroskopischen bzw. minimal-invasiven Techniken zeigten tendenziell bessere funktionelle Ergebnisse anhand des Constant-Scores (gewichtete Mittelwertdifferenz 5,60; 95%-Konfidenzintervall 0,36–10,64). Hinsichtlich Komplikationsrate, Repositionsergebnis und AC-Gelenk-Instabilität zeigte sich kein signifikanter Unterschied.

Schlussfolgerungen. Bei inkonsistenter Studienlage gibt es keine Evidenz für eine Überlegenheit offener oder arthroskopischer/minimal-invasiver Verfahren. Um herauszufinden, ob die arthroskopische Versorgung zu einem signifikant besseren funktionellen Behandlungsergebnis führt, sind vergleichende Studien mit randomisiertem, kontrolliertem Design notwendig.

Schlüsselwörter
Verfahrenswahl · Arthroskopie · Offene Verfahren · Rockwood-Klassifikation · Akromioklavikulargelenk

Therapy of acute acromioclavicular joint instability. Meta-analysis of arthroscopic/minimally invasive versus open procedures

Abstract

Background. A variety of surgical procedure are desrcibed for the treatment of acute acromioclavicular (AC-) joint injuries. Beside open techniques arthroscopic assisted procedures spread widely. Each surgical technique offers advantages and disadvantages, but none is currently accepted as a gold standard. Therefore, the study aims to review the evidence for arthroscopic and open surgical procedures in the treatment of acute AC joint instabilities.

Material and methods. According to the Cochrane Handbook for Systematic Reviews of Interventions we conducted a defined search of Medline and Embase database for articles publisher over the last ten years.

Results. The search resulted in 961 studies of which 32 were included in this review and 3 studies were suitable for a meta-analysis. The functional outcome (Constant score) showed a tendency towards better results after arthroscopic procedures (weighted mean difference 5.60, 95 % confidence interval 0.36–10.64). There were no significant differences with respect to complication rates, secondary dislocation in the vertical plane, revision surgery and AC joint instability.

Conclusion. There is insufficient evidence to inform the surgical management of acute AC joint instability. Due to inconsistent study designs there is no evidence for a general superiority of any of the open or arthroscopic procedures. Randomized, controlled studies are necessary to demonstrate whether arthroscopic techniques show a potential benefit in terms of a better functional outcome.

Keywords
Surgical management · Arthroscopy · Open procedures · Rockwood classification · Acromioclavicular joint

Tab. 1 Übersicht der in den eingeschlossenen Studien untersuchten Parameter

	Offen vs. ASK	Andreani et al., 2014 [28]	Metzlaff et al., 2014 [29]	Jensen et al., 2014 [9]	*ASK*	Beris et al., 2013 [31]	Li et al., 2013 [32]	Liu et al., 2015 [13]	Venjakob et al., 2013 [16]	El Sallakh et al., 2012 [33]	Scheibel et al., 2011 [15]	Cohen et al., 2010 [34]	Petersen et al., 2010 [35]	Salzmann et al., 2010 [36]	Wei et al., 2010 [37]	Murena et al., 2009 [38]	*Offen*	Cerciello et al., 2014 [39]
Funktionelle Scores																		
Constant-Score		x	x	x		x	x	x	x	x	x	x	x	x	x	x		x
VAS				x		x	x		x					x	x			x
DASH-Score						x												
TAFT-Score			x	x							x							
SST-Score				x					x					x				
SSV-Score											x							
SF-36-Score									x					x				
UCLA-Score		x																
ACJI-Score			x								x							
ASES-Score																		
Bildgebung																		
Panorama/Zanca		x	x	x			x		x		x		x	x				x
CC-Differenz			x	x							x					x		
Alexander-Aufnahme			x								x							
Sonographie				x														
Klinisch																		
Komplikationen		x	x	x		x	x	x	x	x	x	x	x	x	x	x		x
ROM										x	x	x			x			
Rückkehr zum Sport								x										

Tab. 1 Übersicht der in den eingeschlossenen Studien untersuchten Parameter (Fortsetzung)

	Chen et al., 2014 [40]	Ye et al., 2014 [50]	Verdano et al., 2012 [49]	Sandmann et al., 2012 [41]	Liu et al., 2012 [42]	El Shewy et al., 2011 [43]	Kienast et al., 2011 [44]	Lädermann et al., 2011 [45]	Salem et al., 2009 [55]	Shin et al., 2009 [56]	Choi et al., 2008 [52]	Greiner et al., 2009 [46]	Koukakis et al., 2008 [53]	Law et al., 2007 [54]	Wang et al., 2008 [48]	Dimakopoulos et al., 2006 [47]	Ryhänen et al., 2006 [51]	*Auftreten des Parameters (%)*
Funktionelle Scores																		
Constant-Score	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		96,9%
VAS		x		x			x	x										34,4%
DASH-Score			x	x				x				x						15,6%
TAFT-Score							x											12,5%
SST-Score			x															12,5%
SSV-Score												x						6,3%
SF-36-Score																		6,3%
UCLA-Score						x												6,3%
ACJI-Score																		6,3%
ASES-Score				x		x												6,3%
Bildgebung																		
Panorama/Zanca			x	x	x			x		x		x	x	x		x		56,3%
CC-Differenz				x			x			x		x		x				28,1%
Alexander-Aufnahme				x														9,4%
Sonographie																		3,1%
Klinisch																		
Komplikationen	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	100%
ROM												x					x	18,8%
Rückkehr zum Sport																	x	6,3%

ASK arthroskopisch, *VAS* visuelle Analogskala, *DASH* „disabilities of the arm, shoulder and hand", *SST* „simple shoulder test", *SSV* „subjective shoulder value", *SF-36* „short form 36", *UCLA* University of California, Los Angeles, *ACJI* „acromioclavicular joint instability", *ASES* American Shoulder and Elbow Surgeons, *CC* korakoklavikulär, *ROM* „range of motion".

Tab. 2 Übersicht über die eingeschlossenen komparativen Studien

Studie	Studiendesign, Evidenzlevel	Verfahren	Verletzungstyp nach Rockwood	Patientenanzahl		Mittleres Alter (J)	Mittleres Follow-up (M)	
				Offen	ASK		Offen	ASK
Andreani et al. 2014 [28]	Retrospektive Kohortenstudie, III	SingleTightRope®, Fa. Arthrex + 3 Wochen temporäre K-Drähte vs. Hakenplatte (LCP-HP, Fa. Synthes)	IV–VI	9	19	32,3	24	
Metzlaff et al. 2014 [29]	Retrospektive Kohortenstudie, III	MINAR®, Fa. Carl Storz vs. Hakenplatte (Dreithaler plate, Fa. AAP)	III – V	20	24	37,6	32	
Jensen et al. 2014 [9]	Retrospektive Kohortenstudie, III	Doppel TightRope®, Fa. Arthrex vs. Hakenplatte (LCP-HP, Fa. Synthes)	III + V	30	26	39	48	17
Total				59	69			

J Jahre, *M* Monate, *W* Wochen, *ASK* arthroskopisch/minimal-invasiv.

Tab. 3 Übersicht über die eingeschlossenen Studien mit arthroskopischen/minimal-invasiven Verfahren

Studie	Evidenzlevel	Verfahren	Typ (RW)	Patientenanzahl	Mittleres Alter (J)	Mittleres FU (M)	Constant-Score	Komplikationen
Beris et al. 2013 [31]	CS, IV	Doppel TightRope®, Fa. Arthrex	III, IV	12	27,5	18,3	94,8	Keine
Li et al. 2013 [32]	CS, IV	Doppeltes Suture Button System (n.a.), AC Augmentation mit Nahtanker	IV, V	10	46,4	33,6	92,4	Keine
Liu et al. 2015 [13]	CS, IV	Flip button/polyethylene belt, Fa. Aesculap	III-V	12	48	24	92	Einmal Redislokation, einmal Korakoidfraktur
Venjakob et al. 2013 [16]	CS, IV	Doppel TightRope®, Fa. Arthrex	III-V	23	–	58	91,5	2-mal dorsale Subluxation
El Sallakh et al. 2012 [33]	CS, IV	SingleTightRope®, Fa. Arthrex	IV, V	10	30	24	96,3	Einmal Repositionsverlust bei Implantatversagen
Scheibel et al. 2011 [15]	CS, IV	Doppel TightRope®, Fa. Arthrex	V	28	38,6	26,5	91,5	Keine
Cohen et al. 2010 [34]	CS, IV	SingleTightRope®, Fa. Arthrex	III, IV	16	38	12	91	2-mal partieller Repositionsverlust bei Buttonmigration
Petersen et al. 2010 [35]	CS, IV	Doppeltes MINAR®, Fa. Carl Storz	III-V	23	–	23,3	94,1	2-mal Repositionsverlust, einmal Schmerzen bei Sport
Salzmann et al. 2010 [36]	CS, IV	Doppel, TightRope®, Fa. Arthrex	III-V	23	38,5	30,6	94,3	2-mal Implantatversagen (Korakoidfraktur und Buttondislokation)
Wei et al. 2010 [37]	CS, IV	V-förmige tripleEndobutton-Konstruktion, Acufex®, Fa. Smith & Nephew)	III-V	15	42,8	12	91,3	2-mal Schmerzen und leichte ROM ↓
Murena et al. 2009 [38]	CS, IV	Fibrewire®, Fa. Arthrex-Endobutton (Acufex®, Fa. Smith & Nephew)-System	III-V	16	33,3	31	97	4-mal partieller Repositionsverlust durch Buttonmigration

RW Rockwood, *J* Jahre, *FU* Follow-up, *M* Monate, *CS* „case series", *CC* korakoklavikulär, *ROM* „range of motion".

Draht-Arthrodese des AC-Gelenks für initiale 3 Wochen durchgeführt.

Alle 3 Arbeiten ermittelten und quantifizierten das funktionelle Ergebnis mittels Constant-Score und eine Arbeit zusätzlich den UCLA-Score (University of California, Los Angeles [28]). Zwei Arbeiten erfassten anhand von Röntgenbildern die CC-Differenz als Maß des Repositionsergebnisses [9, 29]. Die horizontale Instabilität wurde in allen 3 Studien quantifiziert: In einer Arbeit [29] mittels Alexander-Aufnahme [30] in einer anderen durch sonographische Untersuchung [9] und in einer dritten klinisch [28]. Zwei Arbeiten erhoben zusätzlich den Taft-Score. Sämtliche Arbeiten berichteten über aufgetretene Komplikationen (**Tab. 1**).

Für das funktionelle Outcome, gemessen anhand des Constant-Score, ergab sich durch eine gewichtete Mittelwertdifferenz von 5,6 mit einem 95%-Konfidenzintervall (CI) von 0,36 bis 10,84 (Heterogenitätskoeffizient $p = 0{,}72$) ein nichtsignifikanter Vorteil für die arthroskopischen Verfahren. Die Analyse der Komplikationen erfolgte durch Kalkulation des relativen Risikos (RR) und ergab mit einer Mittelwertdifferenz von -0,65 mit einem CI von -7,16 bis -0,17 (Heterogenitätskoeffizient $p = 0{,}237$) keinen relevanten Vorteil für eines der Verfahren. Ähnliche Ergebnisse zeigten sich für den postoperativen Repositionsverlust mit einer Mittelwertdifferenz von -0,05 und einem 95%-CI von -1,94 bis 1,84 (Heterogeni-

tätskoeffizient $p=0{,}96$). Für die AC-Gelenknstabilität gemessen mit dem Taft-Score ergab sich ebenfalls kein signifikanter Unterschied zwischen beiden Verfahren bei einer gewichteten Mittelwertdifferenz von 0,2 mit einem CI von -0,66 bis 1,07 (Heterogenitätseffizient $p=1{,}72$). In **Abb. 2** sind die Ergebnisse der einzelnen Analysen in Form von Forest-Plots dargestellt.

Fallserien

Arthroskopische Studien

Unter den 11 eingeschlossenen arthroskopischen Studien [13, 15, 16, 31–38] verwendeten die Autoren in 3 Studien ein einfaches Faden-Endobutton-System, in 7 ein doppeltes und in einer ein Triple-Endobutton-System (**Tab. 3**). Das mittlere Follow-up dieser Arbeiten betrug zwischen 12 und 58 Monaten. Alle Arbeiten quantifizierten das funktionelle Ergebnis mittels Constant-Score, eine Arbeit zusätzlich die AC-Gelenkinstabilität mittels Taft- und ACJI-Score („acromioclavicular joint instability" [15]). Eine bildgebende Quantifizierung der horizontalen Instabilität erfolgte nur in einer Studie [15]. Der Constant-Score erreichte im Mittel Werte zwischen 91 und 97, Komplikationen wurden zwischen 0 und 30% angegeben (**Tab. 1**). Der Repositionsverlust wurde nur in 2 Arbeiten anhand der mittleren CC-Differenz im Vergleich zur Gegenseite quantifiziert und betrug 1 [38] bzw. 4,2 mm [15].

Offene Verfahren

In den 18 Arbeiten zum offenen Verfahren [39–56] verwendeten die Autoren in 5 Fällen eine CC-Bandnaht/Cerclage ohne temporäre AC-Gelenkfixierung und 3-mal mit Fixierung, dabei einmal mit zusätzlichem korakoakromialem Bandtransfer, in 4 Fällen eine Hakenplatte (einmal n.n., 3-mal Fa. Synthes), in einem Fall eine mobile Gelenkplatte zur akromioklavikulären Stabilisierung, in einem Fall einen korakoklavikulären Haken (C-Hook), in einem Fall einen primären autologen Sehnentansfer, in einem Fall eine CC-Stabilisierung mit Nahtanker und in einem Fall eine Nahtankerfixierung mit zusätzlichem korakoakromialem (CA)-Band-Transfer. Das mittlere Follow-up dieser Arbeiten betrug zwischen 10 und 90 Monaten. In 88,9% der Studien wurde das funktionelle Ergebnis mittels Constant-Score quantifiziert, eine Arbeit ermittelte zusätzlich die AC-Gelenk-Instabilität mittels Taft-Score [44]. Der mittlere Constant-Score erreichte Werte zwischen 89 und 97,8. Komplikationen traten zwischen 0 und 69% auf (**Tab. 4**). Der CC-Abstand wurde in 5 Arbeiten untersucht, wobei dieser teilweise im Vergleich zur Gegenseite und über das gesamte follow-up [56] und in anderen Studien nur prä- und postoperativ erhoben wurde [44].

Diskussion komparative Studien

Die Metaanalyse der komparativen Studien ergab tendenziell bessere funktionelle Ergebnisse nach arthroskopischer Versorgung bei allen 3 Studien, wobei Andreani et al. [28] den größten funktionellen Unterschied zwischen beiden Verfahren aufzeigten (**Abb. 2**). In Zusammenschau der Arbeiten ergibt sich jedoch keine Signifikanz für den Vorteil eines Verfahrens ($p=0{,}723$, **Abb. 2**). Bei der Interpretation der Ergebnisse muss beachtet werden, dass sich die verwendeten Verfahren im Detail unterscheiden. Andreani et al. [28] verwendeten ein singuläres TightRope®-System in Kombination mit einer temporärer Arthrodese (2 Kirschner-Drähte) für 3 Wochen, und als offenes Verfahren eine Hakenplatte, die interessanterweise über den Zeitraum des Follow-up (24 Monate) in nur 3 Fällen (33,3%) entfernt wurde [28]. Jensen et al. [9] und Metzlaff et al. [29] beschrieben ein vergleichbares Studien-Setup, allerdings einmal mit doppeltem TightRope®-System und einmal mit singulärem minimalinvasivem MINAR® System. In den beiden letztgenannten Studien wurde routinemäßig die Materialentfernung der Hakenplatte durchgrführt.

Welchen Effekt die zusätzliche Verwendung einer zweiten CC-Fixierung bzw. einer additiven AC-Gelenk-Fixierung auf das funktionelle Ergebnis hat, lässt sich anhand der verfügbaren Studienlage nicht beantworten. Aktuelle biomechanische Arbeiten zeigen jedoch, dass bei doppelter Faden-Suture-Button-Fixierung eine zusätzliche transossäre Fadencerclage des AC-Gelenks die horizontale Stabilität der Versorgung deutlich verbessert [57].

Während für das funktionelle Ergebnis eine positive Tendenz für die arthroskopischen Verfahren identifiziert werden konnte, zeigte die Analyse der übrigen Parameter keine Favorisierung einer Operationstechnik. Komplikationen ereigneten sich in beiden Gruppen ohne signifikanten Unterschied zwischen den Verfahren. Folglich ist in der Gesamtschau kein Verfahren hinsichtlich der Komplikationsrate überlegen ($p=0{,}236$). Zur Ermittlung des Repositionsverlustes standen 2 Arbeiten zur Verfügung. Die Arbeit von Jensen et al. [9] zeigten nichtsignifikante Vorteile der arthroskopischen Verfahren zu ergeben, wohingegen die Ergebnisse von Metzlaff et al. [29] gleiches für die offenen Verfahren ergaben. Daher konnte auch im Rahmen der Metaanalyse kein signifikanter Vorteil eines Verfahrens gezeigt werden konnte ($p=0{,}962$).

Diskussion Fallserien

Die identifizierten Fallserien und Kohortenstudien lassen sich nicht in einer komparativen Weise auswerten, erlauben aber eine deskriptive Analyse. Insgesamt eigneten sich weniger Arbeiten zur arthroskopischen Versorgung für den Einschluss in diese Studie als Arbeiten zu offenen Verfahren. Dieses Ergebnis kann als Ausdruck der Versorgungsrealität interpretiert werden. Balke et al. [22] haben in einer nationalen Versorgungsstudie berichtet, dass die Mehrheit der Anwender im Bereich der Unfallchirurgie/Orthopädie eine Hakenplatte verwendete, während die Gruppe der Schulterspezialisten eher ein arthroskopischen Verfahren präferierte.

Interessant ist die große Varianz der offenen Versorgungstechniken. Diese unterscheiden sich in ihrem Vorgehen teilweise erheblich und erstrecken sich von einem primären Sehnentransfer zur Augmentation des readaptierten korakoakromialen Bandapparats [54] bis hin zu einer akromioklavikulären Stabilisierung mithilfe einer dynamischen Gelenkplatte ohne Adressierung des CC-Komplexes [42]. Im Gegensatz dazu steht eine vergleichs-

weise homogene Technik der arthroskopischen Versorgungen. Die hier beschriebenen Studien unterschieden sich letztendlich nur in der Anzahl der verwendeten Faden-Suture-Button-Systeme, wobei sich die verschiedenen Systeme zumindest nicht wesentlich unterscheiden.

Trotz dieser unterschiedlichen Operationsstrategien zwischen den Varianten der offen Versorgung und den arthroskopischen Techniken war die Spanne der funktionellen Ergebnisse beider Fallserienkollektive nahezu identisch, was sich überwiegend mit den Ergebnissen der komparativen Studien deckte. Eine erhebliche Schwierigkeit bei der Bewertung der unterschiedlichen Operationsverfahren ergibt sich durch die teilweise subjektive Bewertung und Definition der Komplikationen. Eine einheitliche Einteilung in schwere und leichte Komplikation fehlt, ist jedoch Voraussetzung, um die Sicherheit und Qualität eines Verfahrens im Vergleich mit anderen Techniken abschließend beurteilen zu können.

Diskussion der Studienlage

Aus 961 Studien, welche die primären Suchkriterien erfüllten, konnten nur 32 in die weitere Auswertung eingeschlossen werden. Dabei überschreitet keine dieser Studien den Evidenzlevel III. Entsprechend den Richtlinien für evidenzbasierte Medizin muss auch die vorliegende Metaanalyse daher dem Evidenzlevel IIc zugeordnet werden [24].

» Die untersuchten Outcomeparameter sind inkonsistent

Neben dem niedrigen Evidenzniveau der verfügbaren Studien fällt auf, dass die untersuchten Outcomeparameter inkonsistent sind. Nur 2 Parameter erwiesen sich als konsequent über den gesamten Untersuchungszeitraum erhoben:

- alle Studien erfassten die Komplikationen,
- das funktionelle Outcome wurde in 96,9 % der Arbeiten anhand des Constant-Scores angegeben.

Constant-Score

Viele nationale und internationale Gesellschaften entschieden sich vor etwa 15 Jahren für den Constant-Score [58] als ein Standardmessinstrument für die Schulterfunktion. Unter anderem durch diese Empfehlung, die weit verbreitete Anwendung und die gute wissenschaftliche Aufarbeitung ist der Constant-Score ein valides Mittel zur Beurteilung des funktionellen Outcome des Schultergelenks. Es muss jedoch kritisch diskutiert werden, ob der Constant-Score auch die Funktionseinschränkungen und Beeinträchtigung des Patienten mit AC-Gelenk-Verletzung adäquat erfasst. So zeigte sich in der Studie von Wang et al. [48] ein exzellentes funktionelles Ergebnis mit einem Constant-Score von 94,5/100 Punkten, obwohl die Autoren über 69 % relevante Komplikationen (K-Draht-Migration und Repositionsverlust) berichten. Erstaunlich ist in diesem Zusammenhang auch, dass nur eine Minderheit der Arbeiten [9, 15, 29, 44] die postoperative AC-Gelenk-Stabilität durch angemessene Scoringsysteme, wie z. B. den Taft-Score, quantifizierte.

Komplikationen

Obwohl alle Studien die Komplikationen erfassen, ist deren Definition inhomogen. Einige Arbeiten führen die Kalzifikation des CC-Bänder oder kosmetische Beeinträchtigung als Komplikation an [43, 49], während andere Autoren die Komplikationen vom postoperativen Serom bis zur verfahrensassoziierten Fraktur klar differenzieren [44].

Bildgebung

In Bezug auf die verwendete Bildgebung muss ebenfalls eine inhomogene Röntgendiagnostik zur Bestimmung der Verletzungsschwere und zur postoperativen Repositions- bzw. Stabilitätskontrolle festgehalten werden. Das ISAKOS Consensus Paper schlägt eine bilaterale Zanca- [59] bzw. Panorama- als eine der Standardaufnahmen zur Beurteilung des AC-Gelenks und zur Bestimmung der CC-Distanz vor [2]. Weitere Spezialaufnahmen, wie die Alexander- [30] oder Basamania-Aufnahme [60] wurden zur Beurteilung der horizontalen Instabilität empfohlen. Die Zanca- oder Panoramaaufnahme wurde jedoch nur in 56,3 % der Studien verwendet und Spezialaufnahmen nur in Ausnahmefällen (9 % [29, 41]), was verwunderlich ist, wenn die Qualität einer Operationstechnik zur AC-Gelenk-Stabilisierung evaluiert bzw. verglichen werden soll.

Zusammenfassend konnten wir in dieser Übersichtsarbeit eine Vielzahl offener und arthroskopischer Verfahren zur Behandlung der akuten AC-Gelenk-Instabilität identifizieren. Die meisten dieser Studien beschreiben postoperativ sehr gute funktionelle Ergebnisse. Es handelt sich jedoch überwiegend um Fallserien von niedrigem Evidenzlevel. Die Qualität dieser Studien ist aufgrund inhomogener und insuffizienter Outcomeparameter sowie unklarer Definition von Verfahrenskomplikationen oft gering. Es gibt keine wissenschaftliche Evidenz für die Überlegenheit eines bestimmten chirurgischen Verfahrens zur Therapie der akuten AC-Gelenk-Instabilität.

Fazit für die Praxis

- **Die operative Behandlung der akuten AC-Gelenk-Instabilität führt mit offenen und arthroskopischen Verfahren zu guten bis exzellenten Behandlungsergebnissen.**
- **Zum jetzigen Zeitpunkt gibt es keine Evidenz für die Überlegenheit eines bestimmten Verfahrens.**
- **Es gibt eine Vielzahl beschriebener chirurgischer Techniken zur Behandlung der akuten AC-Gelenk-Instabilität.**
- **Die vorhandenen Studien sind inhomogen in Bezug auf die untersuchten Zielparameter und die eingeschlossenen Patientenkollektive.**
- **Nur eine Minderheit der vorliegenden Studien zur operativen Behandlung der akuten AC-Gelenk-Instabilität quantifizierte im Follow-up die AC-Gelenk-Stabilität.**
- **Vorteile eines arthroskopischen Vorgehens sind möglicherweise ein tendenziell besseres funktionelles Ergebnis, die Option der Mitbehandlung glenohumeraler Begleitpathologien**

und das Fehlen einer obligaten Materialentfernung.

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Einhaltung ethischer Richtlinien

Interessenkonflikt. T. Helfen, G. Siebenbürger, B. Ockert und F. Haasters geben an, dass kein Interessenskonflikt besteht.

Dieser Beitrag enthält keine Studien an Menschen oder Tieren.

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Concomitant glenohumeral injuries in Neer type II distal clavicle fractures

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Abstract

Background: To identify the prevalence of concomitant glenohumeral injuries in surgically treated Neer type II distal clavicle fractures and relate its clinical importance.

Methods: Between 11/2011 and 11/2015 41 patients, suffering from a displaced and unstable distal clavicle fracture were included. 20 patients (group 1) received surgical treatment by means of plate osteosynthesis in combination with an arthroscopically assisted coraco-clavicular ligament augmentation. In group 2 ($n = 21$ patients) the fracture was treated by hooked plating solely, and diagnostic arthroscopy was conducted during hardware retrieval after the fracture had healed. All arthroscopies were performed in a standardized fashion, images were blinded retrospectively, and evaluated by two independent investigators.

Results: In total, concomitant glenohumeral pathologies were found in 26.8% of cases (41 patients, mean age 43.6 ± 16.6 years). In Group 1 ($n = 20$, arthroscopically assisted fracture treatment) the prevalence was 25%, in Group 2 ($n = 21$, diagnostic arthroscopy during implant removal) 28.5% ($p = 0.75$). Concomitant glenohumeral injuries included Labrum- and SLAP-tears, partial and full thickness rotator cuff tears as well as lesions to the biceps pulley system. Concomitant injuries were addressed in 2 patients of group 1 (10%, 2× labrum repair) and in 3 patients of group 2 (14.3%, of Group 2 (2× arthroscopic cuff repair of full thickness tear, 1× subpectoral biceps tenodesis in an type IV SLAP lesion, $p = 0.68$).

Conclusion: The present study could clarify the acute and for the first time mid-term implication and clinical relevance of concomitant glenohumeral injuries. They have been observed in averaged 27% of Neer type II distal clavicle fractures at these two times. However, the findings of this study show that not all concomitant lesions remain symptomatic. While lesions are still present after fracture healing, it's treatment may be depicted upon symptoms at the time of implant removal. In turn, early diagnosis and treatment of concomitant injuries seems reasonable, as untreated injuries can remain symptomatic for more than 6 months after the fracture and recovery may be delayed.

Keywords: Distal clavicle fracture, Concomitant injuries, Arthroscopic treatment, Osteosynthesis

Background

Fractures of the distal clavicle account for approximately 17% of all clavicle fractures [1]. For stable and non-displaced fractures conservative treatment leads to satisfactory outcome, however in unstable fractures surgical treatment is recommended [2]. Surgical treatment consists of closed or open reduction followed by fracture fixation, nevertheless, numerous surgical techniques have been described including k-wire, plating, hookplating or suture fixation.

Recently, arthroscopic assisted treatment of displaced distal clavicle fractures has been reported with the advantage of a minimal invasive approach, early recovery and good functional outcome. However, as arthroscopic assisted treatment is increasingly performed concomitant intraarticular glenohumeral pathologies are observed with distal clavicle fractures [3]. Most commonly, injuries involve the superior labrum anterior-posterior complex (SLAP), the biceps pulley or the rotator cuff and account for approximately 25–46% of cases.

Associated glenohumeral injuries have been described in acute distal clavicle fracture, as well as in dislocation of the acromioclavicular joint, however, the implication and clinical relevance in the treatment of distal clavicle

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fractures is yet unknown [4–6]. Purpose of this retrospective study was to evaluate the prevalence of concomitant injuries in surgically treated displaced distal clavicle fractures. Furthermore, glenohumeral lesions should be evaluated for clinical relevance. We hypothesised that the prevalence of concomitant injuries is similar when assessed during diagnostic arthroscopy of successfully healed distal clavicle fractures and would represent a pathology with clinical implication.

Methods

This retrospective study was conducted by approval of the local ethical board. Between November 2011 and November 2015, patients ≥18 years of age with a displaced fracture of the distal clavicle were included and surgically treated. Patients with a history of shoulder surgery or symptoms of glenohumeral pathology (instability, rotator-cuff tear, biceps tendon pathology) prior to the fracture event were excluded.

Fracture displacement was identified on standard radiographs in anterior-posterior as well as in Rockwood's view and were classified as described by Neer [2]. Patients were excluded if the fracture was non displaced or other than a Neer II type. All remaining patients were subsequent divided according to the received treatment in 2 groups.

In group 1 ($n = 20$) patients received surgical treatment by means of locked plating and arthroscopically assisted coracoclavicular fixation (Clavicle Fracture System, Arthrex®, Naples, USA). Arthroscopically assisted coracoclavicular fixation consisted of a thorough diagnostic arthroscopy through a standard posterior portal including 8 steps of imaging: After entrance into the glenohumeral joint by use of blunt trocar, the first view was the triangle formed by the long biceps tendon, the humeral head and the subscapularis tendon. 2nd view was onto the biceps origin and the superior labrum anterior-posterior (SLAP) complex. The biceps origin was manipulated using a probe in order to detect a SLAP lesion. 3rd and 4th views included the medial and lateral Pulley system, the superior glenohumeral ligament (SGHL) and the encircled long biceps tendon. Hereafter the articular surface of the glenoid and humerus and the medial gleno-humeral ligament (MGHL) were examined (5th view). The 6th view was on the supraspinatus tendon and the footprint in abduction and external rotation, while the 7th view was used to exclude infraspinatus tendon tears and avulsion of the teres minor or a posterior avulsion of the glenohumeral ligament (reversed HAGL). Finally, the 8th view was to assess the axillary recess for the presence of loose bodies, lesions to the inferior gleno-humeral ligament (IGHL) and HAGL lesions. Cartilage injury of the glenoid or the humeral head was evaluated for in all of 8 standard views. Subacromial arthroscopy was not performed in patients of group 1.

Patients of group 2 ($n = 21$) received open reduction and locking plate osteosynthesis with 3.5 mm Clavicle Hook Plate (LCP, DePuy Synthes®, Zuchwil, Switzerland). All patients of group 2 underwent diagnostic arthroscopy at the time of implant removal, which was then performed in the identical manner as described above. In addition, a subacromial arthroscopy was conducted prior to implant removal.

Patients of both groups were clinically and radiographically followed for 12 months. Functional outcome has been recorded and is presented by the Constant Score (CS), the Oxford Shoulder Score (OSS) and the abduction. Arthroscopic images were blinded retrospectively in order to eliminate interpretational bias by the surgeon or the physical examination. All images were evaluated independently by two investigators. Full thickness rotator cuff tears were classified according to Bateman [7], partial supraspinatus tendon lesions were classified in accordance to Ellman [8], subscapularis tendon lesions were further classified as described by Fox and Romeo [9]. Injuries of the superior labrum in relation to the biceps tendon anchor were classified according to Snyder et al. [6] and Maffet et al. [10] Lesions of the pulley system were classified as described by Habermeyer et al. [11]

Data was enrolled through Microsoft Excel 2010 (Microsoft, Redmond, WA), followed by a statistical analysis using IBM SPSS Statistics, version 25 (SPSS, Chicago, IL). Data are given in terms of the arithmetic mean and standard deviation. The study of Pauly et al. was used to estimate the power and sample Size [12]. The authors reported the prevalence of concomitant intra-articular pathologies following high-grade dislocation of the acromioclavicular (AC) joint with 15%. Based on these findings, a sample size of 35 is needed with a 95.0% confidence interval and a normal approximation of 0.150. Frequencies were calculated for ordinal data, and the χ^2 test was applied for group comparison. Rational data were described by mean and standard deviation. To compare the groups, analysis of variance and post hoc tests were used for parametric data, and the Mann-Whitney *U* test was used for nonparametric data. $P \leq .05$ was considered significant for differences in group comparison.

Results

Of 41 patients (mean age: 43.6 ± 16.6 years) with a Neer type II displaced fracture of the distal clavicle, concomitant glenohumeral pathologies were found in 11 patients (27%).

In Group 1 ($n = 20$, mean age: 53 ± 17.5 years, fracture pattern: Neer IIa $n = 3$, Neer IIb = 17) concomitant glenohumeral pathologies were detected in 5 patients (25%) during primary arthroscopically assisted treatment (Table 1). In

Table 1 Distribution and significance of concomitant injuries

Concomitant injury	Group 1[n]	Group 2[n]	*p*-value
SLAP-lesion	0 (0%)	1 (4.7%)	*1*
SSP-transmural tear	1 (5%)	2 (9.5%)	*1*
SSP-partial rupture	2 (10%)	3 (14.3%)	*1*
SSC partial rupture	0 (0%)	1 (4.7%)	*1*
Pulley lesion	0 (0%)	1 (4.7%)	*1*
Labrum lesion	2 (10%)	0 (0%)	*0.23*
Bursitis glenohumeral	0 (0%)	2 (9.5%)	*0.48*

Group 2 ($n = 21$, mean age: 39.7 ± 14.6, $p = 0.01$, fracture pattern: Neer IIa $n = 1$, Neer IIb = 20) glenohumeral pathologies were found in 6 patients (28.5%) during diagnostic arthroscopy at the time of hardware removal 6.7 ± 3.5 months following primary non-arthroscopic treatment. Concomitant glenohumeral injuries included SLAP-lesions, SSP transmural and partial lesions, SSC partial lesions as well as Pulley and Bankart lesions. (Table 1). Distribution of classification of the injuries is shown in Table 2.

A distinct treatment, other than debridement, was performed in 2 patients (10%, 2 x labrum refixation) of Group 1 and in 3 patients of group 2 (14.3%, 2× arthroscopic cuff repair, 1 x subpectoral biceps tenodesis in SLAP type IV). A characteristic example for the findings is shown in Fig. 1. Of group 2, 5 patients (23.8%) patients presented with ongoing clinical symptoms related to the glenohumeral finding. 1 patient (4.8%) showed a positive Jobe's Test (full thickness rotator cuff tear and 1 patient had a positive O'Brien's Test (SLAP type IV lesion). The last case is exemplary presented in Fig. 2. Three patients of group 2 (14.3%) complained of persisting subacromial impingement symptoms until hook plate removal, without glenohumeral finding.

Results of the CS and the OSS as well as the degrees of abduction are shown in Tables 3 and 4. Functional outcome parameters were mainly superior in group 1. Significance was given only in the overall abduction values regardless of concomitant injuries. In the subgroup of existing concomitant injuries of group 2 implant removal and late arthroscopy benefits the patients' functional outcome of all measured functional outcome parameters.

Table 2 Distribution of degrees of injuries according to their individual classification

Injury classification	Group 1	Group 2
SLAP-lesion *(Snyder)*	–	N = 1 *(VI)*
SSP transmural tear *(Bateman)*	N = 1 *(II)*[a]	N = 1 *(III)*
		N = 1 *(VI)*
SSP-partial rupture *(Ellman)*	N = 2 *(I)*[a]	N = 2 *(I)*a
		N = 1 *(II)*a
SSC partial rupture *(Fox/Romeo)*	–	N = 1 *(Ib)*a
Pulley lesion *(Habermayer)*	–	N = 1 *(II)*a
Labrum lesions	N = 2	–

[a]only arthroscopic debridement

Discussion

Fractures to the distal third of the clavicle represent 10–30% of all clavicle fractures and can be treated conservatively with satisfying outcome in the majority of cases. However, symptomatic non-union under conservative treatment exists and therefore, distal clavicle fractures with instability should be treated operatively, with respect to patient's age and functional demands. Over the last decades, surgical treatment of distal clavicle fractures developed from open reduction and fixation by k-wires, conventional plates or hook-plating to minimal invasive approaches and arthroscopically assisted fracture management. Arthroscopically assisted fracture fixation may be beneficial in terms of minimally invasive approach as well as assessment and treatment of associated glenohumeral lesions. While impaired functional outcome and prolonged pain was historically contributed to fracture non-union, several authors noted that other reasons for a limited shoulder function may be present [13]. In this context, due to an increase of arthroscopic assisted fracture treatment, concomitant glenohumeral lesions were observed more frequently and proclaimed as potentially causing shoulder dysfunction [14].

Beirer et al. detected concomitant intra-articular glenohumeral injuries in 13 of 28 patients (46.4%) with initially suspected isolated lateral clavicle fracture. Surgical treatment was performed in 8 of 28 cases (28.6%) of which superior-labrum-anterior-posterior (SLAP) lesions, injuries to the pulley-complex as well as rotator cuff tears were regarded as relevant injuries. The authors concluded that subsequent surgical treatment of these formerly missed but therapy-relevant injuries may increase functional outcome and reduce complication rate. However, several arthroscopic and imaging studies have shown that there are glenohumeral pathologies in otherwise asymptomatic patients. Tempelhof et al. showed a prevalence of rotator cuff tears in 13% of patients aged 50 to 59 years with an overall rate of 23% of all patients with asymptomatic shoulders [15].

In the present study glenohumeral injuries, concomitant to a displaced fracture of the distal clavicle were found in 27% of cases. This result supports the data of existing studies reporting of acute determined concomitant glenohumeral injuries in 25–46% of patients with distal clavicle fractures [3]. For the first time, our study showed that glenohumeral pathologies are not only observed during primary arthroscopic fracture treatment, but are also present more than 6 months thereafter. No study exists to show late arthroscopy findings in distal clavicle fractures. With the particular collective of

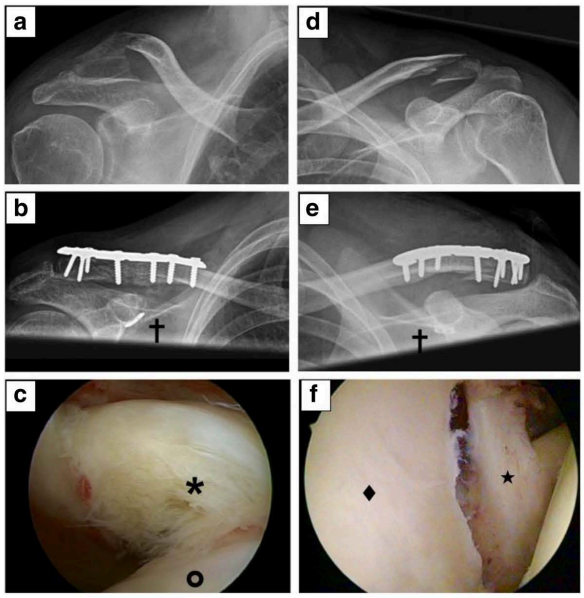

Fig. 1 Findings of Group 1 (initial arthroscopy). **a-c** 53 years old female with Neer type IIb fracture treated by plate osteosynthesis with coraco-clavicular augmentation [†]. **a** Preoperative x-ray. **b** Postoperative x-ray. **c** SSC Lesion (Fox/Romeo Ib) [✶] humeral head in front [O]. **d-e** 32 years old male with Neer type IIb fracture treated by plate osteosynthesis with coraco-clavicular augmentation [†]. **d** Preoperative x-ray. **e** Postoperative x-ray. **f** anterior Bankart Lesion [★], glenoid in the front[♦]

patients undergone late arthroscopy we could examine this issue.

Some concomitant injuries could potentially heal others are clinically irrelevant. In some cases this turns out only in the further course of healing. In 21 patients (group 2) of our study the fracture was treated non-arthroscopically, but diagnostic arthroscopy was conducted 6.7 ± 3.5 months thereafter and glenohumeral lesions were found in 6 patients (28.5%). Interestingly, this result was similar to patients of group 1 (25%) which shows that lesions may not dissolve over time. In contrast, not all patients that suffered from a glenohumeral lesion were symptomatic at that time. However, 2 patients were symptomatic and diagnostic arthroscopy revealed a full thickness rotator cuff tear. While both patients were asymptomatic before the fracture event there is little to judge, whether this cuff tear was a result of the trauma, or not. Nevertheless, Tempelhof et al. proclaim that there are certain parameters that may convent an asymptomatic rotator cuff tear into a symptomatic tear, however, for a fracture of the distal clavicle this remains speculative [16]. Symptoms may have been misinterpreted as unspecific subacromial impingement caused by the implant itself. One may argue that symptoms may have resolved with hardware removal alone.

There are several limitations of this study: First, the number of patients is low and the results may be biased due to a retrospective design. Secondly, patients were excluded if the fracture was not classified as Neer type II. Thus, this study does not evaluate the total amount of concomitant glenohumeral lesions in distal clavicle fractures. In fact, there may have be a selection bias because of the indication for an arthroscopically assisted approach with coracoclavicular ligament augmentation. However, we suggest that a Neer type IIb fracture represents a distal clavicle fracture with extensive tissue damage, to be distinguished from the more mild type I injuries, according to Neer himself [16]. During the period of study both implant types have been applied. In the early phase hook plate system dominated, later subsequently locked plating and arthroscopically assisted coracoclavicular fixation has become the method of choice. The study period implies a development process of the implants. For this reason we were unable to randomize and thus study is retrospective. Our preliminary and already published work regarding the used implants has demonstrated a tendency better functional outcome after the arthroscopically assisted osteosynthesis [17]. Therefore this treatment has become to our method of choice. The tendency of better functional outcome was further strengthened by this study.

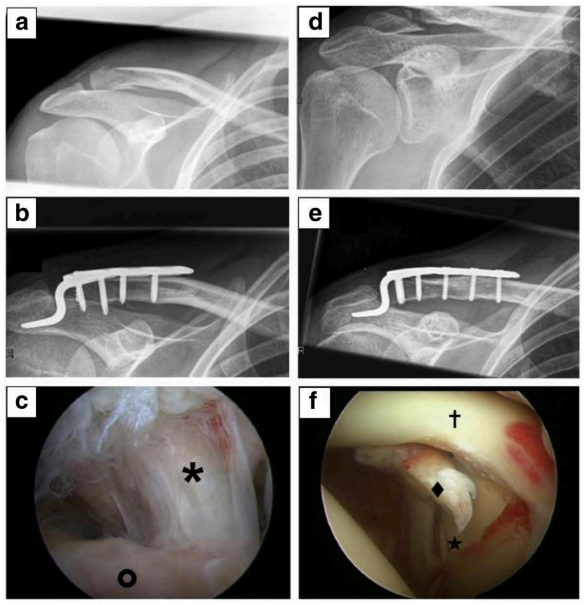

Fig. 2 Findings of Group 2 (late arthroscopy). **a-c** 40 years old male with Neer type IIb fracture treated by hook-plate osteosynthesis. **a** Preoperative x-ray. **b** Postoperative x-ray. **c** SSP transmural Lesion (Bateman III) [✶], footprint area in front [O]. **d-e** 24 years old male with Neer type IIb fracture treated by hook-plate osteosynthesis. **d** Preoperative x-ray. **e** Postoperative x-ray. **f** SLAP Lesion (Snyder IV) [♦], long biceps tendon[†], glenoid [★]

There is no recommendation such fractures to be referred only by arthroscopic experienced surgeons. However the awareness in case of persistent complaints either to perform an arthroscopically assisted implant removal or at least MRI-Imaging after implant removal is necessary. This treatment phase is not that critical of the time; priming of arthroscopically assisted implant removal should be possible.

Table 3 Functional outcome

	Group 1	Group 2	*[p]*
CS total	92.2 ± 5.6	90.6 ± 8.9	*0.49*
CS (-CI)	93.6 ± 4.9	90.9 ± 9.7	*0.33*
CS (+CI)	87 ± 4.9	88.8 ± 1.9	*0.43*
OSS total	46.9 ± 2.4	45.6 ± 4.9	*0.28*
OSS (-CI)	45.5 ± 5.6	47.4 ± 2	*0.23*
OSS (+CI)	44.8 ± 3.3	43.3 ± 6.7	*0.69*
CS (late)	–	90.8 ± 1.9	
OSS (late)	–	45.3 ± 4.6	

CS Constant Score, *(-CI)* without concomitant injuries, *(+CI)* with concomitant injuries, *OSS* Oxford Shoulder Score, *(late)* after late arthroscopy and surgical intervention

Conclusion

Concomitant intra-articular glenohumeral injuries in type Neer II distal clavicle fractures are not only observed during fracture treatment, but also 7 months thereafter in more than a quarter of cases. As glenohumeral lesions may not dissolve over time, diagnostic arthroscopy is recommended in cases were hardware removal is indicated and the patient is symptomatic. In turn, early diagnosis and treatment of relevant concomitant intra-articular glenohumeral injuries is reasonable, as delayed diagnosis and treatments might delay recovery. Whether or not glenohumeral pathologies concomitant to a distal clavicle fracture are of traumatic origin, however, remains uncertain.

Table 4 Range of Motion (Abduction)

	Group 1	Group 2	*[p]*
Abduction [°]	179 ± 3	172 ± 13	*0.02*
Abd [°] (-CI)	180 ± 2	174 ± 13	*0.06*
Abd [°] (+CI)	177 ± 4	163 ± 17	*0.15*
Abd [°] (late)	–	169 ± 9	

(-CI) without concomitant injuries, *(+CI)* with concomitant injuries, *(late)* after late arthroscopy and surgical intervention

Abbreviations
AC: Acromioclavicular; CS: Constant score; HAGL: Posterior avulsion of the glenohumeral ligament; IGHL: Inferior gleno-humeral ligament; LCP: Locking compression plate; LMU: Ludwig Maximilians University; MGHL: Medial gleno-humeral ligament; MRI: Magnetic Resonance Imaging; OSS: Oxford shoulder score; SGHL: Superior glenohumeral ligament; SLAP: Superior labrum anterior-posterior complex

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Availability of data and materials
The dataset used and analysed during the current study is available from the corresponding author on reasonable request.

Authors' contributions
TH: planning study, writing and ethic's approval; GS patients examination and scheduling; FH surgeon and statistics; WB surgron, consultation, proofreading; BO surgeon, idea to study, writing esp. discussion. All authors have read and approved the manuscript.

Ethics approval and consent to participate
This retrospective study was conducted by approval of the local ethical board (Ludwig Maximilians University, Munich (LMU) #232–11), participants gave their written content during follow-up.

Consent for publication
Not applicable

Competing interests
The authors declare that they have no competing interests.

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10. Appendix

10.1 Gesamtverzeichnis wissenschaftlichen Veröffentlichungen

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