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Klinik für Orthopädie und Unfallchirurgie

Klinik der Ludwig-Maximilians-Universität München

Etablierung einer multizentrischen Datenbank – Epidemiologie und klinisches Outcome von Tibiakopffrakturen: eine retrospektive Analyse und klinische Untersuchung der postoperativen Instabilität

Dissertation

zum Erwerb des Doktorgrades der Medizin

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vorgelegt von

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1. Affidavit

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Eidesstattliche Versicherung

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Ich erkläre hiermit an Eides statt, dass ich die vorliegende Dissertation mit dem Titel

**Etablierung einer multizentrischen Datenbank — Epidemiologie und klinisches Outcome von Tibiakopffrakturen:
eine retrospektive Analyse und klinische Untersuchung der postoperativen Instabilität**

selbständig verfasst, mich außer der angegebenen keiner weiteren Hilfsmittel bedient und alle Erkenntnisse, die aus dem Schrifttum ganz oder annähernd übernommen sind, als solche kenntlich gemacht und nach ihrer Herkunft unter Bezeichnung der Fundstelle einzeln nachgewiesen habe.

Ich erkläre des Weiteren, dass die hier vorgelegte Dissertation nicht in gleicher oder in ähnlicher Form bei einer anderen Stelle zur Erlangung eines akademischen Grades eingereicht wurde.

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2. Übereinstimmungserklärung

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Erklärung zur Übereinstimmung der gebundenen Ausgabe der Dissertation mit der elektronischen Fassung

Neidlein, Claas

Name, Vorname

Hiermit erkläre ich, dass die elektronische Version der eingereichten Dissertation mit dem Titel:

Etablierung einer multizentrischen Datenbank — Epidemiologie und klinisches Outcome von Tibiakopffrakturen:
eine retrospektive Analyse und klinische Untersuchung der postoperativen Instabilität

in Inhalt und Formatierung mit den gedruckten und gebundenen Exemplaren übereinstimmt.

München, 25.06.2025

Ort, Datum

Claas Neidlein

Unterschrift Claas Neidlein

3. Inhaltsverzeichnis

4. Abkürzungsverzeichnis

MUM	Muskuloskelettales Universitätszentrum München
LMU	Ludwig-Maximilians-Universität München
ORIF	Offene Reposition und interne Fixierung
TPF	Tibiaplateaufraktur
AO/OTA	Arbeitsgemeinschaft für Osteosynthesefragen
CT	Computertomographie
MRT	Magnetresonanztomographie
PTOA	Post-traumatic osteoarthritis

5. Publikationsliste

5.1 Publikationen der kumulativen Dissertation

Die folgenden Publikationen entstanden während meiner Forschungstätigkeit am Muskuloskelettalen Universitätszentrum München (MUM) in der Arbeitsgruppe von Herrn PD Dr. med. Julian Fürmetz. Die ersten beiden Publikationen sind Teil der kumulativen Dissertation.

5.1.1 Publikation 1

Bormann M*, **Neidlein C***, Gassner C, Keppler AM, Bogner-Flatz V, Ehrnthaller C, Prall WC, Böcker W, Fürmetz J. Changing patterns in the epidemiology of tibial plateau fractures: a 10-year review at a level-I trauma center. Eur J Trauma Emerg Surg. 2023 Feb;49(1):401-409. doi: 10.1007/s00068-022-02076-w. Epub 2022 Sep 3. PMID: 36057677.

*Markus Bormann and **Claas Neidlein** have contributed equally to this work

5.1.2 Publikation 2

Bormann M, **Neidlein C**, Neidlein N, Ehrl D, Jörgens M, Berthold DP, Böcker W, Holzapfel BM, Fürmetz J. High Prevalence of Persistent Measurable Postoperative Knee Joint Laxity in Patients with Tibial Plateau Fractures Treated by Open Reduction and Internal Fixation (ORIF). J Clin Med. 2023 Aug 27;12(17):5580. doi: 10.3390/jcm12175580. PMID: 37685647; PMCID: PMC10488731.

5.2 Publikationen zusätzlich zu der kumulativen Dissertation

Folgende Publikationen sind **nicht** Teil der Dissertation, werden aber dennoch erwähnt. Sie spiegeln den Aufwand wider eine Datenbank zu einer Frakturentität in einem großen universitären Zentrum wissenschaftlich zu beleuchten, um einen Beitrag für eine zukünftig bessere Versorgung von Patient:innen zu leisten.

5.2.1 Publikation 3

Bormann M, **Neidlein C**, Keppler AM, Prall WC, Böcker W, Fürmetz J. Einfluss der COVID-19-Pandemie auf die Frakturepidemiologie am Beispiel der Tibiaplateaufraktur [Influence of the COVID-19 pandemic on fracture epidemiology exemplified by tibial plateau fractures]. Unfallchirurgie (Heidelb). 2023 Dec;126(12):967-974. German. doi: 10.1007/s00113-022-01263-z. Epub 2022 Dec 28. PMID: 36576535; PMCID: PMC9795428.

5.2.2 Publikation 4

Neidlein C, Watrinet J, Pätzold R, Berthold DP, Prall WC, Böcker W, Holzapfel BM, Fürmetz J, Bormann M. Patient-Reported Outcomes following Tibial Plateau Fractures: Mid- to Short-Term Implications for Knee Function and Activity Level. J Clin Med. 2024 Apr 17;13(8):2327. doi: 10.3390/jcm13082327. PMID: 38673600; PMCID: PMC11051425.

5.2.3 Publikation 5

Bitschi D, Fürmetz J, Gilbert F, Jörgens M, Watrinet J, Pätzold R, Lang C, **Neidlein C**, Böcker W, Bormann M. Preoperative Mixed-Reality Visualization of Complex Tibial Plateau Fractures and Its Benefit Compared to CT and 3D Printing. J Clin Med. 2023 Feb 23;12(5):1785. doi: 10.3390/jcm12051785. PMID: 36902573; PMCID: PMC10002526.

5.2.4 Publikation 6

Bormann M, Bitschi D, **Neidlein C**, Berthold DP, Jörgens M, Pätzold R, Watrinet J, Böcker W, Holzapfel BM, Fürmetz J. Mismatch between Clinical-Functional and Radiological Outcome in Tibial Plateau Fractures: A Retrospective Study. J Clin Med. 2023 Aug 27;12(17):5583. doi: 10.3390/jcm12175583. PMID: 37685650; PMCID: PMC10488212.

5.2.5 Publikation 7

Hörmandinger C, Bitschi D, Berthold DP, **Neidlein C**, Schroeder L, Watrinet J, Pätzold R, Böcker W, Holzapfel BM, Fürmetz J, Bormann M. Lack of standardisation in the management of complex tibial plateau fractures: a multicentre experience. Eur J Trauma Emerg Surg. 2024 Aug 2. doi: 10.1007/s00068-024-02616-6. Epub ahead of print. PMID: 39095621.

5.2.6 Publikation 8

Watrinet J, Wenzel L, Fürmetz J, Augat P, Blum P, **Neidlein C**, Bormann M, Stuby F, von Rüden C. Möglichkeiten und Grenzen der intraoperativen 2D-Bildgebung in der Unfallchirurgie [Possibilities and limits of intraoperative 2D imaging in trauma surgery]. Unfallchirurgie (Heidelb). 2023 Dec;126(12):935-941. German. doi: 10.1007/s00113-023-01381-2. Epub 2023 Oct 23. PMID: 37870559.

6. Vorträge und Posterbeiträge auf Kongressen

Des Weiteren konnten zahlreiche Ergebnisse der Dissertation im Rahmen von Kongressen vorgestellt werden.

6.1 Vorträge

„**Influence of the corona pandemic on fracture epidemiology of tibial plateau fractures**” 11/2021 auf dem 10. Jahreskongress der Deutschen Kniegesellschaft in Leipzig

„**No difference in Complicationrate between External fixation and brace therapy in bicondylar tibial plateau fractures**” 10/2023 auf dem Deutschen Kongress für Orthopädie und Unfallchirurgie in Berlin

„**No difference in Complicationrate between External fixation and brace therapy in bicondylar tibial plateau fractures**” 11/23 auf dem 12. Jahreskongress der Deutschen Kniegesellschaft in Essen

6.2 Posterbeiträge

„**Patient reported outcome after surgical treated tibial plateau fracture – what can we expect**” 09/2022 auf dem 39. Jahreskongress der Gesellschaft für Arthroskopie und Gelenkchirurgie (Postervortrag)

7. Preise und Auszeichnungen

Auf dem 10. Jahreskongress der Deutschen Kniegesellschaft in Leipzig wurden Teile meiner Dissertation bei der Verleihung des Wissenschaftspreises ausgezeichnet:

2. Platz des CO.DON-AWARD (500€) für den besten Abstract im Rahmen des 10. Jahreskongress der Deutschen Kniegesellschaft in Leipzig: „Epidemiology and treatment strategies of tibial plateau fractures in the last 10 years - data from a European level-I-trauma center”

3. Patz des CO.DON-AWARD (300€) für den besten Abstract im Rahmen des 10. Jahreskongress der Deutschen Kniegesellschaft in Leipzig: „Influence of the corona pandemic on fracture epidemiology of tibial plateau fractures”

8. Beitrag zu den Veröffentlichungen

8.1 Beitrag zu Publikation I

PD Dr. med. Julian Fürmetz war für die Konzeption des Studiendesigns und der Fragestellung sowie für das Management und Koordination des Projekts verantwortlich. PD Dr. med. Julian Fürmetz, Dr. med. Markus Bormann und **Claas Neidlein** entwickelten die Forschungsfrage und Methodik der Studie. **Claas Neidlein** erstellte in umfassender Arbeit eine Datenbank durch Extrahierung und Analyse der Patientenfälle. Prof. Dr. med. Viktoria Bogner-Flatz und Prof. Dr. med. Wolf Christian Prall halfen bei der Bereitstellung der Patientenfälle. **Claas Neidlein**, Dr. med. Markus Bormann, Dr. med. Christoph Gassner, Prof. Dr. med. Wolf Christian Prall, PD Dr. med. Julian Fürmetz waren für die Klassifikation der Frakturen verantwortlich. **Claas Neidlein** war für die ausführliche statistische Auswertung sowie Erstellung von Grafiken und Tabellen verantwortlich. PD Dr. med. Julian Fürmetz, Dr. med. Markus Bormann und **Claas Neidlein** waren für die Interpretation der Ergebnisse verantwortlich. **Claas Neidlein**, Dr. med. Markus Bormann, PD Dr. med. Julian Fürmetz und Dr. med. Alexander Keppler erstellten das Manuskript. **Claas Neidlein** war für die Zusammenfügung von Korrekturen und Ausformulierung sowie Finalisierung verantwortlich. **Claas Neidlein** war für den Prozess der Einreichung der Publikation sowie den Reviewprozess des Journals verantwortlich. Prof. Dr. med. Christian Ehrnthaller und Prof. Dr. med. Wolfgang Böcker halfen bei der Durchsicht der Veröffentlichung.

Claas Neidlein und Dr. med. Markus Bormann teilen sich die Erstautorenschaft für diese Publikation, da beide maßgeblich zu dem Erfolg dieser Arbeit beigetragen haben. Beide waren intensiv an der Analyse und Klassifikation der Frakturen beteiligt sowie der Analyse und Diskussion der Ergebnisse. Dr. med. Markus Bormann konnte die Ergebnisse klinisch einordnen, während **Claas Neidlein** für die wissenschaftliche Einordnung verantwortlich war und vergleichende Originalarbeiten zusätzlich analysierte. **Claas Neidlein** hat den Großteil des Originalmanuskript verfasst und Dr. med. Markus Bormann war für die Finalisierung und Korrekturen verantwortlich.

Aufgrund des großen Aufwands und der engen Zusammenarbeit, halten wir eine geteilte Erstautorenschaft für gerechtfertigt.

8.2 Beitrag zu Publikation II

PD. Dr. med. Julian Fürmetz entwickelte die Forschungsfrage und identifizierte die Studienziele und war für die Supervision und das Management des Projekts verantwortlich. Dr. med. Markus Bormann, **Claas Neidlein** und PD Dr. med. Julian Fürmetz diskutierten und integrierten relevante Konzepte des Forschungsprojektes. PD. Dr. med. Julian Fürmetz beschaffte die Untersuchungsmaterialien und organisierte die Finanzierung des Projektes. Dr. med. Markus Bormann und PD. Dr. med. Julian Fürmetz waren für die Bereitstellung von Untersuchungsräumen verantwortlich. **Claas Neidlein** rekrutierte die Patienten aus der institutseigenen Datenbank. **Claas Neidlein** war für die ausführliche klinische Untersuchung der Patienten sowie die Befragung der Patienten und Vor- sowie Nachbetreuung der Patienten verantwortlich. **Claas Neidlein** war für die statistische Analyse und Erstellung von Grafiken und Tabellen verantwortlich. PD Dr. med. Julian Fürmetz, Dr. med. Markus Bormann, PD. Dr. med. Daniel Berthold und **Claas Neidlein** waren für die Interpretation der Ergebnisse verantwortlich. **Claas Neidlein**, Dr. med. Markus Bormann und PD Dr. med. Daniel Berthold haben große Teile des Manuskripts verfasst. Niels Neidlein half bei der Übersetzung in die englische Sprache und bei der Durchsicht der Veröffentlichung. **Claas Neidlein** war für die Zusammenfügung von Korrekturen verantwortlich. Prof. Dr. med. Dennis Ehrl, Prof. Dr. med. Wolfgang Böcker, Prof. Dr. med. Boris Michael Holzapfel und Dr. med. Maximilian Jörgens waren an der Durchsicht des Manuskripts beteiligt.

9. Einleitung

9.1 Einführung in das Projekt

Die Grundidee des Projekts stammte aus der Erkenntnis, dass insbesondere für den deutschsprachigen Raum, bis dato nur mangelnde epidemiologische Daten über Tibiakopffrakturen vorlagen. Bisherige Publikationen basierten auf Fallstudien mit begrenzten Fallzahlen. Epidemiologische Daten aus Deutschland und dem deutschsprachigen Raum fehlten. Daten bezüglich des klinischen und radiologischen Outcomes von Tibiakopffrakturen sind in der Literatur sehr vielschichtig. Bezüglich des Outcomes nach Tibiakopffrakturen ist die Literatur sehr heterogen. Aus diesen Gründen wurde im Rahmen der Promotion eine Datenbank etabliert, die die letzte Dekade (vom 01.01.2011 bis 31.12.2020) bezüglich Tibiakopffrakturen hinsichtlich multipler Parameter analysiert. Diese Datenbank wird nun prospektiv weitergeführt und deutschlandweit von mehreren Kliniken der Maximalversorgung mit Daten eingepflegt. Aus den gesammelten Daten der letzten Dekade entstanden diverse Studien und Publikationen, die das Verständnis rund um Tibiakopffrakturen analysieren. Die folgende Einleitung stellt einen Überblick über die im Rahmen der Dissertation entstandenen Publikationen dar.

9.1.1 Ziele der Studien

Das Ziel der vorliegenden Studien war es, die Ursachen der posttraumatischen Arthrose nach Tibiakopffrakturen zu identifizieren und zu analysieren. Der Fokus lag dabei auf den epidemiologischen Veränderungen und der Kniegelenksinstabilität nach operativer Therapie mittels offener Reposition und interner Fixierung (ORIF) als potenzieller Risikofaktor für die Entstehung der posttraumatischen Arthrose. Da die Zahl an Fällen von posttraumatischer Arthrose unbefriedigend hoch liegt, wurde untersucht, ob ein Zusammenhang in der epidemiologischen Entwicklung zu erkennen ist und welche Patientengruppen besonders davon betroffen scheinen.

Die erste Studie analysierte epidemiologische Entwicklungen von Tibiakopffrakturen in einem Level-I-Traumazentrum in Zentraleuropa über einen Zeitraum von 10 Jahren (01.01.2011 bis 31.12.2020). Bis zu diesem Zeitpunkt lagen nur wenige aktuelle epidemiologische Daten zu Tibiakopffrakturen für den deutschsprachigen Raum vor. Besonderer Fokus lag dabei auf der Entwicklung der Frakturinzidenz auch in Abhängigkeit des Alters und Geschlechts der Patienten, sowie der Unfallursachen und der Frakturmorphologie.

Ziel war es, die hohe Rate an posttraumatischer Arthrose im Zusammenhang mit epidemiologischen Trends zu verstehen. Der Fokus lag dabei auf möglichen Ursachen für diese Entwicklung und der Identifizierung von Risikopatienten, wie zum Beispiel dem geriatrischen Patientenkollektiv im Sinne der Osteoporose.

Durch die umfassende Patientenanzahl und dem langen Beobachtungszeitraum stellt diese Studie einen wesentlichen Beitrag zum Verständnis der Tibiakopffraktur dar.

Das Ziel der zweiten Studie war es, die postoperative Kniegelenksinstabilität nach ORIF als Risikofaktor für die Entstehung der posttraumatischen Arthrose zu analysieren. Bisher wurden Tibiakopffrakturen als primär knöcherne Verletzungen betrachtet, während meniskale und ligamentäre Strukturen vernachlässigt wurden. In der Studie konnte jedoch gezeigt werden, dass signifikante Kniegelenksinstabilitäten nach ORIF unabhängig von der Frakturmorphologie auftraten. Durch den Nachweis der Kniegelenksinstabilität wurde dies als maßgeblicher Faktor zur Entstehung der posttraumatischen Arthrose diskutiert. Diese Erkenntnis war bis dahin in der Literatur nicht in diesem Umfang beschrieben und leistet einen wichtigen Beitrag zum Verständnis der komplexen Ursache der posttraumatischen Arthrose.

Beide Studien sind durch die übergeordnete Fragestellung nach den Ursachen der posttraumatischen Arthrose nach Tibiakopffrakturen verbunden. Die erste Studie liefert aktuelle epidemiologische Daten und identifiziert potenzielle Ursachen für die Entwicklung der posttraumatischen Arthrose. In der zweiten Studie wird die postoperative Kniegelenksinstabilität als einer der zentralen Risikofaktoren für die Entstehung der posttraumatischen Arthrose fokussiert.

Die Erkenntnisse der Arbeiten tragen entscheidend zum besseren Verständnis der Entstehung der posttraumatischen Arthrose bei und bieten neue Ansätze für Präventions- und Behandlungsstrategien von Tibiakopffrakturen.

9.1.2 Epidemiologie

Tibiakopffrakturen stellen schwere Frakturen für Patienten und Operateur:innen dar: 35% der Frakturen weisen eine komplexe Frakturmorphologie auf (AO/OTA 41 B und C) und das posterolaterale Plateau ist in bis zu 89% der Fälle involviert (1). Zwischen 70-89% der operativ versorgten TPF weisen eine postoperative Malreduktion auf (1).TPF haben einen großen Einfluss auf das Leben der Patienten und schränken diese in ihrer Lebensgestaltung und in ihrem Alltag stark ein (2). Die Frakturen haben einen signifikanten Einfluss auf die Kniefunktion, das Schmerzlevel und das Aktivitätsniveau der Patienten (2). Patienten mit Tibiakopffrakturen tendieren dazu, die Prognose der Verletzung zu überschätzen, was zusätzliche Probleme in der Patientenzufriedenheit mit sich bringt (3).

Tibiakopffrakturen werden in der Literatur mit einer Inzidenz von 10 bis ca. 29 pro 100.000 Personen pro Jahr angegeben (4–7). Sie machen ca. 1-2% aller Frakturen des menschlichen Körpers aus (8). Es konnte ein Inzidenzanstieg von bis zu 68% innerhalb der letzten Dekade nachgewiesen werden, der insbesondere ältere Frauen betrifft (4,9–11). Zudem ist ein Anstieg des Patientenalters zu erkennen: Die Patienten sind mit zur Zeit 54.9 Jahren im Schnitt 7.4 Jahre älter als noch vor 10 Jahren (4).

Durch ein verändertes Mobilitätsverhalten der Bevölkerung hin zu einem immer höheren Aktivitätsniveau sowie durch den demografischen Wandel mit einer immer ältere Bevölkerung, mit einem hohen Aktivitätslevel (z.B. E-Bike), haben sich auch spezifische Risikofaktoren für Tibiakopffrakturen verändert (4,12–15).

Die Ursache für die Zunahme der Inzidenz wird als multifaktoriell beschrieben, wobei der demografische Wandel und eine Zunahme an Stolperstürzen im geriatrischen Patientenkollektiv von entscheidender Bedeutung erscheinen (4,16). Aufgrund der epidemiologischen Veränderungen wurden Tibiakopffrakturen zuletzt als Osteoporose assoziierte Frakturen diskutiert (4). Außerdem sind Tibiakopffrakturen in postmenopausalen Frauen bereits als Indikatorpathologien der Osteoporose wie Wirbelkörperfrakturen, Frakturen des distalen Radius, proximale Humerusfrakturen und Oberschenkelhalsfrakturen, klassifiziert (17,18).

9.1.3 Klassifikationen/Bildgebung/Diagnostik

In Deutschland haben sich die Klassifikationen nach Schatzker (19), Moore (20), und Arbeitsgemeinschaft für Osteosynthesefragen (AO/OTA) (21) etabliert. Diese wurden auf Basis der konventionellen Röntgendiagnostik entwickelt, die allerdings aufgrund der 2-dimensionalen Betrachtung die Komplexität der Frakturmorphologie nur bedingt abbildet. Durch die dynamische Entwicklung der modernen Medizin wurden die genannten Klassifikationen mit Computertomographie basierten Klassifikationen ergänzt, die durch die 3-dimensionale Darstellung der Frakturverhältnisse eine genauere Einschätzung der Frakturmorphologie erlauben (1,4,22–25). Die Computertomographie ist mittlerweile Standard in der klinischen Diagnostik der Tibiakopffraktur (1,4,22,24). Bisher konnte sich jedoch keines der neuen Klassifikationssysteme als globaler Standard durchsetzen und häufig wird weiterhin auf die ursprünglichen Klassifikationssysteme zurückgegriffen (4,26)

9.1.4 Unfallursache

Weiterhin können Tibiakopffrakturen anhand des Traumamechanismus eingeteilt werden. In der Literatur hat sich die Einteilung anhand des Unfallmechanismus in sogenannte „High-Energy“ (z.B. Hochrasanz Verkehrsunfälle, Sturz aus > 3m) und „Low-Energy“ (z.B. Stolperstürze) Trauma etabliert (27,28). Daneben besteht die Möglichkeit, Tibiakopffrakturen anhand der Komplexität der Frakturmorphologie einzuteilen. Dabei wird anhand der Schatzker-Klassifikation zwischen „einfachen-“ (Schatzker I-III) und „komplexen-“ Frakturen (Schatzker IV-VI) unterschieden (2,28).

9.1.5 Operative Versorgung

Die meisten Tibiakopffrakturen werden in Deutschland operativ versorgt (76%) (4). Im europaweiten Vergleich unterscheiden sich die Operationsraten jedoch deutlich. In Belgien liegt die Operationsrate von Tibiakopffrakturen bei nur 37%, während sie in Dänemark bei 92.1% liegt (5,29). Trotz ähnlicher Frakturinzidenzen unterscheiden sich die Versorgungskonzepte deutlich. Bislang fehlen umfassende Daten, um eine evidenzbasierte Bewertung der operativen gegenüber der konservativen Therapie vorzunehmen und eine fundierte Entscheidung hinsichtlich der optimalen Behandlungsstrategie zu treffen.

Bezüglich der operativen Versorgung wurden zahlreiche Verfahren vorgestellt.

Durch die detailliertere Bildgebung und das sich daraus ergebende verbesserte Frakturverständnis wurden neue Zugangswege für die operative Frakturversorgung von Tibiakopffrakturen etabliert (11,30,31).

Die osteosynthetische Versorgung hat das Ziel einer anatomische Rekonstruktion der Gelenkfläche sowie der Beinachse (11,32,33). Weiterhin wurden zusätzliche Arthroskopische Verfahren zur Begutachtung der Fraktur und die Betrachtung von ligamentären und meniskalen Begleitverletzungen etabliert (11,30). Dennoch bleiben dabei häufig meniskale und ligamentäre Strukturen unberücksichtigt (11,34). Übersehene begleitende ligamentäre und meniskale Verletzungen sowie Verletzungen des posterolateralen Bandkomplexes werden in der Literatur mit bis zu 90% angegeben (11,34–36). Weiterhin konnte gezeigt werden, dass die aus den begleitenden ligamentären und/oder meniskalen Verletzungen hervorgehende Kniegelenksinstabilität zu subjektiv schlechteren Ergebnissen der Patientenzufriedenheit führt und einen Risikofaktor für die Entwicklung einer posttraumatischen Arthrose darstellt (11,37–42). Die fehlende Berücksichtigung dieser Strukturen führt zu einem Risiko für die Entstehung der posttraumatischen Arthrose (11,43).

Trotz der zahlreichen operativen Verfahren gibt es momentan keine klaren Empfehlungen zur Behandlung von Kniegelenksinstabilitäten bei Tibiakopffrakturen. Durch die Nichtbeachtung der ligamentären Begleitkomponente sowie den unklaren Empfehlungen, entwickeln bis zu 44% der Patienten eine posttraumatische Arthrose des Kniegelenks und 3-7% der Patienten benötigen innerhalb von 10 Jahren eine endoprothetische Versorgung des betroffenen Kniegelenks (5,9,11,43–49).

Die unmittelbare postoperative Mobilisierung ist insbesondere im geriatrischen Patientenkollektiv von großer Bedeutung. Deswegen werden neue Behandlungsstrategien, wie die primäre Endoprothetische Versorgung vor dem Hintergrund einer immer älter werdenden Bevölkerung, diskutiert (4,50).

9.1.6 Prognose und langfristige Ergebnisse

Es gibt verschiedene Faktoren, die für eine gute Prognose entscheidend sind. Solche Faktoren sind beispielweise eine ausreichende Gelenkkongruenz oder eine annähernd anatomische Beinachse (2,51,52). In der Literatur werden gute subjektive und funktionelle Ergebnisse für das kurz- bis mittelfristige Outcome nach Tibiakopffrakturen beschrieben (2,27,53–58). Für das langfristige Outcome sind allerdings nur wenig Daten bekannt (2).

9.1.7 Fazit

Durch die steigende Inzidenz von Tibiakopffrakturen und das hohe Risiko an posttraumatischer Arthrose, stellen Tibiakopffrakturen eine Herausforderung für den Patienten, Operateur und das Gesundheitssystem dar (4). Es ist von essenzieller Bedeutung, in diesem Bereich weitere Forschung zu betreiben, um klare Empfehlungen zur Versorgung aufstellen zu können. Insbesondere sollten Handlungsempfehlungen auf Basis neuster wissenschaftlicher Erkenntnisse gegeben werden, damit Tibiakopffrakturen nicht weiterhin als rein knöcherne Verletzung betrachtet werden, sondern als Gelenksverletzung.

10. Zusammenfassung:

Das Ziel der ersten Studie war es, aktuelle epidemiologische Daten zu Tibiakopffrakturen aus Deutschland zu liefern.

Dafür wurden alle Tibiakopffrakturen des LMU-Klinikums der letzten 10 Jahre (Januar 2011 bis Dezember 2020) retrospektiv hinsichtlich verschiedener epidemiologischer Daten ausgewertet. Daraus entstand eine Datenbank mit 607 Tibiakopffrakturen, die als Grundlage zahlreicher Studien herangezogen wurde. Diese etablierte Datenbank dient nun als Grundstein für die prospektive Erfassung von Tibiakopffrakturen mehrerer überregionaler Traumazentren.

Der Fokus der ersten Arbeit lag zum einen auf der erstmaligen Beschreibung sowie Analyse der Veränderung der Frakturinzidenz in Deutschland. Zum anderen wurden Trends hinsichtlich der Frakturmorphologie, des Patientenalters, des Unfallmechanismus und der bildgebenden Verfahren zur Diagnostik analysiert.

Die Haupterkenntnis der Studie ist der signifikante Inzidenzanstieg von Tibiakopffrakturen um 68% innerhalb der letzten Dekade. Zuletzt konnte so eine Inzidenz für Tibiakopffrakturen von 23.4 pro 100.000 Personen pro Jahr im Jahre 2020 in Deutschland angegeben werden. Dabei war die Inzidenz bei Frauen (12.1/100.000) innerhalb der Dekade deutlich höher als die der Männer (8.5/100.000). Außerdem konnte eine deutlich höhere Frakturinzidenz bei geriatrischen Frauen (76-85 Jahre) nachgewiesen werden, die mit dem Zusammenhang der Osteoporose diskutiert wurde.

Hinsichtlich der Bildgebung konnte gezeigt werden, dass sich die Computertomographie als Standardbildgebung in der Diagnostik etabliert hat. 91% der Patienten erhielten in der Frakturdiagnostik eine CT. Auf der anderen Seite erhielten nur 22% der Patienten eine MRT-Bildgebung, was ausführlicher in der zweiten Studie diskutiert wird.

Hinsichtlich der Frakturursachen konnten diese wie folgt ausgewertet werden: Hauptunfallursache des gesamten Patientenkollektivs stellten Stolperstürze mit 32.9% dar.

Bei genauerer Betrachtung stach bei jüngeren Patienten, also denjenigen, die jünger als das Durchschnittsalter des Kollektivs waren (52.9 Jahre), eine andere Ursache hervor: Die Mehrzahl der jüngeren Patienten war männlich und der

Traumamechanismus konnte als „High-Energy“ klassifiziert werden (z.B. Verkehrsunfälle). Im Gegensatz dazu war das ältere Patientenkollektiv überwiegend weiblich und die Hauptunfallursache stellten sich als „Low-Energy“ dar (z.B. Stolperstürze).

Ein Vergleich der Daten innerhalb der Dekade führte zu dem Ergebnis, dass insgesamt die High-Energy Unfallmechanismen im Verlauf der Dekade abnahmen und Low-Energy Unfallmechanismen dominierten.

Das Ziel der zweiten Studie war es, Risikofaktoren der Entstehung der posttraumatischen Arthrose zu analysieren. Dieses Ziel ergab sich aus den Erkenntnissen der ersten Studie: Dort konnte zum einen ein signifikanter Anstieg der Frakturinzidenz nachgewiesen werden. Außerdem konnte gezeigt werden, dass die MRT in der Diagnostik von Tibiakopffrakturen kein Standard darstellt. Weiterhin wurde in anderen Studien gezeigt, dass die Rate an posttraumatischer Arthrose nach Tibiakopffrakturen sehr hoch ist. Dies war der Anlass, einen Hauptrisikofaktor der posttraumatischen Arthrose näher zu analysieren: Die posttraumatische Kniegelenkinstabilität.

Dafür wurde die für die erste Studie errichtete Datenbank hinsichtlich verschiedener Einschlusskriterien durchsucht, um so 54 Patienten klinisch auf eine Kniegelenksinstabilität hin zu untersuchen.

Das Hauptergebnis der Studie war ein signifikante Erhöhung in der anterior-posterioren tibialen Translation sowie der tibialen Translation in Innenrotation des Unterschenkels des frakturierten Kniegelenks gegenüber dem gesunden Kniegelenk. Außerdem zeigte das verletzte Kniegelenk signifikante Einschränkungen in der Beweglichkeit (Range of motion).

Dies bedeutet im Ergebnis, dass operativ versorgte Tibiakopffrakturen eine signifikante Kniegelenksinstabilität aufweisen.

Da die Kniegelenksinstabilität ein Risikofaktor für die Entwicklung einer posttraumatischen Arthrose darstellt, können die Ergebnisse der Studie als mögliche Ursache für die hohen Raten an posttraumatischer Arthrose nach Tibiakopffrakturen darstellen.

11. Abstract (English):

The primary objective of the first study was to provide updated epidemiological data on tibial plateau fractures (TPF) in Germany. For this purpose, all TPF treated at the LMU Clinic over the past ten years (from January 2011 to December 2020) were retrospectively analyzed regarding various epidemiological data. This analysis resulted in a database comprising 607 cases of TPF, which served as the foundation for numerous studies. This established database now provides the basis for prospective data collection on TPF across multiple regional trauma centers.

The focus of the first study was twofold: first, to describe and analyze changes in fracture incidence in Germany for the first time, and second, to examine trends regarding fracture morphology, patients age, injury mechanism, and imaging modalities used for diagnosis.

The main finding of the study is a significant increase in the incidence of TPF by 68% over the last decade. By the end of the study period, the incidence of TPF in Germany was reported as 23,4 per 100,000 peoples per year in 2020. Notably, the incidence in females (12,1/100,000) was significantly higher than in males (8,5/100,000) over the decade. Furthermore, there was a notably higher fracture incidence among elderly females (76-85 years), which was discussed in the context of osteoporosis.

Regarding imaging techniques, it was demonstrated that computed tomography (CT) has become the standard modality for fracture diagnosis, with 91% of patients receiving CT imaging. In contrast, only 22% of patients underwent magnetic resonance imaging (MRI), which is discussed in more detail in the second study.

Analysis of injury mechanisms revealed the following: the primary cause of injury across the patient cohort was falls, accounting for 32,9%. A closer look at young patients, those younger than the average cohort age (52,9 years), showed that most were male, and that the trauma mechanism was classified as “high-energy” (e.g., traffic accidents). In contrast, the older patient cohort was predominantly female, with “low-energy” trauma (e.g., falls) being the primary cause.

Comparative analysis over the decade indicated that high-energy trauma mechanisms decreased overall, while low-energy mechanisms became more prevalent.

The second study aimed to analyze risk factors of the development of post-traumatic osteoarthritis (PTOA). This objective arose from the findings of the first study, which identified a significant increase in fracture incidence and noted that MRI is not a standard diagnostic tool for TPF. Additionally, other studies have shown high rates of PTOA following TPF. This led to a focus on a key risk factor for PTOA: post-traumatic knee instability.

To investigate this, the database created in the first study was searched based on specific inclusion criteria to clinically assess knee instability in 54 patients.

The main result of the study was a significant difference in anterior-posterior tibial translation as well as in tibial translation during internal rotation in the fractured knee compared to the healthy knee. Additionally, the injured knee showed significant restrictions in range of motion.

In conclusion, the study indicates that surgically treated TPF exhibit significant knee instability. Since knee instability is a known risk factor for PTOA, these findings explain the high rates of PTOA observed following tibial plateau fractures.

12. Paper I

Changing patterns in the epidemiology of tibial plateau fractures: a 10-year review at a level-I trauma center

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ORIGINAL ARTICLE

Changing patterns in the epidemiology of tibial plateau fractures: a 10-year review at a level-I trauma center

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Abstract

Purpose Mobility patterns of western societies have been changing due to ongoing demographic change. Therefore, continuously updated epidemiological data on fracture morphology and treatment strategies are needed.

Methods This retrospective single-center study included all tibial plateau fractures (TPF) between January 2011 and December 2020 in a level-I trauma center in Central Europe. Epidemiology, trauma mechanism and fracture morphology were analyzed. Age- and sex-specific differences regarding fracture classification (Schatzker, AO/OTA, Moore) and changes during the study period are highlighted.

Results A total of 607 patients (55.2% women, 44.8% men, mean age 52.9 years (± 17.9)) were included in the study, 462 (76.1%) thereof having undergone surgical treatment. Over the decade, an increase in mean age (+ 7.4 years; $p = 0.10$), incidence (+ 68%; $p < 0.05$) and low-energy trauma was observed, with the highest peak in elderly women. Within classifications, AO/OTA 41-B3 (24.9%), Schatzker II (26.8%) and Moore V (46.6%) fractures were the most common.

Conclusion Incidence (+ 68%), mean age and fractures with signs of knee dislocation of tibial plateau fracture increased over the last decade and low-energy trauma mechanism are more frequent. As the increase in incidence is mainly seen in older women, the comorbidities and need for immediate postoperative full weight-bearing have to be considered in treatment strategies.

Keywords Epidemiology · Tibial plateau fracture · Level-I trauma center · Incidence · Osteoporosis

Introduction

Mobility patterns and age structure of western societies are currently changing [1–3]. An aging population, part of which still at a high activity level, alters trauma mechanisms and fracture morphology of tibial plateau fractures (TPF). With increasing age, patient specific risk factors and the number of peri- and postoperative complications due to comorbidities are rising [4]. Immediate postoperative mobilization is essential in orthogeriatric patients, and stability of fracture care to full weight-bearing is necessary as these patients rarely achieve weight-bearing limitation [5]. Therefore, modified and individual treatment strategies including primary total knee arthroplasty (TKA) [6] in the case of TPF are needed. To capture these changes and challenges, continuously updated epidemiological data on the different fracture types are essential for better prevention, treatment, and research.

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TPF are reported with an incidence of 10 per 100.000 person per year associated with a 10-year likelihood of 3–7% for total knee arthroplasty [7, 8]. Recent data describe an increase in incidence of TPF up to 26.9 or 28.7 per 100.000 persons per year [9, 10]. This increase in incidence predominately affects elderly women, which is why some authors describe TPF as being associated with osteoporosis [8, 11, 12].

The dynamic progress of modern medicine within the last decade, in particular the increasing availability of tomographic imaging, has changed diagnostics, understanding and treatment of TPF. This partly explains the marked increase in incidence values [11, 13–16].

The established classifications according to Schatzker [17], Arbeitsgemeinschaft für Osteosynthesefragen (AO/OTA) [18] and Moore [19] have been extended in recent years by new CT-based classification systems, describing a more detailed fracture morphology and some of these classifications include a therapy recommendation [11, 15, 20–23]. However, Schatzker and AO/OTA classifications for TPF are still the most common in the literature for TPF [24].

Considering the increasing incidence and high risk of post-traumatic osteoarthritis, TPF continues to be a challenge for patients, surgeons, and healthcare systems. Therefore, the aim of this study was to provide updated epidemiological data over the last 10 years. The study focuses on incidence, fracture morphology at different ages and trauma mechanism.

Patients and methods

Study design and participants

This retrospective single-center study includes TPF of the last decade (January 2011 to December 2020) from a German level-I trauma center. The study was approved by the local ethics committee (21–0559*)* and complies with the Declaration of Helsinki ethical standards.

Criteria for inclusion were confirmed intra-articular TPF, imaging before treatment (X-ray, computed tomography (CT), magnetic resonance imaging (MRI)), a detailed documentation about trauma mechanism, and information on gender, age, and the affected side. Information was obtained from the institutional databank. Extraarticular fractures (AO/OTA 41-A), tibial shaft fractures as well as inconsistent documentation were criteria for exclusion. In addition to the epidemiological data, imaging technique, cause of accident, diagnosis, therapy, and classification of the fractures were assessed.

To allow comparability with other epidemiological studies, all fractures included were classified according to the established systems of Schatzker, AO/OTA and Moore. The institutional research group (one head of department (JF), two consultants (CG, MB), one scientific assistant (CN)) performed classification of all fractures and discrepancies in classifications between the raters were solved by discussion. If there were signs of knee dislocation, the fractures were classified according to Moore [19] in addition to Schatzker [17] and/or AO/OTA [18]. For this reason, different numbers are found within the classifications.

Incidences were calculated based on the number of citizens and the percentage of emergency care provided by the institutional hospital [25]. Furthermore, the age-adjusted incidence was calculated according to the age structure of the city population.

According to other studies, trauma mechanisms were divided into high energy and low energy [7, 11]. High-impact ski accident, fall from more than 3 m and traffic/bicycle accident were defined as high-energy.

Differences between groups were tested using t test or analysis of variance (ANOVA) in normal distributed variables. Non-normally distributed variables were tested using Mann–Whitney *U* test or Kruskal–Wallis test. Significance was set at $p < 0.05$. Statistics and graphics were performed using RStudio (Version 1.4.1717 © 2009–2021 RStudio, PBC).

Results

Patient demographics

A total of 764 patients with TPF were identified from the institutional databank, of whom 607 patients (55.2% women, 44.8% men; mean age 52.9 years (± 17.9)) met inclusion criteria. 157 cases had to be excluded, 52 due to an extraarticular/shaft fracture, 10 due to a periprosthetic fracture, 41 because primary treatment was done in another hospital and 54 because of inconsistent documentation (including missing X-ray/CT scan). The right knee was involved in 44%, the left knee in 55% of the cases. Bilateral fractures were present in 1% of the cases.

462 patients (76.1%) were treated surgically, 457 (98.9%) by open reduction and internal fixation, and 5 (1.1%) by primary TKA.

The average age increased by 7.4 years over the decade (from 47.5 years to 54.9 years; p = n.s.). In female patients, a bimodal age-fracture distribution can be seen, with a first peak between 26 and 35 years and a second peak in patients aged 56–66 years. In male patients a unimodal peak between the age of 46 and 55 years (Fig. 1B) is observed.

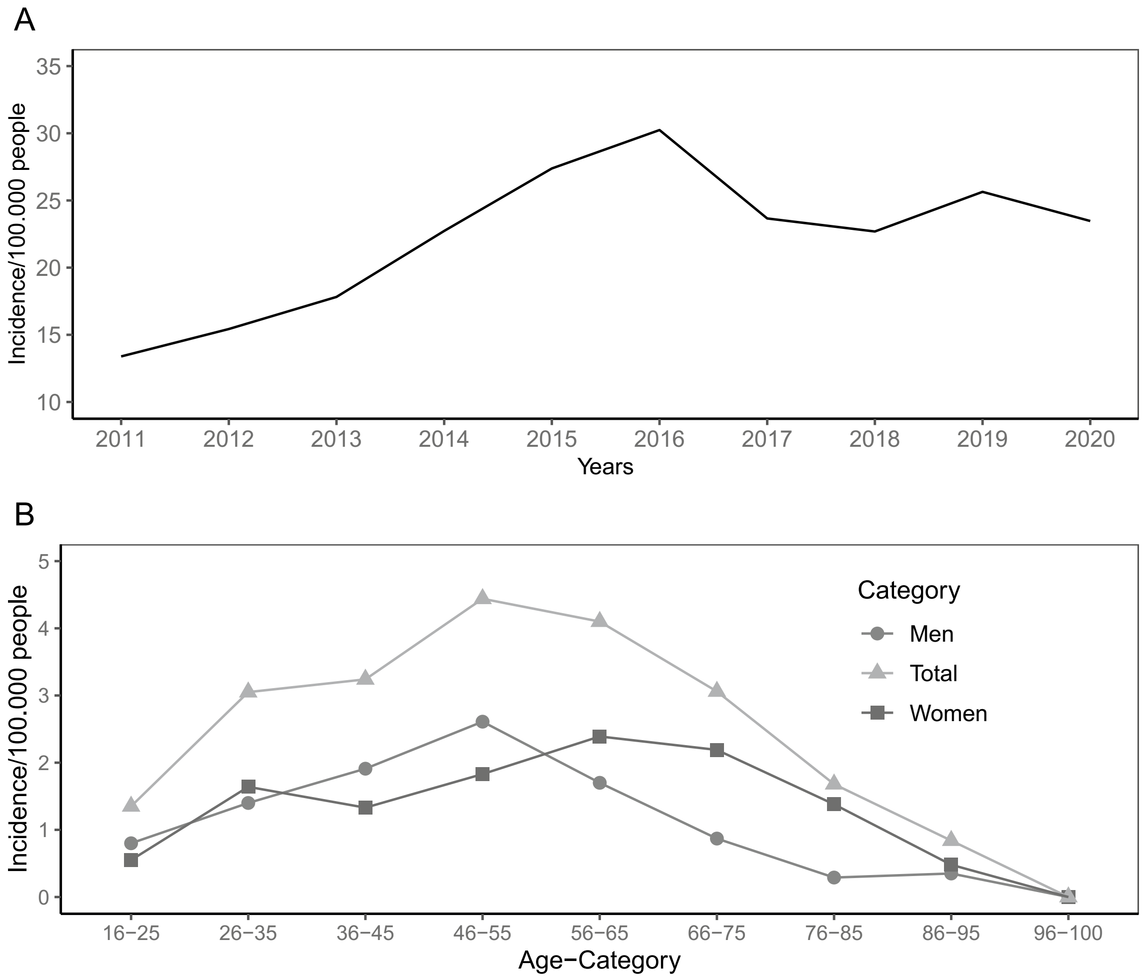

Fig. 1 **A** total incidence of the decade; **B** incidence across age-category within men/women over the decade

Incidence

The overall incidence of TPF in our study was 22.3/100.000 persons per year, with an average increase of 68% during the decade from 13.9/100.000 persons per year in 2011 to 23.4/100.000 persons per year in 2020 ($p < 0.05$) (Fig. 1A). During the decade, women had a higher mean incidence of 12.1 per 100.000 persons per year with an increase of 49.4% in the study period (8.5/100.000 persons per year in 2011 to 12.7/100.000 persons per year in 2020; $p < 0.05$). In men, there was a mean incidence of 10.2 per 100.000 per year in the study period, with an increase of 98.1% from 5.4/100.000 persons per year in 2011 to 10.7/100.000 persons per year in 2020.

Incidence in both men and women increased in a phase shifted manner until age 55 in men and age 65 in women. Thereafter, incidence in men declined sharply, while in women, it declined only slightly, with a higher incidence in women than in men until the age 85 (Fig. 2B).

Imaging

Over the decade, 91% of the patients received CT imaging as primary diagnostics, 71% X-ray and 22% MRI imaging as primary diagnostics. Preoperative tomographic imaging shows a nonsignificant increase of 10% for CT and 15.6% for MRI over the decade, with constantly high levels in recent years.

Trauma mechanism

The main trauma mechanisms were low-energy falls (32.9%), bicycle falls (15%), traffic (21.1%) and skiing accidents (10%). The causes of accident can be classified into high-energy mechanisms (skiing, bicycling, traffic accidents and falls from height) and low-energy mechanism (low-energy falls, other). In younger patients (below mean age (52.9 years)), male patients predominated (55%), as did skiing accidents (14.8%) and high-energy trauma (23.5%).

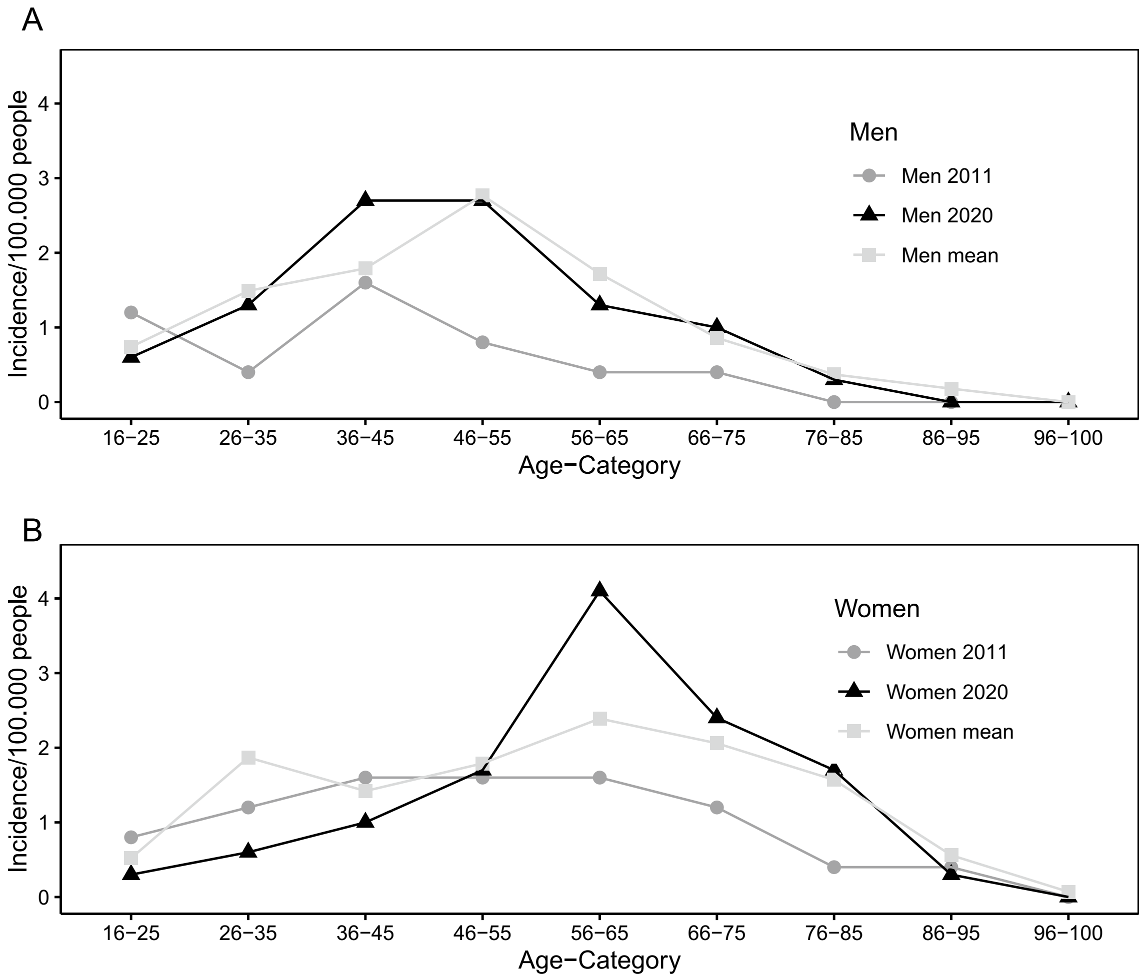

Fig. 2 Development of age-adjusted incidence, incidence in men increased in the age-categories from 26 to 85 (**A**). The incidence in women shows a peak increase in the age-category from 56 to 65 ($p < 0.05$) (**B**)

Older patients (above mean age) were mainly females. Furthermore, in this age group, low-energy falls (40%) predominated. Within the decade, a divergent development between high- and low-energy mechanisms can be seen with an increase in low-energy mechanism (Fig. 3A, B).

Classification

Based on the available radiological imaging (x-ray, CT), the fracture classification was made (Fig. 4). A total of 549 TPF were classified according to Schatzker. There was a significant 12.4% increase in Schatzker IV fractures. A decrease in Schatzker I fractures over the decade (-19%, n.s.) as well as a decrease in Schatzker VI fractures (-7%, n.s.) was seen. Schatzker II fractures constantly represented a large proportion of TPF. 557 fractures were classified according to AO/OTA. The development over the decade was in line with that of the fractures classified with Schatzker.

220 fractures were classified using the Moore classification. Over the decade, there was a significant 3% increase in Moore fractures from 38% in 2011 to 41% in 2020.

There was a significant age difference between women and men with Schatzker II, III, and VI fractures and corresponding AO/OTA B3, B2, and C fractures over the 10 years studied (Fig. 5). In addition, women with type Moore 2, 3, and 5 fractures were also significantly older.

Within Schatzker classification, type II fractures presented a significant mean age difference of 9.9 years ($p<0.01$) between male ($n=71$) and female ($n=76$) patients aged 47.5 (± 15.5) and 57.5 (± 17.5) years, accordingly. Type III fractures showed a significant ($p<0.01$) higher mean age of 55.7 (± 19.9) years in women ($n=70$) compared to 45.7 (± 16.2) years in men ($n=42$). There is also a significant ($p<0.01$) age difference in Schatzker VI fractures of 9.6 years (men ($n=68$) 50.1 (± 13.4) years; women ($n=69$) 59.7 (±17.1) years).

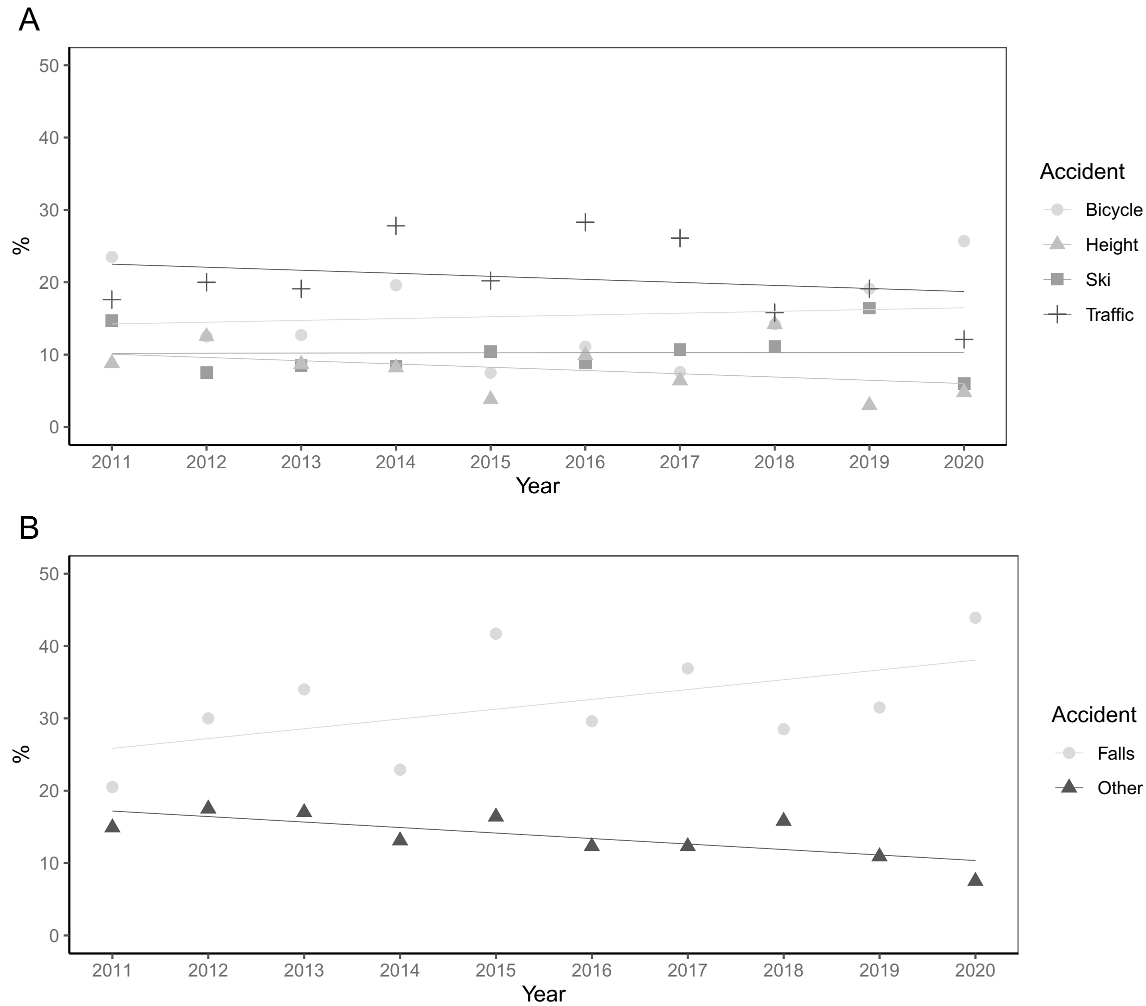

Fig. 3 Frequency of different trauma mechanisms including trend line over the decade, **A** high-energy, **B** low-energy

Concomitant injuries

During the decade, there were no relevant differences in serious concomitant injuries (additional fractures, intracerebral hemorrhage, organ injury).

Length of hospital stay

The median length of hospital stay decreased significantly by 33.6% from 14.6 days in 2011 to 9.7 days in 2020.

Discussion

This study describes a marked increase in the overall incidence of TPF and different changes in incidence in men and women. The mean age of the study cohort increases sharply during the study period, and the age distribution differs between genders. In addition, low energy falls have been identified as the most common trauma mechanism and have become much more frequent in recent years.

The increase in incidence of our study is comparable to other recent European studies reporting changes from 13.3/100.000 in 2011 to more than 25/100.000 in 2019 or 23.4/100.000 in 2020 [9, 26].

The reasons for that increase appear to be multifactorial. The demographic change increasingly shifts the patient population to the older age group being at higher fracture risk. The increase being as high as 7.4 years within this study population over a 10-year time. This is highlighted by a 330% increase of incidence in geriatric female patients (age 76–85 y). Falls increase with age, affecting one-third annually in persons older than 65 years, and approximately 10% of these falls result in a fracture [27].

In addition, these increased incidence rates associated with older age suggest that osteoporosis is a key factor in the development of fracture incidence. Osteoporosis-related fractures of the lower extremity have generally increased in

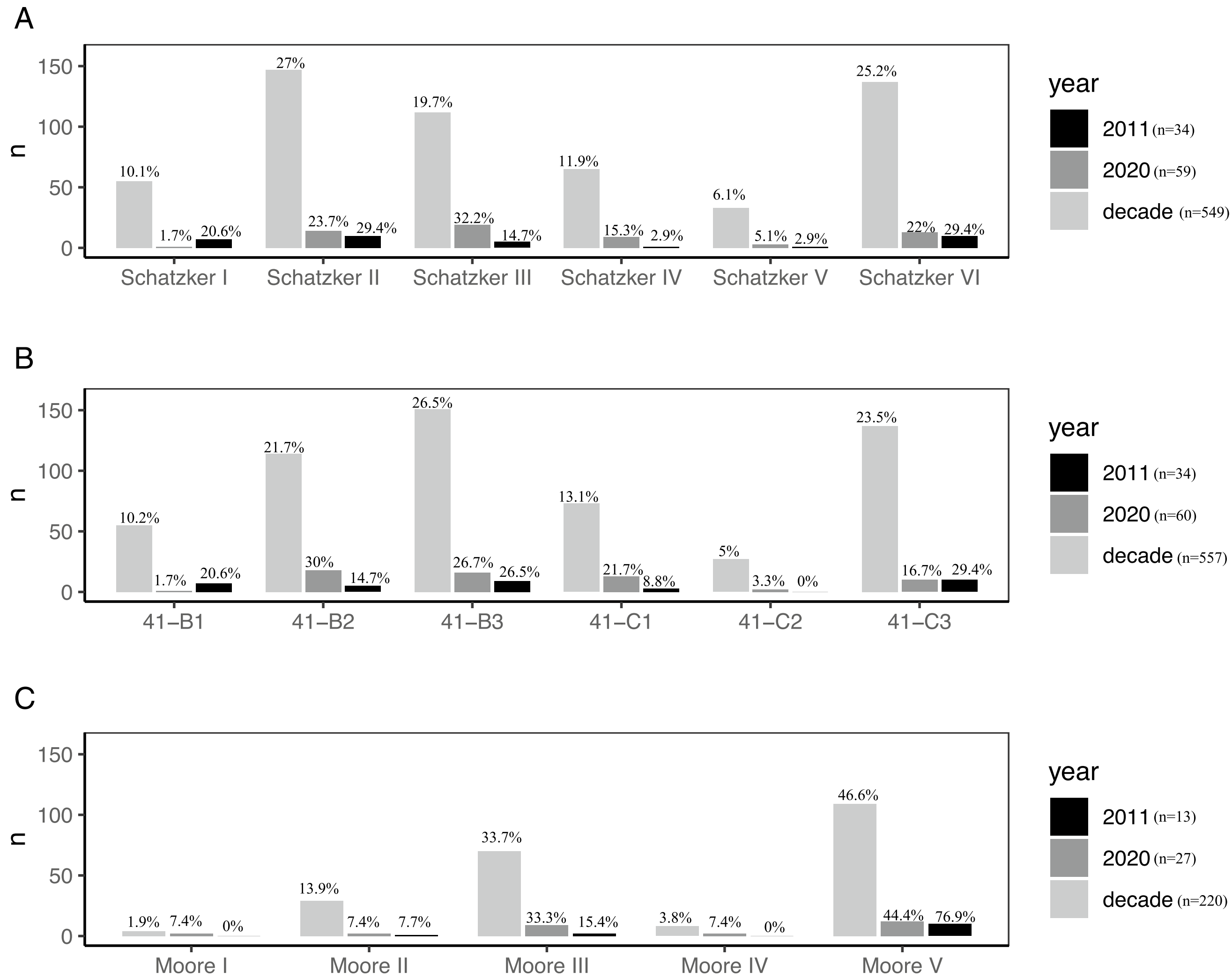

Fig. 4 Classifications according to (**A**) Schatzker (**B**) AO/OTA (**C**) Moore

the German population between 2009 and 2019 (femoral neck: + 23%; proximal tibia: + 9%; distal femur: + 30%; [10]) In contrast, some fractures (e.g., distal radius) decrease in incidence and total number [2, 10, 28, 29], which is achieved primarily through prevention programs like the Fracture liaison services and adequate treatment of osteoporosis [30, 31]. Nevertheless, osteoporosis affects about 8 million people in Germany, with a prevalence of 50% in women over 75 y [32, 33]. TPF in elderly women are already classified as "major osteoporotic fractures" like fractures of vertebral body, distal radius as well as proximal humerus and femur fractures [34, 35]. But unfortunately, there is a limited awareness for underlying osteoporosis in TPF, leading to a delay in diagnostics and initiation of therapy [36]. Oladeji and colleagues report a prevalence of osteoporosis of 14.3% in TPF patients above 65 years [8], but detailed information about this relevant risk factor is still missing. This study is the first to demonstrate the increase of different TPF fracture types together with the trauma mechanisms. The predominance of female and elderly patients with frequent low-energy falls identifies relevant risk factors that should be considered in prevention, treatment, and further research of TPF. Due to the increasing number of fragility fractures and the associated increasing fracture-related burden, we also recommend establishing fracture prevention schemes such as fracture liaison services and the introduction of fall assessment and prophylaxis into geriatric assessment [12].

The applied diagnostic imaging was changing little over time in our study. Tomographic imaging is usually available and used for fracture diagnostics of the knee, as the sensitivity of conventional radiographic imaging in acute knee trauma for the detection of fractures is only 78–83% [37]. Especially fractures in the coronal plane are often not recognized on x-rays [38]. Some studies also show that MRI is more sensitive to impression fractures and lateral displacement than X-ray/CT [39]. The increase in

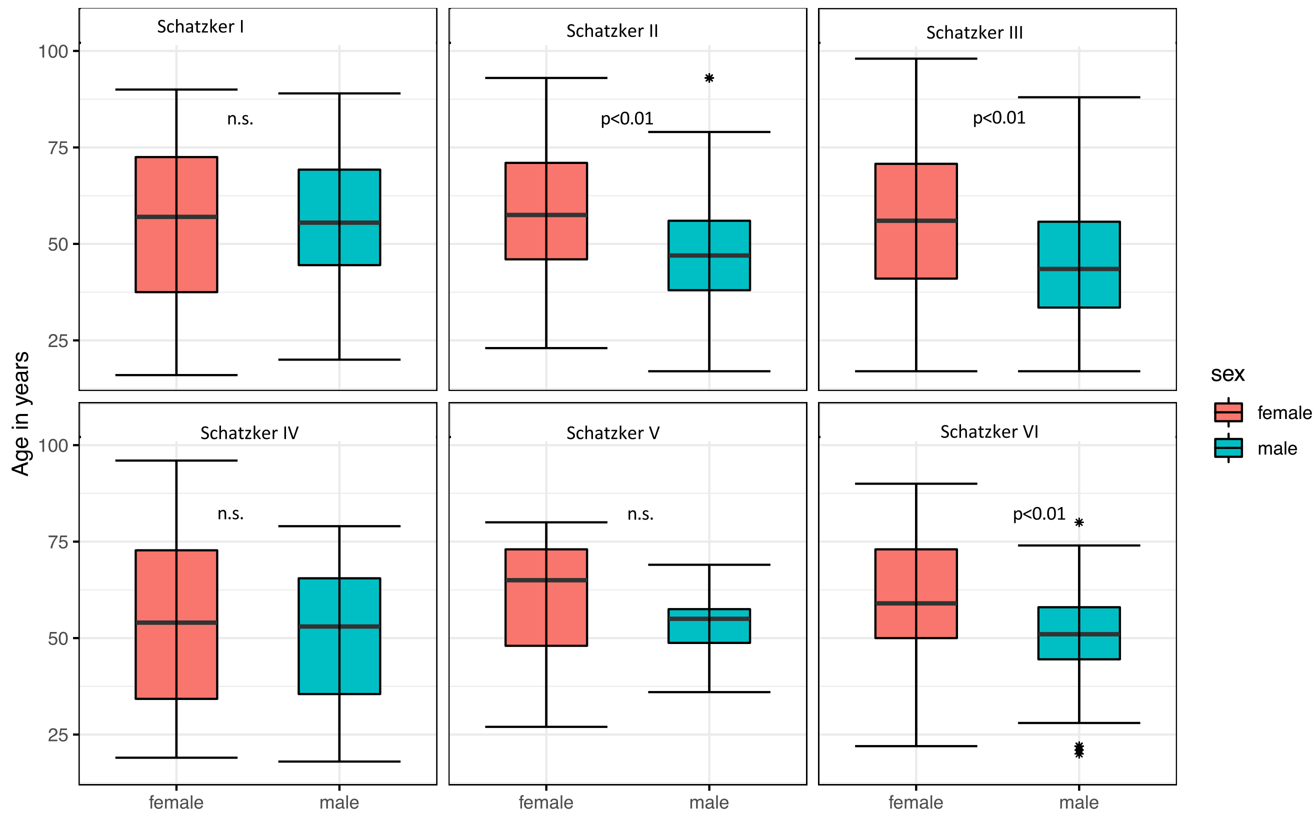

Fig. 5 Sex-specific age differences and fracture classification of the complete patient collective: Classification according to Schatzker. Type 2, type 3, and type 6 fractures with significant mean age differences

tomographic imaging in this study was not significant. However, a small part of the increase in fracture incidence appears to be due to the more frequent use (+ 10%) of tomographic imaging.

To allow comparability with other epidemiological studies, in this study, fractures were classified according to the established radiographic classifications of Schatzker, AO/OTA and Moore. This study describes significant differences for different fracture types in terms of patient gender and age. However, Schatzker and AO classification were originally developed for conventional imaging and can only represent the complexity of fractures to a limited extent. Additional tomographic imaging for suspected TPF is nowadays the clinical standard of care corresponding to our study results. Several new classification systems based on tomographic imaging have been developed trying to account for the complexity of the fracture [11, 15, 20]. However, the inter- and intra-observer reliability of these more complex classification systems is lower and not all CT-based classifications describe the morphology of the fracture at all levels. Altogether, this is the reason why none of the 38 systems described in literature has yet become established as a standard classification system, which would be urgently needed [40].

Although the incidence of TPF in this study is similar to the incidence in Belgium [26], the rate of surgery in this study population differs (76% vs. 37%). Data from Denmark [7], where the rate of surgical treatment is 92.1%, demonstrate how different the treatment strategies are in various countries. Outside Europe, a study group from Singapore describes a surgery rate of 50% [13]. The mean age of patients with TPF in Singapore is younger as it is in Europe (49 vs. 53 years), thus not patients age but different training of surgeons or different medical care systems seem to be the reason for different treatment strategies. Detailed outcome studies of operative and non-operative treatment in patients of different ages are lacking at present. There are only few older studies comparing surgical and conservative treatment of TPF concluding that conservative treatment is a reasonable alternative to surgery; no studies are available from recent years [41]. As patients age, new treatment modalities such as direct primary knee arthroplasty are also coming more into focus [6]. Whether such treatment, osteosynthesis, or the conservative approach offers advantages in the geriatric patient population is not yet clear and is the subject of current investigations.

Conclusion

Incidence (significant), especially in postmenopausal women (significant) and mean-age (n.s.) of TPF increased during the last decade. There has also been a marked increase in fractures with evidence of knee dislocation. TPF due to a low energy trauma increased during the decade (n.s.) and low energy-fall is the main trauma mechanism. These changes should be considered in prevention (fall prophylaxis) and treatment strategies with special attention on age, fracture type and comorbidities (osteoporosis).

Limitation

This study is limited in its explanatory power as it is a single-center study.

Declarations

Conflict of interest All authors declare that they have no conflict of interest. All authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval The study was approved by the local Ethical Committee. (21–0559).

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13. Paper II

High Prevalence of Persistent Measurable Postoperative Knee Joint Laxity in Patients with Tibial Plateau Fractures Treated by Open Reduction and Internal Fixation (ORIF)

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Abstract: The development of post-traumatic osteoarthrosis after tibial plateau fracture (TPF) is multifactorial and can only be partially influenced by surgical treatment. There is no standardized method for assessing pre- and postoperative knee joint laxity. Data on the incidence of postoperative laxity after TPF are limited. The purpose of this study was to quantify postoperative laxity of the knee joint after TPF. Fifty-four patients (mean age 51 ± 11.9 years) were included in this study. There was a significant increase in anterior–posterior translation in 78.0% and internal rotation in 78.9% in the injured knee when compared to the healthy knee. Simple fractures showed no significant difference in laxity compared to complex fractures. When preoperative ligament damage and/or meniscal lesions were present and surgically treated by refixation and/or bracing, patients showed higher instability when compared to patients without preoperative ligament and/or meniscal damage. Patients with surgically treated TPF demonstrate measurable knee joint laxity at a minimum of 1 year postoperatively. Fracture types have no influence on postoperative laxity. This emphasizes the importance of recognizing TPF as a multifaceted injury involving both complex fractures and damage to multiple ligaments and soft tissue structures, which may require further surgical intervention after osteosynthesis.

Keywords: tibial plateau fractures; instability; post-traumatic osteoarthritis; tibial slope

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1. Introduction

The incidence of tibial plateau fractures (TPFs) has increased by up to 68% in the last decade [1–5]. In recent years, computed tomography scans (CT) became the gold standard in the primary diagnostic of TPF [6,7]. Thus, the more comprehensive depiction of the fracture led to the development of new classification systems and altered the surgical approaches for tibial plateau fractures [8,9]. The choice of surgical approach for osteosynthesis is mostly made depending on the type of fracture as well as concomitant ligamentous and (osteo-)chondral or meniscal injuries, and treatment involving anterior, posterior, and arthroscopic approaches may be required [8].

Although there are various surgical options to choose from, 23 to 44% of the patients develop post-traumatic osteoarthrosis (PTA), leading to 3 to 7% of the patients requiring total knee arthroplasty (TKA) within 10 years after sustaining TPF [10–17]. Interestingly, some authors report worse functional outcomes in patients with TKA after sustaining PTA when compared to patients with TKA indicated for primary osteoarthritis (OA) [18–20]. However, the development of PTA is multifactorial and has not yet been definitively clarified [21–23]. These factors include cartilage lesions, meniscal lesions, post-traumatic knee joint laxity, post-traumatic joint step, post-traumatic axial deviation, and/or widening of the tibial plateau, as well as higher age [21]. Osteosynthetic treatment aims to anatomically reconstruct the joint surface, leg axis, and width of the tibial plateau to minimize these risk factors [24,25]. However, meniscal and ligamentous injury factors often go unrecognized in tibial plateau fractures [26], as to date there is no strong recommendation for using additional (magnetic resonance imaging) MRI imaging in patients following TPF [27].

In this context, concomitant meniscal and ligament injuries are recognized as individual risk factors associated with early TKA following TPF [12]. It has been widely shown that persistent knee joint laxity leads to a subjectively worse outcome [28–30], and that persistent knee joint laxity is a relevant risk factor for the development of PTA [21–23]. In addition, studies of ligamentary knee surgery show that an unstable knee joint also leads to a subjectively worse outcome [28–30]. Several studies show how different devices can measure laxity of the knee joint [31,32]. Consequently, this comes along with higher complication rates, while the number of (semi-)constrained prostheses after PTA is higher in this patient cohort [10,13,15,18,19].

Unfortunately, no clear recommendation has been established of how to best diagnose and treat intraoperative knee joint laxity in TPF. A German guideline recommends testing ongoing intraoperative laxity testing after osteosynthetic treatment [27]. However, it is not specified whether the examination should be conducted using fluoroscopic stress images or solely through clinical examination. The guideline suggests additional peripheral stabilization only for cases with significant medial and/or lateral laxity. Thus, the objective of this study is to investigate knee joint laxity after the surgical treatment of tibial plateau fractures using ORIF. The hypothesis was that most patients would show ongoing knee joint laxity using a comprehensive and meticulous testing apparatus.

2. Materials and Methods

2.1. Patient Selection

A retrospective chart review was performed on patient data collected at a Level I trauma center between February 2014 and March 2020. Institutional review board approval was obtained before the initiation of the study. Patients eligible for study inclusion were those aged ≥18 years treated surgically for TPF; unilateral fracture; isolated fracture of the affected leg; preoperative X-ray and/or computed tomography; and repaired or intact ligament status of the affected knee. Ligamentous status at the time of surgery was assessed pre-surgery and after ORIF before soft-tissue closure using MRI or clinical examination by the surgeon. Information was obtained from the institutional databank, intraoperative documentation, patient's anamnesis, and/or MRI-scan. Patients were excluded if they showed extra articular fracture, fractures other than TPF, previous ligamentous injury and/or surgery, and bilateral fractures and did not have detailed intraoperative documentation. The minimum follow-up time after surgery was 12 months. Fractures were classified according to the established system of Schatzker [33]. The fractures were additionally classified according to Moore [34] if there was radiological evidence of knee dislocation. All fractures were classified by the institutional research group, which consisted of a head of department (J.F.), a consultant (M.B.), and a scientific assistant (C.N.). Disagreements between the raters' classifications were resolved by discussion.

This study was divided into four parts. (1) First, all patients were analyzed as a group; (2) then, they were grouped according to their fracture type: simple fractures (Schatzker Type I to III) vs. complex fractures (Schatzker Type IV to VI). (3) Third, they were subdivided into one population with additional ligament repair (e.g., ACL reconstruction, in some cases with additional meniscal repair) during the primary surgery and one population where no additional ligament repair was performed. (4) In a fourth step, the entire collective was divided into a group with ≥2 mm and a group with <2 mm anterior–posterior (AP) translation.

2.2. Analysis of Laxity

Dynamic valgus instability (medial deviation) was measured using the Orthelligent system (OPED GmbH, Valley, Germany). The patients were asked to perform a single leg stand with a 20–30° flexion in the knee joint and to hold that position for 20 s (Figure 1). The test was performed three times, with the average value taken.

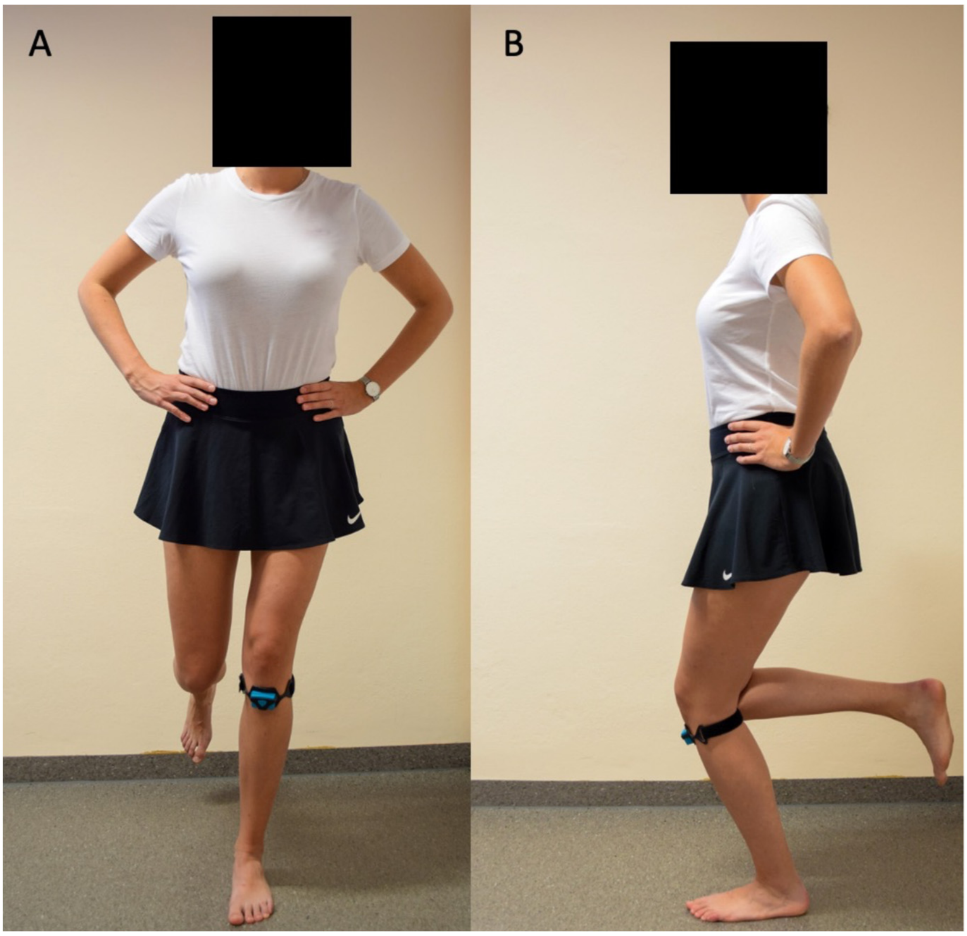

Figure 1. Single leg stand measuring dynamic valgus instability, (**A**) coronal view, (**B**) sagital view.

The Laxitester (ORTEMA Sport Protection, Markgröningen, Germany) was used to assess knee laxity. With a torque of 2 N (Newton), the internal and external rotation laxity of the lower leg were obtained. The device's accuracy has been described as 5° [31]. In addition, a Lachmeter (Equipamentos Ortopedicos LTDA, Preto, Brazil) was used to measure anterior–posterior (AP) translation in the neutral position of the lower leg, as well as internal and external laxity [31,35]. AP translation was measured from the neutral position of the knee in a 30° flexion angle to the maximum anterior tibial translation.

All measurements were taken with the ankle locked in a predetermined dorsiflexion using the trapezoidal shape of the talus. As a result, the torque generated to the foot is transferred to the lower leg (Figure 2). Range of motion was measured using a Goniometer. All tests were performed on both the injured and the healthy knee, serving as its own control group.

Figure 2. The measurement of instability was performed using Laxitester and Lachmeter (**A**) and Laxitester (**B**,**C**).

2.3. Statistical Analysis

Statistical analysis was performed using a *t*-test to compare group differences for variables with normal distribution. The Kruskal–Wallis or Mann–Whitney U test was used to analyze variables with non-normal distribution. The significance level was set at $p < 0.05$. A post hoc power analysis incorporating the total sample size, proportion of patients with TPF, and concomitant instability, with an alpha value of 0.05, demonstrated a power of 89.1% for our study. For statistical analysis and graphical depiction, RStudio (version 1.4.1717 2009–2021 RStudio, PBC, 250 Northern Ave, Boston, MA 02210, USA) was used.

3. Results

3.1. Participants

At the final follow-up, 54 patients ($n = 32$ women; $n = 22$ men) with a mean age of 51 ± 11.9 years were included in this single-center study. Fracture classification and trauma mechanisms as well as other demographic data are presented in Figure 3 and Table 1.

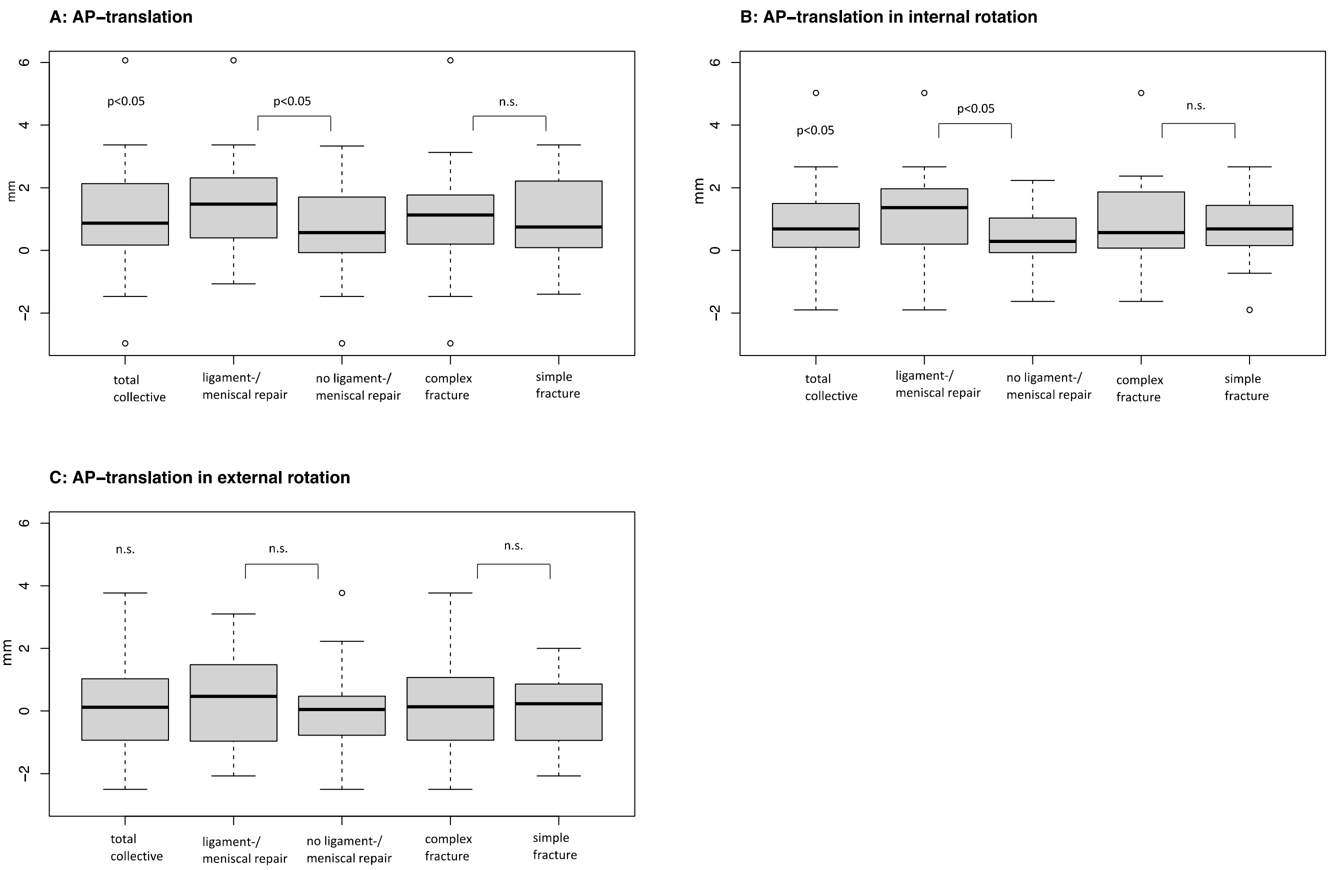

Figure 3. The instability of the total collective and subpopulations was depicted using boxplot for the three parameters: (**A**) anteroposterior (ap) translation, (**B**) ap translation in internal rotation, and (**C**) ap translation in external rotation. The significance level pertains to total collective = injured leg vs. healthy leg (control); subgroup ligament/meniscal repair vs. subgroup no ligament/meniscal repair; subgroup complex fracture vs. subgroup simple fracture. N.s.=not significant.

Table 1. Demographic data of the total patient collective. Note: results of the measurement of instability are presented as mean (95% confidence interval).

Criteria	Total Collective (*n* = 54)	*p*-Value
Male vs. female (%)	40.7% vs. 59.3%	<0.05
Mean age at surgery (years)	47 ± 11.9	-
Mean age at follow-up (years)	51 ± 11.9	-
Schatzker (*n*)		
I	0	-
II	25	-
III	3	-
IV	3	-
V	0	-
VI	23	-
Cause of accident (%)		
Falls	33.4%	-
Traffic	20.4%	-
Ski	20.4%	-
Bicycle	18.5%	-
Fall from height	0%	-
other	7.4%	-

Table 1. *Cont.*

Criteria	Total Collective (n = 54)	p-Value
ROM flexion (°) [1]	127.1 ± 11.2 vs. 129.7 ± 5.3	<0.05
ROM extension (°) [1]	2.1 ± 1.7 vs. 2.7 ± 0.8	<0.05
Initial imaging (%)		
X-ray	74.1%	-
Computed tomography	98.1%	-
Magnetic resonance imaging	20.4%	-
Initial treatment		
Brace	81.5%	-
External fixator	18.5%	-
Surgery time (minutes)	165.1 ± 76.8	-
ASA score	1.8 ± 0.5	-
Mean difference BMI [2]	24.2 ± 3.1 vs. 24.9 ± 3.7	n.s.
AP translation [3]	1.02 (0.6 to 1.5)	<0.05
AP translation in internal rotation [3]	0.71 (0.5 to 1.1)	n.s.
Internal rotation angle [3]	1.6° ± 10.6°	n.s.
AP translation in external rotation [3]	0.08 (−0.1 to 0.5)	n.s.
External rotation angle	−5.1° ± 10.1	<0.05
Medial deviation [3]	0.45	n.s.

[1] Injured vs. healthy leg; [2] pre-surgery vs. follow-up; [3] mean side to side difference in millimeters.

3.2. Measurements

For all patients, there were significant differences (increased laxity to injured leg) in the AP translation (mean (M) = 1.02; SD ± 1.4 mm; $p < 0.05$) and AP translation in internal rotation (0.71 ± 1 mm, $p < 0.05$) between the injured leg and the healthy side. Furthermore, there were significant differences in range of motion ($p < 0.05$). In addition, patients had a significant deficit in external rotation (M = −5.1°, SD ± 10.1; $p < 0.05$). The results are presented in Table 1.

3.3. Complex vs. Simple Fractures

The complex fracture group consisted of 26 complex fractures with a mean age of 48.0 ± 11.9 years at the time of surgery (n = 3 Schatzker Type IV; n = 23 Type VI). The simple fracture group consisted of 28 fractures (n = 25 Schatzker Type II; n = 3 Type III) with a mean age of 44.5 ± 12.0 years. The demographic data are presented in Table 2. The fractured leg was compared. When assessed for fracture type, complex fractures show significantly ($p < 0.05$) less external rotation (−7.4° ± 11.2 vs.−3.1° ± 15.1) compared to simple fractures. Significant differences regarding the AP translation in the Laxitester measurement were not observed. There was also no significant difference between complex and simple fractures regarding the medial deviation of the knee. The results are presented in Table 2.

Table 2. Population complex vs. simple fractures. Note: results of the measurement of instability are presented as mean (95% confidence interval).

Criteria	Complex Fractures (n = 26)	Simple Fractures (n = 28)	p-Value
Male vs. female (%)	38.5% vs. 61.5%	42.9% vs. 57.1%	n.s.
Mean age at surgery (years)	48 ± 11.9	44.5 ± 12	n.s.
Mean age at follow-up (years)	51.6 ± 11.9	50.5 ± 12	
Schatzker (n)			
I	0	0	-
II	0	25	-
III	0	3	-
IV	3	0	-

Table 2. *Cont.*

Criteria	Complex Fractures (n = 26)	Simple Fractures (n = 28)	p-Value
V	0	0	-
VI	23	0	-
Cause of accident (%)			
Falls	23.1%	42.9%	<0.05
Traffic	26.9%	14.3%	<0.05
Ski	19.2%	21.4%	n.s.
Bicycle	26.9%	10.7%	<0.05
Fall from height	0%	0%	n.s.
Other	3.8%	10.7%	n.s.
ROM flexion (°) [1]	126.3 ± 14.1 vs. 129.8 ± 7.8	127.8 ± 7.8 vs. 129.6 ± 5	n.s.
ROM extension (°) [1]	2.3 ± 1.8 vs. 2.9 ± 0.7	1.8 ± 1.6 vs. 2.6 ± 0.9	n.s.
Initial imaging (%)			
X-ray	69.2%	78.6%	<0.05
Computed tomography	100%	96.4%	n.s.
Magnetic resonance imaging	19.2%	21.4%	n.s.
Initial treatment			
Brace	65.4%	96.4%	<0.01
External fixator	34.6%	3.6%	<0.01
Surgery time (minutes)	173 ± 91	157.8 ± 62.1	n.s.
ASA score	2 ± 0.5	1.6 ± 0.5	-
Mean difference BMI [2]	24.8 ± 2.6 vs. 24.8 ± 4.4	23.6 ± 3.5 vs. 24.7 ± 3.8	n.s.
AP translation [3]	1.12 (0.4 to 1.8)	1.02 (0.5 to 1.5)	n.s.
AP translation in internal rotation [3]	0.83 (0.3 to 1.4)	0.71 (0.3 to 1.1)	n.s.
Internal rotation angle [3]	1.2° ± 9.6	2.9° ± 11.6	n.s.
AP translation in external rotation [3]	0.35 (−0.2 to 1)	0.08 (−0.3 to 0.5)	n.s.
External rotation angle	−7.4° ± 11.2	−3.1° ± 15.1	<0.05
Medial deviation [3]	0.67	0.25	n.s.

[1] Injured vs. healthy leg; [2] pre-surgery vs. follow-up; [3] mean side to side difference in millimeters.

3.4. Ligament Repair vs. No Ligament Repair

When assessed for additional ligament repair, patients were classified into two groups. A lateral collateral ligament and/or anterior cruciate ligament brace was used for ligament repair. Group 1 consisted of 24 patients undergoing ORIF with additional ligament repair (n = 10 Schatzker Type II; n = 1 Type III; n = 13 Type VI). The mean age of this group was 48.2 ± 11.6 years. Group 2 consisted of 30 patients with no additional ligament repair (n = 0 Schatzker Type I; n = 15 Type II; n = 2 Type III; n = 3 Type IV; n = 10 Type VI) The mean age of this group was 46.2 ± 12.2 years. Further demographic data are presented in Table 3.

Table 3. Population: ligament repair vs. no ligament repair. Note: results of the measurement of instability are presented as mean (95% confidence interval).

Criteria	Ligament Repair (n = 24)	No Ligament Repair (n = 30)	p-Value
Male vs. female (%)	41.7% vs. 58.3%	40% vs. 60%	n.s.
Mean age at surgery (years)	48.2 ± 11.6	46.2 ± 12.2	n.s.
Mean age at follow-up (years)	52.5 ± 11.6	49.8 ± 12.2	
Schatzker (n)			
I	0	0	-
II	10	15	-
III	1	2	-
IV	0	3	-
V	0	0	-
VI	13	10	-
Cause of accident (%)			

Table 3. *Cont.*

Criteria	Ligament Repair (n = 24)	No Ligament Repair (n = 30)	p-Value
Falls	33.3%	33.3%	n.s.
Traffic	20.8%	20%	n.s.
Ski	20.8%	20%	n.s.
Bicycle	20.8%	16.7%	n.s.
Fall from height	0%	0%	n.s.
other	4.2%	10%	n.s.
ROM flexion (°) [1]	126.2 ± 14 vs. 129.5 ± 6.9	127.8 ± 8.4 vs. 129.8 ± 4.2	<0.05
ROM extension (°) [1]	2.3 ± 1.7 vs. 2.7 ± 0.6	1.9 ± 1.7 vs. 2.7 ± 1	n.s.
Initial imaging (%)			
X-ray	79.2%	70%	n.s.
Computed tomography	100%	96.7%	<0.05
Magnetic resonance imaging	20.8%	20%	n.s.
Initial treatment			
Brace	75%	86.7%	<0.05
External fixator	25%	13.3%	n.s.
Surgery time (minutes)	160 ± 72.7	169.1 ± 80.7	<0.05
ASA score	1.8 ± 0.4	1.8 ± 0.6	-
Mean difference BMI [2]	24.4 ± 3.7 vs. 24.2 ± 4.1	24 ± 2.7 vs. 25.5 ± 3.2	n.s.
AP translation [3]	1.51 (0.9 to 2.1)	0.71 (0.1 to 1.2)	<0.05
AP translation in internal rotation [3]	1.19 (0.6 to 1.8)	0.44 (0.1 to 0.8)	<0.05
Internal rotation angle [3]	−0.3° ± 12.4	3.8° ± 8.5	<0.05
AP translation in external rotation [3]	0.38 (−0.2 to 1)	0.07 (−0.3 to 0.6)	n.s.
External rotation angle	−7.5° ± 10.3	−3.1° ± 9.6	<0.05
Medial deviation [3]	0.25	0.61	n.s.

[1] Injured vs. healthy leg; [2] pre-surgery vs. follow-up; [3] mean side to side difference in millimeters.

There were significant differences between the injured legs in AP translation as well as in AP translation in internal rotation ($p < 0.05$). There was a significant difference in the internal rotation angle as well as in the external rotation angle ($p < 0.05$). Significant differences in the flexion of range of motion ($p < 0.05$) were observed, while the deficit in external rotation was significantly ($p < 0.05$) higher in the ligament repair group (−7.5° ± 10.3 vs. −3.1° ± 9.6). There was no significant difference in the number of patients receiving a preoperative MRI scan, while the no ligament repair group showed significantly higher rates of preoperative CT scans.

Surgery time showed a significant difference between the groups ($p < 0.05$), with a shorter surgery time in the ligament repair group of 9.1 ± 106.9 min.

Patients with no additional ligament repair showed significantly higher rates ($p < 0.05$) in the initial treatment with a brace.

3.5. AP Translation ≥2 mm vs. <2 mm

Overall, fifteen patients (27.8%) had an AP translation ≥2 mm. Out of these, ten had a simple (Schatzker Type II) and five a complex fracture ($n = 1$ Schatzker Type IV; $n = 4$ Schatzker Type VI). The group with an AP translation ≥2 mm also showed a significantly ($p < 0.05$) increased AP translation in internal rotation (1.7 ±1.2 vs. 0.44 ±0.97, $p = 0.00013$) and in external rotation (1.2 ±1.4 vs. −0.2 ±1.1, $p = 0.0055$). Preoperative MRI scans were performed more often ($p < 0.05$) in the group with an AP translation <2 mm (25.6%) than in the group with an AP translation ≥2 mm (6.7%).

4. Discussion

The most important finding of this study was that the majority of the patients demonstrated significant relevant knee joint laxity 1 year postoperatively after sustaining TPF when compared to their healthy knee. In other words, the data from this study show that significantly increased anterior translation and anterolateral rotation after surgically treated tibial plateau fracture occurs when using a validated and reliable testing apparatus.

Postoperative persistent knee joint laxity is often related to several factors and multifactorial. Unaddressed meniscal or ligamentous injuries as well as malreduction may evidently contribute to this instability. Other studies previously described up to 90% of concomitant injuries such as meniscal/ligamentous lesions and lesions of the posterolateral complex, some remaining neglected [26,36,37]. As 20.4% of all patients in this study had a preoperative MRI scan, only 6.7% of the patients with an AP translation of ≥2 mm had a preoperative MRI available, emphasizing the difficulty in detecting concomitant injuries in TPF. Also, the high prevalence of simple fractures in the group with an AP translation ≥2 mm may indicate that preoperative MRI imaging is required more frequently for these fractures.

When it comes to persistent anterolateral rotatory laxity (ALRL), the anterolateral complex (ALC), involving the iliotibial band with its three layers, the accompanying Kaplan fibers, and the anterolateral ligament, has been effectively shown to offer resistance against internal rotational torques, particularly at greater levels of knee flexion [38–44]. As the tibial insertion of these structures is located at Gerdy's tubercule or slightly posterior to it [38,41,43,45], it is in conflict with the standardized anterolateral approach to the tibial plateau. During this procedure, the iliotibial band, which is often detached from Gerdy's tubercule with or without a bone flake, may cause damage to the ALC [7,33,46]. In addition, the trauma mechanism leading to TPF may also lead to injuries to the ALC, thus leading to persistent ALRL.

In this study, the anterolateral approach was the most used approach [46,47]. As such, this may be a possible explanation as to why there is no significant difference in the laxity of simple and complex fractures. In contrast, complex fractures were often treated in combination with another approach (61.4% lateral approach, 24.6% combined). This may also be an explanation for the high proportion of Schatzker Type II fractures in the cohort with an AP translation ≥2 mm, as these fractures were treated using an anterolateral approach.

In the total collective, significant instability was detected in two (AP translation and AP translation in internal rotation) of the three measured dimensions, while in the cohort with an AP translation of ≥2 mm, significant instability in all three dimensions could be observed. A measured postoperative AP translation of ≥2 mm seems to indicate that multidirectional laxity may be present.

The anatomical reduction in the joint surface, axis, and tibial slope is also an important factor for the stability of the knee joint [18,21]. During surgery, the posterolateral corner impression is frequently not visualized or dealt with properly because of inadequate visualization of the lateral imaging [48]. The resulting steeper tibial slope with an increased stress on the posterolateral corner thus contributes to persistent laxity. To avoid such complications, it is crucial to precisely reduce and stabilize the fracture, reinstate the tibial slope, and give particular attention to the posterolateral corner during the surgical procedure.

The occurrence of postoperative knee stiffness is associated with a bicondylar tibial plateau fracture [49] as well as initial treatment with an external fixator [49–51]. In this study, the complex fractures were initially treated significantly ($p < 0.05$) more often with an external fixator (complex fractures 34.6% vs. simple fractures 3.6%). The study's data indicate that there is no significant difference in the range of motion (ROM) between complex and simple fractures. Nevertheless, the entire group showed a statistically significant decrease in ROM on the operated knee joint compared to the healthy side. Based on the absolute values, which show an average flexion difference of approximately 2° and extension difference of 0.6°, it is unlikely that arthrofibrosis occurred. It is still uncertain how much the postoperative adhesions in the knee joint and approach area affect not only the ROM but also the knee joint's stability. Postoperative adhesions could also be a factor for the measured restricted external rotation of the operated knee joint compared to the healthy opposite side. This deficit is bigger in more complex fractures and fractures with ligament repair. These results conflict with other studies that have shown that external tibial rotation is increased in knees with acute cruciate ligament (ACL) and or posteromedial/posterolateral corner injuries [52,53]. Nevertheless, Mayr et al. were also able to demonstrate a reduced external rotation in their studies with ACL injured knees, though this was not significant [31,54]. It remains unclear which injuries during trauma or surgery contribute to the reduced external rotation. Biomechanical studies show the influence of pathological tibial rotation on the stability and pressure distribution of the knee joint [55,56]. The cause of the reduced external rotation should therefore be clarified in further (cadaveric) studies.

In the population of patients undergoing "ligament/meniscal repair," the injured structures were treated with refixation/internal brace techniques. However, studies have suggested that these techniques may not achieve the same level of stability as ligament reconstruction or intact ligaments [57–61]. In the population "ligament/meniscal repair", a refixation/internal brace of the injured structures was performed, and as a result, higher translation values may be expected in this population.

It is notable that surgical time for cases involving ligament repair was shorter than in the group without ligament repair. We interpret this to suggest that in situations involving complex bone injuries, the osteosynthesis procedure takes longer. Consequently, there might be a tendency to prioritize addressing the primary bone injuries in complex cases, particularly when the overall surgical time is already prolonged. This potentially implies that less attention is given to managing accompanying injuries in complex bone scenarios.

5. Limitations

This study comes along with some limitations inherent to its study design. First, the small sample size from this single-center study potentially creates selection bias due to exclusion criteria, in addition to the retrospective nature of the study design. Second, the study did not account for potential confounding factors. Third, the generalizability of the study may be limited due to the specific population and fracture types studied. Fourth, another important factor for the development of post-traumatic laxity is postoperative rehabilitation [20], which was not considered in this study. Fifth, several studies have shown the influence of thigh muscles on knee laxity [62–65]. However, this study did not include strength testing of thigh muscles.

Finally, undetected meniscal/ligamentous and posterolateral corner lesions may have contributed to postoperative laxity in this study.

The data from this study demonstrated a measurable, significant anterior and anterolateral laxity after surgically treated TPF, which is not adequately assessed pre- and postoperatively in terms of non-bony parameters. Although a preoperative MRI is effective for detecting such instabilities, a more accurate evaluation through clinical and instrumental examination, such as intraoperative fluoroscopic stress images and postoperative instrumental laxity tests, may be necessary. Further research is required to determine whether additional stabilization is necessary for this type of laxity, either initially or secondary during implant removal. To reduce the occurrence of PTA, it is crucial to treat TPF as a complex joint injury rather than just a fracture.

6. Conclusions

When treated by ORIF, patients with TPF demonstrate measurable uni- or multidimensional knee joint laxity at a minimum of 1 year postoperatively. Interestingly, fracture types (according to Schatzker and Moore) have no influence on postoperative laxity. This emphasizes the importance of recognizing TPF as a multifaceted injury involving both complex fractures and damage to multiple ligaments and soft tissue structures, which may require further intervention after osteosynthesis.

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Abbreviations

TPF: tibial plateau fracture; AP: anterior-posterior; IRO: internal rotation; ERO: external rotation; M: mean; SD: standard deviation; ROM: range of motion.

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15. Anhang

Im Anhang befinden sich Nachweise der Preise und Auszeichnungen der Publikationen, die Teil dieser Dissertation sind.

CO.DON HUMAN CELL EXPERTS

CO.DON AWARD

2. PLATZ

im Rahmen des 10. Jahreskongresses
der Deutschen Kniegesellschaft

für

DR. MED. MARKUS BORMANN

KLINIKUM DER LMU MÜNCHEN

mit dem Thema

Epidemiology and treatment strategies of tibial plateau fractures in the last 10 years - data from a European level-I-trauma center

[redacted]

Prof. Dr. med. Wolf Petersen
Deutsche Kniegesellschaft e.V.
Präsident

[redacted]

Tilmann Bur
Vorstand CO.DON AG

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Dr. Achim Simons
Vorstand CO.DON AG

CODON
HUMAN CELL EXPERTS

CO.DON
AWARD

3. PLATZ

im Rahmen des 10. Jahreskongresses
der Deutschen Kniegesellschaft

für

DR. MED. MARKUS BORMANN &
CAND. MED. CLAAS NEIDLEIN
KLINIKUM DER LMU MÜNCHEN

mit dem Thema

Influence of the corona pandemic on fracture epidemiology by the example of tibial plateau fractures

[redacted]
Prof. Dr. med. Wolf Petersen
Deutsche Kniegesellschaft e.V.
Präsident

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Tilmann Bur
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Dr. Achim Simons
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DEUTSCHE KNIEGESELLSCHAFT

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