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Verletzungsmuster älterer Menschen bei Stürzen und Verkehrsunfällen mit Todesfolge

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München, den 04.11.2020

Daniela Heinrich

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Abkürzungsverzeichnis

AIS	**A**bbreviated **I**njury **S**cale (AIS© 2005 update 2008)
et al(.)	**et al**ii
GLF	**G**round **L**evel **F**all
ISS	**I**njury **S**everity **S**core
LWS	**L**enden**w**irbel**s**äule
MAIS	**m**aximum **AIS**
MOP	Deutsches **Mo**bilitäts**p**anel
PFF(s)	**P**roximal **F**emur **F**racture(s)/ **P**roximale **F**emur**f**raktur(en)
RTA(s)	**R**oad **T**raffic **A**ccident(s)
WHO	**W**orld **H**ealth **O**rganization

Publikationsliste

What are the differences in injury patterns of young and elderly traffic accident fatalities considering death on scene and death in hospital?

Heinrich D., Holzmann C., Wagner A., Fischer A., Pfeifer R., Graw M., Schick S.
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July 2017, Volume 131, Issue 4, pp 1023–1037
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Fatal falls in the elderly and the presence of proximal femur fractures.

Schick S., Heinrich D., Graw M., Aranda R., Ferrari U., Peldschus S.
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Einleitung

Bis 2050 wird sich laut *World Health Organization (WHO)* die Anzahl der Personen ab 60 Jahren weltweit verdoppeln (77). In den beiden Veröffentlichungen meiner kumulativen Dissertation liegt der Fokus auf der Bedeutung des erhöhten Anteils älterer Patienten in der medizinischen Versorgung, insbesondere bei Traumata. Ich untersuche die Verletzungsmuster älterer Menschen durch Stürze und Verkehrsunfälle mit Todesfolge, um eine mögliche Vulnerabilität im Vergleich zum erwachsenen Normkollektiv zu prüfen. Ausblick der Arbeit ist es Besonderheiten eines Kollektivs darzustellen, das in den nächsten Jahren immer mehr an Bedeutung gewinnen wird.

Demographischer Wandel und seine Folgen

Geht es um demographischen Wandel, steht vor allem die Veränderung der Altersstruktur im Sinne eines relativen Zuwachses der älteren Bevölkerung in der öffentlichen Diskussion. Aus den „World Population Prospects“ der *Vereinten Nationen* (77) lässt sich entnehmen, dass weltweit ein deutlicher Rückgang der Geburtenrate zu beobachten ist. Gleichzeitig stieg die Lebenserwartung für ein deutsches Neugeborenes innerhalb der letzten 25 Jahre von durchschnittlich 76 Jahre auf 81,3 Jahre an. Auch europa- und weltweit zeigt sich ein deutlicher Aufwärtstrend in der Lebenserwartung, was den zunehmenden Anteil der Älteren an der Gesamtbevölkerung erklärt. Die *Vereinten Nationen* verzeichnen 2017 weltweit einen Anteil an 60+-jährigen von 13%, europaweit 25% und in Deutschland sogar 28%. Bis 2050 wird diese Altersgruppe einen Anteil von 34% an der europäischen Bevölkerung ausmachen und weltweit wird sich die Anzahl der Personen ab 60 Jahren bis 2050 verdoppeln. In der Broschüre zur „13. koordinierten Bevölkerungsvorausberechnung“ des *Statistischen Bundesamts* in Deutschland zeigt sich, dass nicht nur die allgemeine Lebenserwartung steigt, sondern auch eine Verbesserung der Überlebensverhältnisse für ältere Menschen zu sehen ist: In den Jahren 1871-1881 überlebte ein 65-jähriger Mann durchschnittlich weitere 9,6 Jahre (Frauen 10,0 Jahre). Für die Jahre 2010-2012 stieg die weitere Lebenserwartung bei den Männern auf 17,5 Jahre (Frauen 20,7 Jahre). Dazu haben vor allem die Weiterentwicklung der Gesundheitsversorgung, Fortschritte in Hygiene, Ernährung, Wohnsituation, verbesserte Arbeitsbedingungen und zunehmender materieller Wohlstand beigetragen (68).

Veränderungen des Körpers und Vulnerabilität im Alter

Körperliches Altern

Mit zunehmendem Alter treten Funktionseinschränkungen als Folge der abnehmenden Organreserven auf. Anfangs sind sie häufig nur bei Belastung bemerkbar, können im Verlauf aber auch unter Ruhebedingungen auftreten. Dieser Prozess verläuft nicht nach festen

Mustern und auch die verschiedenen Organsysteme eines Individuums altern unterschiedlich schnell, weshalb es im Alter zunehmend zu einer inter- und intrapersonellen Varianz kommt (62). Aus biologischer Sicht ist Altern die Folge einer Vielfalt an molekularen und zellulären Schäden, die sich im Laufe der Zeit ansammeln. Das führt im Verlauf zur Abnahme von körperlichen und mentalen Kapazitäten, einem ansteigenden Krankheitsrisiko und schließlich zum Tod (84). Altern ist ein sehr komplexer Prozess, der auf verschiedenen Ebenen durch mehrere Faktoren beeinflusst wird. Generell wird von einem Zusammenspiel aus Wechselwirkungen intrinsischer Faktoren mit Umwelteinflüssen und dem individuellem Lebenswandel ausgegangen (8, 60, 62).

Vulnerabilität des alten Menschen

Die Zunahme der älteren Bevölkerungsschicht spiegelt sich auch in der Medizin wider, wo in nahezu allen Fachbereichen zunehmend ältere Patienten behandelt werden. Im Jahr 2000 waren in Deutschland 35,3% der Krankenhauspatienten 65 Jahre oder älter; 2016 lag dieser Anteil bereits bei 43,4% (modifizierte Tabelle nach (74)). Auch aus USA und England liegen ähnliche Daten vor (36, 72). Verschiedene Studien zeigen eine deutliche Zunahme an Multimorbidität mit steigendem Alter (20, 23, 78, 83). Zu den häufigsten Erkrankungen ab 65 Jahren zählen dabei Krankheiten des Herz-Kreislauf-Systems, Krebserkrankungen, chronische Lungenerkrankungen, Muskel-Skelett-Erkrankungen und Diabetes mellitus. Betrachtet man Erkrankungen, die die Psyche betreffen, sind Depressionen und demenzielle Syndrome von besonderer Bedeutung (45). Van den Bussche et al. identifizierten bei den 65+-jährigen in Deutschland Bluthochdruck, Fettstoffwechselstörungen, chronische Schmerzen im LWS-Bereich, Diabetes mellitus, Osteoarthritis und chronisch ischämische Herzerkrankungen als die sechs häufigsten chronischen Beschwerden, die einzeln oder in Kombinationen auftraten (79). Besondere Herausforderungen sind die Chronizität der Erkrankungen und deren Auswirkung auf die Funktionalität im Alltag (Mobilität, Alltagskompetenz, Kommunikation und Krankheitsbewältigung), wodurch es häufig zu einem Zusammenspiel aus medizinischen und sozialen Problemen kommt (59).

Ein weiteres Problem stellt die gleichzeitige Einnahme mehrerer Arzneimittel (Polypharmazie) dar, die mit einem erhöhten Risiko für unerwünschte Medikamenten-Nebenwirkungen und Wechselwirkungen der Medikamente untereinander einhergeht (10, 18, 46, 50, 91). In Deutschland nehmen etwa 42% der über 64-jährigen täglich fünf oder mehr Medikamente ein (58). Bei älteren Menschen bestehen eine veränderte Stoffwechsellage und eine reduzierte Nierenfunktion. Das führt dazu, dass Medikamente schneller oder langsamer umgesetzt und ausgeschieden werden als in jungen, gesunden Körpern. Daher kann es zu einer erhöhten

Empfindlichkeit auf Wirkstoffe kommen, die dann beispielsweise verstärkt anticholinerg oder sedierend wirken (45).

Frailty (Gebrechlichkeit)

Isaacs beschrieb 1981 die vier geriatrische Hauptprobleme Immobilität, Instabilität, Intellektuelle Beeinträchtigung und Inkontinenz als die häufigsten Beschwerden älterer Menschen (5, 38). Das heutige geriatrische Denken ist stark vom Phänomen der Gebrechlichkeit (Frailty) geprägt. Dafür gibt es bisher keine einheitlich akzeptierte Begriffsdefinition. Nikolaus (61) beschreibt Frailty als

> „den altersassoziierten Abbau körperlicher und kognitiver Funktionen und zunehmende Vulnerabilität gegenüber Erkrankungen und deren psychosoziale Folgen. Gebrechlichkeit ist ein physiologischer Status mit verminderter (Leistungs-)Reserve und kumulativer Dysregulation der physiologischen Systeme."

Charakteristischerweise ist eine angemessene Reaktion auf Stressoren nicht mehr möglich, weshalb gebrechliche Personen anfälliger für ungünstige Krankheitsfolgen, wie Delir, Stürze, Behinderungen und vorzeitige Sterblichkeit sind (22, 25). Kent et al. berechnen Frailty im Sinne einer bedingten Wahrscheinlichkeit an einer Verletzung zu versterben und grenzen davon Fragility, die relative Wahrscheinlichkeit eine Verletzung zu erleiden, ab (42). Fried et al. definieren fünf Kernkriterien zur Beschreibung von Gebrechlichkeit: allgemeines Erschöpfungsgefühl, reduzierte Muskelkraft, langsame Gehgeschwindigkeit, geringe körperliche Aktivität und ungewollter Gewichtsverlust (22). Bei den 65+-jährigen sahen sie nach dieser Definition eine Prävalenz von 6,9% (22, 25). Das *Robert-Koch-Institut* greift diese Kriterien auf und unterscheidet in einer Studie in die Gruppen „prefrail" (≤ 2 Kriterien zutreffend) und „frail" (≥ 3 Kriterien zutreffend). Demnach waren 2,8% der 65 bis 79-jährigen Frauen und 2,3% der gleichaltrigen Männer körperlich gebrechlich. „Prefrail" waren mit 38,8% in der gleichen Altersgruppe deutlich mehr Personen (24). In geriatrischen Assessments wird zunehmend versucht die Gebrechlichkeit älterer Patienten möglichst genau einzuschätzen. Das soll bei der Identifizierung von Älteren helfen, die ein erhöhtes Risiko für den Verlust der Alltagskompetenz oder Pflegebedürftigkeit haben. Frailty wird daher auch häufig zu den geriatrischen Hauptproblemen gezählt (21, 88).

Eine wichtige Rolle spielt auch die Sarkopenie (13, 56, 61), ein fortschreitender, altersassoziierter Verlust an Skelettmuskulatur, Muskelkraft und -funktion, der zu einer Erhöhung des Risikos für Immobilität, schlechte Lebensqualität und den Tod beiträgt (7, 13–15, 28). Die Abnahme der Muskelmasse ist bei 65+-jährigen häufig zu sehen und nimmt mit steigendem Alter zu (14, 37, 55). Problematisch ist dabei nicht der Verlust der Muskelmasse selbst, sondern vielmehr der Verlust von Kraft und Funktionalität. Verschiedene Studien bestimmen die Greifstärke „grip strength" als Maß für die allgemeine Muskelkraft und zeigen, dass eine reduzierte Kraft deutlich mit einer erhöhten Mortalität assoziiert ist (3, 26, 40, 47, 67, 69). Morley schlug 2017 mit den „Modern Giants of Geriatrics“ eine Neudefinition der häufigsten Syndrome der modernen Geriatrie vor und berücksichtigt darin: Frailty, Sarkopenie, Gewichtsverlust/ Mangelernährung/ Appetitlosigkeit, kognitive Beeinträchtigung, Delir, Stürze, Depression, Demenz, Polypharmazie und Fatigue (54).

Aktivität im Alltag und Traumata

Europaweit sind 5% der Generation 65+ weiterhin erwerbstätig; sie bringen sich bei ehrenamtlichen Tätigkeiten ein, belegen Volkshochschulkurse, sind Gasthörer an Universitäten und gehen weiterhin gerne auf Reisen (33). Auch die Mobilität der Älteren hat zugenommen: immer mehr Senioren haben einen Führerschein, sie nutzen ihr Auto länger oder sind als Fahrradfahrer unterwegs (75).

Der demographische Wandel und die anhaltende Aktivität der Älteren, sowie ihre Vulnerabilität zeigen sich auch in einem Anstieg geriatrischer Traumata (12, 17, 31, 51, 82). Die Eigenschaften und Risiken der Traumata unterscheiden sich dabei signifikant von denen anderer Erwachsener (51). Die Kombination von Komorbiditäten, verschriebenen Medikamenten und Frailty, erhöht die Anfälligkeit für Traumata und daraus folgende Komplikationen wie Infektionen, Pneumonien, Thromboembolien und Multiorganversagen (70). Das *Robert-Koch-Institut* fand bei der Gruppe der 65+-jährigen eine Osteoporose-Prävalenz von 24% bei den Frauen und 5,6% bei den Männern (71). Für Osteoporose stellt das Alter einen wesentlichen, unabhängigen Risikofaktor dar. Folgen sind eine abnehmende Knochenmasse und -qualität, sowie eine verringerte Frakturresistenz. Mit steigendem Alter ist daher eine exponentielle Zunahme an Fragilitätsfrakturen zu beobachten (39). Aus Daten der *Techniker Krankenkasse* wurde bei über 50-jährigen Osteoporose-Erkrankten eine krankheitsbedingte Frakturrate von 52% beobachtet; mit zunehmendem Alter stieg diese weiter an (30). Aber auch ohne Osteoporose frakturieren gealterte Knochen leichter (70). Die erhöhte Frakturanfälligkeit im Alter führt dazu, dass es auch bei Traumata mit leichter Krafteinwirkung auf den Körper zu Verletzungen kommen kann. Die Älteren haben aber nicht nur ein erhöhtes Verletzungsrisiko und bei vergleichbaren Unfällen eine höhere Verletzungsschwere, auch die Mortalität ist bei älteren Trauma-Patienten deutlich erhöht (17, 49). Grossmann et al. finden einen Anstieg der Mortalität um 6,8% für jedes Jahr über 65 (29). Bereits das Alter alleine und zusätzlich vorbestehende Erkrankungen, Nebenerkrankungen, funktionelle Einschränkungen sowie Gebrechlichkeit scheinen zu dieser Erhöhung beizutragen (2, 19, 52, 57, 65). Wutzler et. al zeigen, dass bei vergleichbarem Injury Severity Score (ISS) die Letalität nach einem Trauma mit dem Alter deutlich zunimmt und dass sich Verletzungsart, Therapie und Outcome bei schwer verletzten Älteren signifikant vom

Normalkollektiv unterscheiden (87). Perdue et. al finden sogar eine zweifach erhöhte Mortalität bei dem Vergleich von älteren und jüngeren Patienten mit äquivalentem ISS (65).

Traumata: Verkehrsunfälle und Stürze

Bei Traumata des älteren Menschen spielen vor allem Verkehrsunfälle und Stürze eine wichtige Rolle, welche von der *WHO* als weltweit häufigste Ursachen für den Tod durch unbeabsichtigte Verletzungen beobachtet wurden (85). In dem 2012 von *WHO* und *Monash University* gemeinsam veröffentlichten „Fatal Injury Surveillance in Mortuaries and Hospitals: A Manual for Practitioners" (4) machten Verkehrsunfälle 24% aller (beabsichtigten und unbeabsichtigten) Verletzungstoten aus und Sturzunfälle waren in 10% der Fälle die Todesursache. Betrachtet man das gesamte Unfallgeschehen so sind vor allem junge Männer betroffen. Berücksichtigt man aber die Unfallfolgen, stellen aufgrund der Konsequenzen insbesondere die älteren Menschen eine bedeutende Gruppe dar.

Stürze

Stürze sind der häufigste Verletzungsmechanismus und die führende Unfalltod-Ursache der älteren Generation und daher als Thema von großer Bedeutung. Laut *Robert-Koch-Institut* können in Deutschland mehr als die Hälfte (53,7%) aller Unfälle der über 60-jährigen auf Stürze zurückgeführt werden (80). Etwa ein Drittel der über 65-jährigen stürzt jedes Jahr, die Hälfte von ihnen sogar mehrmals (63). Die Sturzquote der Menschen, die in Einrichtungen leben, ist dabei wesentlich höher als die derer, die zu Hause wohnen (63). Kramarow et al. berichten, dass sich die Todesrate bei Sturzunfällen von Älteren in den USA vom Jahr 2000 bis 2013 nahezu verdoppelt hat (44). Diese Zunahme der Todesfälle durch Stürze wurde auch von Orces beobachtet (64).

Sturzursache sind gemäß Nikolaus et al. häufig Muskelschwäche der Beine, Störung von Gang- und Gleichgewicht, optische Defizite und kognitive und funktionelle Beeinträchtigungen; auch Schwindel oder psychotrope Medikamente können einen Sturz begünstigen (63). Meist kommen mehrere Gründe zusammen, die zum Teil auch in kausalem Zusammenhang stehen. Auch „extrinsische Faktoren" wie zum Beispiel eine schlechte Beleuchtung der Wohnung, das Vorliegen von Stolperfallen, fehlende Haltegriffe und weitere, sowie das Zusammenspiel dieser mit dem individuellen Risikoverhalten der Älteren spielen eine entscheidende Rolle (63, 90). Folgen sind häufig Frakturen, Immobilität, Behinderung oder Tod. Verschiedene Studien zeigen, dass die Lebensqualität der Älteren durch einen Sturz deutlich eingeschränkt wird (32). Bei 47,2% der Menschen ab 60 Jahren kommt es nach einem Sturz zum Knochenbruch und 41,4% der Gestürzten müssen stationär im Krankenhaus behandelt werden (80). Etwa 10% der Stürze gehen mit schwerwiegenden Verletzungen wie Schenkelhalsfrakturen, subduralen Hämatomen oder Weichteil- oder Kopfverletzungen einher. Sturzunfälle sind bei älteren Menschen die führende Ursache für Behinderungen (63). Durch die Verletzungsfolgen kommt es häufig zu starken Einschränkungen und eine Unterbringung in Langzeitpflege-Einrichtungen kann notwendig werden (27). Stürze und sturzbezogene Verletzungen sind starke Indikatoren für das Einweisungsrisiko von Senioren in Pflegeheime: für zwei- oder mehrfach Gestürzte ist das Risiko einer Einweisung fünffach erhöht. Senioren, die einen Sturz mit schweren Verletzungen in der Vorgeschichte aufweisen, zeigen bereits ein zehnfach erhöhtes Risiko für den Bedarf einer Langzeitpflege (53). Hinzu kommt die häufig bestehende Angst vor weiteren Stürzen und deren Folgen. Selbst etwa ein Drittel der Senioren, die bisher nie gestürzt sind, schränken aus Angst davor zu fallen ihre Aktivität ein. Konsequenzen sind eine Abnahme der sozialen Kontakte und die Einschränkung oder Unterlassung alltäglicher Handlungen wie Anziehen, Baden und Einkaufen (63, 89).

Verkehrsunfälle

Weltweit versterben pro Jahr mehr als 1,2 Millionen Menschen im Straßenverkehr; über 50 Millionen weitere erleiden schwere Verletzungen, Unfallfolgeschäden oder bleibende Behinderungen. Nach Schätzung der *WHO* waren 2015 Verkehrsunfälle altersübergreifend die neunthäufigste Todesursache weltweit (86). Durch die demographische Entwicklung und ihre zunehmende Mobilität spielen ältere Menschen auch im Verkehrsgeschehen eine immer wichtigere Rolle. Laut *Deutschem Mobilitätspanel (MOP)* sind drei Viertel der über 70-jährigen im Besitz eines Führerscheins (16). Anfang 2015 besaßen 71% der Haushalte mit Haupteinkommenspersonen ab 65 Jahren mindestens ein Fahrrad, 7% ein E-Bike. Mindestens ein Pkw war in 74% der Seniorenhaushalte zu finden (34).

Betrachtet man die Unfallbeteiligung von Senioren sind diese im Vergleich zu dem Anteil, den sie an der Gesamtbevölkerung ausmachen, deutlich unterrepräsentiert. So waren im Jahr 2016 bei Unfällen mit Personenschaden nur 13,1% aller Unfallbeteiligten ältere Menschen. Anders bei den Todesopfern: hier machten die 65+-jährigen einen Anteil von 32,7% aus. Damit hat sich der Anteil der 65+-jährigen an den Verkehrstoten in Deutschland innerhalb der letzten 20 Jahren fast verdoppelt, obwohl gleichzeitig das Risiko im Straßenverkehr getötet zu werden für alle Altersgruppen deutlich sank. Im Vergleich mit anderen Altersgruppen fällt auf, dass die Älteren bei Verkehrsunfällen besonders gefährdet sind und oft schwerere Folgen erleiden: 25,5% der Älteren waren nach Verkehrsunfällen schwer verletzt, bei den unter 65-jährigen nur 15,6%. Ein Unterschied zeigt sich auch bei dem Anteil der Getöteten, der bei den jüngeren bei 0,6% liegt, bei den Senioren aber bereits bei 2,1%. Das kann zum einen durch die Vulnerabilität der Älteren erklärt werden, zum anderen muss aber auch die Art der Verkehrsteilnahme berücksichtigt werden, denn die 65+-jährigen nehmen zum Bespiel häufiger als Fußgänger am Verkehr teil und sind so ungeschützter und verwundbarer. 2014 stellten Senioren 26% der getöteten Pkw-Insassen, 48% der getöteten FußgängerInnen und 57% der getöteten RadfahrerInnen (34, 75).

Auch bei den Unfallursachen zeigen sich Unterschiede, wenn man die verschiedenen Altersgruppen getrennt betrachtet. Während bei den unter 65-jährigen Pkw-Fahrern erhöhte Geschwindigkeit, Alkoholeinfluss und fehlendes Abstandhalten zu den häufigsten Unfallursachen zählen, finden sich bei Senioren eher Vorfahrtsmissachtung und Fehler beim Abbiegen, Wenden und Rückwärtsfahren (61, 75). Das lässt sich unter anderem durch die nachlassende Reaktionsfähigkeit der älteren Pkw-Fahrer erklären, die nur bedingt durch langjährige Fahrpraxis, geringe Risikobereitschaft und vorausschauendes Fahren kompensiert werden kann. Auch Alterserkrankungen können sich auf die Fahrtauglichkeit auswirken: reduzierter Visus, Sehfeld-Einschränkungen, vermindertes Kontrast- und Dämmerungssehen begünstigen Unfälle. Herz-Kreislauf- oder Stoffwechsel-Erkrankungen können bei schlechter medikamentöser Einstellung die Fahreignung beeinflussen. Hinzu kommen weitere sensorische und kognitive Defizite, sowie Neben- und Wechselwirkungen von Medikamenten (61).

Verbindung der Veröffentlichungen

Thema beider Veröffentlichungen ist die Frage nach Besonderheiten in Verletzungsmustern bei Traumata des älteren Menschen. Beiden Veröffentlichungen liegen Autopsie-Daten des Instituts für Rechtsmedizin der Ludwig-Maximilians-Universität München zugrunde, dessen grobes Einzugsgebiet das südliche Bayern ist. Bei Obduktionen werden die verschiedenen Körperregionen und Organe genau untersucht, die einzelnen Verletzungen detailliert beschrieben und im Obduktionsbericht festgehalten. Aus dem Autopsie-Register des Instituts wurden die Fälle nach Todesursache ausgewählt und aus den jeweiligen Obduktionsberichten die einzelnen Verletzungen entnommen. Diese wurden dann zur einheitlichen Beschreibung und Vergleichbarkeit untereinander anhand des „Abbreviated Injury Scale“-Katalogs (AIS© 2005 Update 2008) kodiert (1). Mit Hilfe dieser international anerkannten Kodierung kann die Schwere verschiedener Verletzungen auf einer Skala von 1 (gering) bis 6 (maximal) eingestuft werden und der Verletzungsschweregrad „Injury Severity Score“ (ISS) bei Polytrauma berechnet werden. Außerdem wird eine standardisierte Beschreibung von Verletzungen ermöglicht.

Besonderer Fokus liegt in beiden Publikationen auf der Altersgruppe 65+ Jahre. Untersucht wird inwieweit ältere Menschen anderen Umständen ausgesetzt waren als jüngere Menschen bei gleichen, tödlichen Verletzungsfolgen, beziehungsweise ob verschiedene Verletzungsmuster zum Tod geführt hatten und ob es Möglichkeiten gibt diese Folgen zu verhindern oder abzuschwächen.

In der Veröffentlichung „What are the differences in injury patterns of young and elderly traffic accident fatalities considering death on scene and death in hospital?“ (35) erfolgte dazu neben der Unterteilung nach Todesort (Krankenhaus oder Unfallort) vor allem auch eine Gegenüberstellung der zwei Altersgruppen „jung“ (15 bis einschließlich 64 Jahre) und „älter“ (65+ Jahre). Es wurden Unterschiede in den Verletzungsmustern zwischen den Altersgruppen gesucht, beispielsweise ob bei den älteren Menschen vergleichsweise häufiger andere Körperregionen, oder gleiche Körperregionen schwerer betroffen sind als bei den Jüngeren. Außerdem wurde anhand des jeweils errechneten ISS verglichen, ob bei den Älteren bereits weniger schwere Verletzungen zum Tod führen. Die bei älteren Menschen häufiger beobachteten Frakturen des Brustkorbs wurden hinsichtlich ihrer Bedeutung als Todesursache bei den über 64-jährigen einzeln untersucht.

In „Fatal falls in the elderly and the presence of proximal femur fractures“ (73) wurden dagegen ausschließlich über 64-jährige Menschen einbezogen. Es wurde zwischen verschiedenen Sturzarten unterschieden: Stürze in der Ebene wurden mit Stürzen auf oder von Treppen verglichen. Des Weiteren erfolgte eine Gegenüberstellung von Stürzen in der Ebene mit folgender proximaler Femurfraktur und ohne. Dabei wurden neben Verletzungsmuster und -schwere auch die Sturzumstände betrachtet. Soweit mit den gegebenen Daten möglich, wurden auch Osteoporose und Osteo-Sarkopenie, Alkohol und weitere Faktoren auf ihren Einfluss auf Verletzungen und Sturzursache evaluiert. Durch eine Häufigkeitsanalyse bestimmter Verletzungen, wie zum Beispiel Frakturen der Halswirbelsäule (cervical spine fractures), innerhalb der jeweiligen Sturzarten, wurde untersucht ob das Vorhandensein gewisser Verletzungen bereits auf eine Sturzart hindeuten kann. Des Weiteren wurde die bei Stürzen häufig beobachtete Fraktur des proximalen Femurs hinsichtlich ihrer Bedeutung als im Verlauf zum Tode führende Verletzung genauer untersucht.

Beide Veröffentlichungen sind keine Fall-Kontroll-Studien, sondern Beobachtungen und Analysen von Daten aus der Rechtsmedizin. Da das Fallkollektiv dadurch automatisch eingeschränkt ist und ausschließlich aus Todesfällen besteht, dürfen Schlüsse für mögliche Präventionsmaßnahmen nicht zu voreilig gezogen werden. Beispielsweise sahen wir bei den älteren Verkehrstoten seltener schwere abdominelle Verletzungen, was an einer erhöhten Vulnerabilität, an unterschiedlichen Sitzpositionen, dem durchschnittlich höheren BMI der Älteren, oder einer Kombination mehrerer Faktoren liegen könnte. Daher bedarf es weiterer, gezielt aufgebauter Studien.

Darstellung des Eigenanteils

Ich bin Erstautor der Veröffentlichung „What are the differences in injury patterns of young and elderly traffic accident fatalities considering death on scene and death in hospital?“ (35). Dafür griff ich auf eine institutsinterne Fallsammlung zu und verwendete die von C. Holzmann (mit Unterstützung von A. Fischer und S. Schick) erhobenen Daten, der die Verletzungen von Verkehrstoten mit Polytrauma aus dem Institut für Rechtsmedizin der Ludwig-Maximilians-Universität München der Jahre 2004 und 2005 nach AIS kodierte (66). Diese wurden von S. Schick und mir um die Fälle der gleichen Jahrgänge ohne Polytrauma erweitert und auf neue Fragestellungen hin untersucht. Nach Zusammentragen und Extraktion der für mich relevanten Informationen, analysierte überwiegend ich die Daten mit Microsoft Office Excel und IBM SPSS Statistics und führte statistische Tests durch. Des Weiteren übernahm ich vollständig die Nachkodierung der Verletzungen von einzelnen fehlenden - oder im Nachhinein eingeschlossenen – Fällen. Anschließend begann ich die Aufbereitung der Daten für die Publikation. Dies beinhaltete sowohl das Schreiben des Artikels, inklusive Literaturrecherche und Ergebnisdiskussion, als auch Formatierung und Organisation des fristgerechten Ein- und Wiedereinreichens nach Überarbeitung des Papers gemäß den Anmerkungen der Reviewer. Alle diese letztgenannten Tätigkeiten wurden überwiegend bis mehrheitlich von mir durchgeführt. Mein Arbeitsanteil an dem veröffentlichten Paper beträgt insgesamt 42,5%.

Für die Veröffentlichung „Fatal falls in the elderly and the presence of proximal femur fractures" (73) trage ich eine Mitautorschaft. Mein Arbeitsanteil bestand hierbei vor allem in der Datenerhebung durch Auswahl und Aufbereitung der Fälle. Dazu wählte ich aus dem Autopsie-Register des Instituts für Rechtsmedizin der Ludwig-Maximilians-Universität München die mit Sturzunfällen in Zusammenhang gebrachten Todesfälle von 2008 bis 2014 und entnahm den jeweiligen Obduktionsberichten die beschriebenen Verletzungen der Toten, welche ich anschließend einzeln nach AIS kodierte (Kontrolle durch A. Fischer und S. Schick). Des Weiteren extrahierte ich Zusatzinformationen zu Auffindungssituation und Unfallumständen aus den vorliegenden gutachterlich verwendeten Unterlagen, wie z.B. Kopien von Polizeiberichten, sofern diese im Institut für Rechtsmedizin vorhanden waren und weitere Informationen boten. Alle diese Tätigkeiten wurden vollständig von mir durchgeführt. Ich begann mit der Plausibilitätskontrolle und der anschließenden Datenanalyse mittels statistischer Testung mit Microsoft Office Excel und IBM SPSS Statistics. An der endgültigen Auswertung war ich mehrheitlich beteiligt. Mein Beitrag zu dem Manuskript waren insbesondere inhaltliche und sprachliche Ergänzungen und Korrekturen, sowie Literaturrecherche und -verweise und in Teilen die Formatierung aller Kapitel der Publikation. Zudem habe ich zu großen Teilen bei dem Erstellen der finalen Version, sowie der Antworten an die Reviewer mitgearbeitet. Mein Arbeitsanteil an dem veröffentlichten Paper beträgt insgesamt 40%.

Zusammenfassung

Unser Ziel war es Besonderheiten der Verletzungsmuster älterer Menschen (65+ Jahre) nach tödlichen Verkehrsunfällen und Stürzen zu identifizieren und zu beschreiben. Dazu wurden Autopsie-Daten aus dem Institut für Rechtsmedizin in München in zwei retrospektiven Studien analysiert. Die daraus erstellten Fallkollektive umfassen 309 Verkehrstote aus den Jahren 2004 und 2005 und 261 tödliche Sturzunfälle aus den Jahren 2008 bis 2014.

Die Studien wurden unter meiner Autoren- beziehungsweise Ko-Autorenschaft im *International Journal of Legal Medicine* publiziert:

- Heinrich D., Holzmann C., Wagner A., Fischer A., Pfeifer R., Graw M., Schick S.
  "What are the differences in injury patterns of young and elderly traffic accident fatalities considering death on scene and death in hospital?" (35)
- Schick S., Heinrich D., Graw M., Aranda R., Ferrari U., Peldschus S.
  "Fatal falls in the elderly and the presence of proximal femur fractures." (73)

Bei Verkehrsunfällen werden aktuell Rippenfrakturen als Risikofaktoren für eine höhere Mortalität diskutiert (6, 9, 41, 43). Etwa 60% der Verkehrstoten versterben noch am Unfallort und werden in den krankenhaus-basierten Traumaregistern nicht berücksichtigt. Daher blieben ihre Verletzungsmuster bisher weitestgehend unbekannt. Wir beziehen gerade auch diese Gruppe in unsere Auswertung ein. Unsere Ergebnisse zeigen deutliche Unterschiede in den Verletzungsmustern der verschiedenen Altersgruppen je nach Todesort. Die am Unfallort verstorbenen Älteren (≥65 Jahre) hatten häufiger schwere Thoraxverletzungen und Beckenfrakturen als die Jüngeren (≤65 Jahre), bei denen meist der Kopf die am stärksten verletzte Körperregion war. Ernste abdominelle Verletzungen waren bei den 65+-jährigen seltener zu sehen. Der ISS war weitgehend unabhängig vom Alter. Bei den im Krankenhaus Verstorbenen dagegen, hatten die Älteren einen deutlich niedrigeren ISS als die Jüngeren und insgesamt weniger schwerverletzte Körperregionen (MAIS 3+), sowie seltener schwere Verletzungen von Abdomen und Kopf. Die Anzahl der Rippenfrakturen war bei den älteren Verkehrstoten zwar signifikant höher, allerdings waren diese nur selten die Todesursache, wenngleich der Thorax am häufigsten die am stärksten verletzte Körperregion war. Wenn es um Präventionsmöglichkeiten geht, zeigen unsere Ergebnisse, dass die am Unfallort Verstorbenen, besonders auch im Hinblick auf Verletzungs- und Unfallmechanismen, nicht vernachlässigt werden dürfen. Rippenfrakturen als Risikofaktor für höhere Mortalität konnten wir an unseren Ergebnissen nicht nachvollziehen, aber sie können als Indikator für die Verletzungsschwere der Thoraxorgane genutzt werden.

Bei den Stürzen blieben - nach Ausschluss von beabsichtigten (Gewalt oder Suizid), postmortalen oder mit Möbeln assoziierten Stürzen – 77 Stürze in der Ebene und 39 Treppenstürze zur detaillierten Analyse. Obwohl die am stärksten verletzte Körperregion bei beiden Sturzarten am häufigsten der Kopf war (62% der Treppenstürze und 49% der Stürze in der Ebene), unterscheiden sich die Verletzungsmuster deutlich: Verletzungen der unteren Extremität waren vor allem bei Stürzen in der Ebene zu sehen. Besonderen Fokus legten wir auf die viel diskutierte proximale Femurfraktur (PFF), die bei keinem der Treppenstürze vorkam, aber bei 18 der 77 Stürze in der Ebene. In 17 Fällen (22% aller Stürze in der Ebene) war die PFF die einzig schwere Verletzung und führte in Folge zu Hospitalisierung und Tod. Alkohol als sturzbegünstigender Faktor und Frakturen der zervikalen Wirbelsäule fanden sich häufiger bei Treppenstürzen. Bei den anderen personenbezogenen Sturzumständen, beispielsweise den Komorbiditäten, ließen sich keine deutlichen Unterschiede zwischen den Sturzarten erkennen. Unsere Ergebnisse deuten darauf hin, dass durch das Verhindern von PFFs – zum Beispiel durch Optimierung von Hüftprotektoren – möglicherweise 22% der Tode durch Stürze in der Ebene hätten verhindert werden können; insbesondere in der Gruppe der 75 bis 84-jährigen mit Mobilitätseinschränkungen. Des Weiteren legen unsere Ergebnisse die Vermutung nahe, dass bei Autopsien von Sturztoten eine PFF eher auf einen Sturz in der Ebene hindeutet, während eine Verletzung der zervikalen WS häufiger bei Treppenstürzen zu sehen ist. Thompson et al. berichten eine Zunahme von zervikalen WS-Frakturen bei zunehmender Sturzhöhe und Alter (76). Allerdings kommen diese auch bei Stürzen in der Ebene vor (11, 48, 81).

Allgemein konnten wir zeigen, dass die 65+-jährigen als eine gesonderte Gruppe mit spezifischen Verletzungsmustern zu betrachten sind. Bei den Verkehrstoten zeigen sich diese Unterschiede sowohl zwischen den Altersgruppen als auch den jeweiligen Todesorten. Auch bei den Sturztoten finden sich zwischen den Sturzarten deutliche Unterschiede in den Verletzungsmustern. Um Präventionsmaßnamen abzuleiten, sollten in zukünftigen Studien bei Verkehrsunfällen Alter und Todesort für gesonderte Betrachtungen berücksichtigt werden und bei Stürzen größere Kollektive gewählt und nach Sturzart unterschieden werden.

Conclusion

We aimed to identify and describe characteristics of injury patterns in the elderly (65+ years) after fatal road traffic accidents and fatal falls. In two retrospective studies we analysed autopsy-data of the Institution of Legal Medicine in Munich. The compiled collective comprises 309 road traffic fatalities of the years 2004 and 2005 and 261 fatal falls from 2008 to 2014. The studies were published in the *International Journal of Legal Medicine* under my author- and co-authorship:

- Heinrich D., Holzmann C., Wagner A., Fischer A., Pfeifer R., Graw M., Schick S.
  "What are the differences in injury patterns of young and elderly traffic accident fatalities considering death on scene and death in hospital?" (35)
- Schick S., Heinrich D., Graw M., Aranda R., Ferrari U., Peldschus S.
  "Fatal falls in the elderly and the presence of proximal femur fractures." (73)

Regarding road traffic accidents (RTAs), rib fractures are currently discussed as risk factor for higher mortality (6, 9, 41, 43). About 60% of road traffic fatalities die on scene and are not included in hospital-based trauma registers. Their injury patterns therefore remained widely unknown until now. We included especially this group in our evaluation. Our results clearly show differences in the injury patterns of the different age groups depending on site of death. Elderly (≥65 years) who died on scene more often had serious thorax injuries and pelvic fractures than the younger (≤65 years). In the younger fatalities the head was the most severely injured body-region most often and serious abdominal injuries occurred more frequently than in the elderly. The ISS was largely independent of age. However, the elderly that died in hospital showed a notably lower ISS than the younger and fewer seriously injured (MAIS 3+) body regions. They also presented with serious head or abdominal injuries less often. The number of rib fractures was significantly higher in the elderly road traffic fatalities but almost never the cause of death; although the thorax most often was the most seriously injured body region. Our results show that those who die on scene must not be neglected when talking about prevention measures, especially when regarding injury and accident mechanisms. We could not show that rib fractures are risk factors for higher mortality, but our results suggest that rib fractures can indicate the ISS of the thoracic organs.

After careful screening and excluding falls caused by intention (violence or suicide), post-mortem falls or falls associated with furniture, we had 77 Ground Level Falls (GLFs) and 39 stair falls left for detailed analysis. Although the head was the most seriously injured body region in both fall categories (62% in the stairs falls and 49% of the GLFs) injury patterns clearly differed: there was a higher share of injuries to the lower extremities in the GLFs. We especially focused on proximal femur fractures (PFFs) that occurred in none of the stairs falls but in 18 of the 77 GLFs. For 17 among them (22% of all GLFs), the PFF was the only serious injury, leading to hospitalization and death. Alcohol as contributing to the fall and cervical spine fractures were seen more frequently in the stairs falls. For the other personal circumstances regarded, for example co-morbidities, no significant differences between the two types of falls were found. Our results suggest, that by preventing PFFs – for example by optimized hip protection – 22% of the GLF deaths could possibly have been avoided; especially in the group of 75 to 84-year olds with limited mobility. The results of our study also indicate that when autopsying fall-deaths a PFF rather hints towards a GLF, whereas cervical spine fractures appear more often in stair falls. Thompson et al. describe an increase of cervical spine fractures with increasing fall height and age (76). However, cervical spine fractures also occur in ground level falls (11, 48, 81).

In general, we were able to show that it is important to regard the elderly as a separate group with specific injury patterns. In road traffic fatalities, differences are seen between the different age groups and regarding the site of death. Also, the two types of fall-related deaths show different injury patterns. To derive conclusions for preventive measures, future studies concerning RTAs should consider age and site of death for further examination and regarding falls, bigger collectives should be chosen, and types of falls should be examined separately.

Veröffentlichung I

What are the differences in injury patterns of young and elderly traffic accident fatalities considering death on scene and death in hospital?

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ORIGINAL ARTICLE

What are the differences in injury patterns of young and elderly traffic accident fatalities considering death on scene and death in hospital?

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Abstract Older traffic participants have higher risks of injury than the population up to 65 years in case of comparable road traffic accidents and further, higher mortality rates at comparable injury severities. Rib fractures as risk factors are currently discussed. However, death on scene is associated with hardly survivable injuries and might not be a matter of neither rib fractures nor age. As 60% of traffic accident fatalities are estimated to die on scene, they are not captured in hospital-based trauma registries and injury patterns remain unknown. Our database comprises 309 road traffic fatalities, autopsied at the Institute of Legal Medicine Munich in 2004 and 2005. Injuries are coded according to Abbreviated Injury Scale, AIS© 2005 update 2008 [1]. Data used for this analysis are age, sex, site of death, site of accident, traffic participation mode, measures of injury severity, and rib fractures. The injury patterns of elderly, aged 65+ years, are compared to the younger ones divided by their site of death. Elderly with death on scene more often show serious thorax injuries and pelvic fractures than the younger. Some hints point towards older fatalities showing less frequently serious abdominal injuries. In hospital, elderly fatalities show lower Injury Severity Scores (ISSs) compared to the younger. The number of rib fractures is significantly higher for the elderly but is not the reason for death. Results show that young and old fatalities have different injury patterns and reveal first hints towards the need to analyze death on scene more in-depth.

Keywords Traffic fatalities · Elderly · Rib fracture · Injury pattern · Prehospital mortality · Abbreviated Injury Scale

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Introduction

According to the United Nations, people aged 60 years and over are predicted to reach a share of 34% of Europe's population in 2050 [2]. They still actively take part in daily life, including working and traffic participation. Regarding the time they spend in traffic daily (on average more than 1 h), the German mobility panel 2013 [3] shows that around 45% of the time are traveled in a car and around 30% are spent as pedestrians.

The increased share of elderly in the population and their vulnerability are reflected in the increase of geriatric trauma as several studies have shown [4–8]. Trauma patients, including road traffic accident (RTA) casualties, aged 65 or older, have a higher mortality [5, 9]. Age alone [10] but also preexisting diseases, functional decline, and co-morbidities coming with age [11–13] seem to increase mortality rates in the elderly.

In comparison to gender and body mass index, age was shown to be a more significant predictor for Abbreviated Injury Scale 3+ (AIS3+) injury risk for more body regions by crash type, especially for thorax and head injuries [14]. In car passengers, the influence of airbag and steering wheel on the cause of injury seems to decrease for the elderly in favor of seat belts. Furthermore, the increasing risk of thoracic injury with age was shown to be significantly higher for women than for men [15]. It was also demonstrated that from 65 years on osteoporosis was the most common contributing factor for injury risk, followed by obesity [15].

Age-dependent changes in bone substance and thorax geometry like single rib and sternum morphology and rib angles have been investigated extensively [16–24]. However, their influence on rigidity and response in terms of deflection and deformation and their contribution to rib fracture risk are not finally solved [25, 26]. Accordingly high-standard finite element (FE) human models are developed, improved, and used for biomechanical impact and injury simulations [17, 22–31]. Load limiters are established, and seat belt pretensioners have been shown to protect elderly car occupants from Maximum Abbreviated Injury Scale 3+ (MAIS3+) thorax injuries [32]. Age elevates the risk for rib fractures, and increasing numbers of rib fractures are contributing to worse outcomes [33–35]. Kent et al. [19] reveal that older drivers are significantly more likely to die of a chest injury and less likely to die of a head injury.

In-hospital mortality is higher for elderly patients due to frailty [36], co-morbidities, and probably due to a so-called inflamm-aging phenomenon [37]. Currently, only little is known about death on scene [38]. In many countries, including Germany, a 60% rate of motor vehicle collision and or trauma fatalities are estimated not to reach hospital [39–43], and therefore, those patients will not occur in clinical trauma registries. Preventing death on scene by focusing on these 60% of RTA fatalities could contribute to the reduction of RTA fatalities as claimed by the Decade of Road action 2011–2020 [44]. It might be assumed that death on scene occurs in cases with critical and maximum injury severity, however, in the elderly frailty (bones, but probably also lung capacity and circulation) also might contribute to mortality. In general, trauma deaths are reported to be preventable in around 40% [39, 45]. The rate within the deaths on scene remains unknown. The question arises, if identifying elderly high-risk patients [46–51] is complicated by a minor manifestation of severe injuries, in addition to the higher risk of dying from comparatively minor injuries.

It is widely accepted that age increases the injury risk and the severity of injuries in comparable accident situations. Furthermore, elderly with the same injury severity as younger patients show a higher mortality. What we do not know is the following:

Do elderly RTA fatalities show a different injury pattern compared to the younger?
Are injury patterns of fatalities different for death on scene and death in hospital, depending on age?
Are rib cage fractures a frequent cause of death in elderly fatalities?

Material and methods

Sample definition

The sample consists of traffic accident fatalities, including death after 30 days, who were autopsied at the Institute of Forensic Medicine, Ludwig-Maximilians-University (LMU) in Munich, in the years 2004 and 2005. Fatalities with death due to other reasons than traffic accidents (e.g., suicide) or with an unclear causal relationship between accident and death were excluded, as well as children younger than 15 years. The capture area roughly covers Southern Bavaria. The autopsy rate is known to be higher for the area of Munich as the capital city, compared to the surroundings.

Data extraction and categorization

Extracted data from autopsy reports and public prosecution files were sex (male/female), age in years, site of accident (urban/rural/autobahn/unknown), traffic participation (bicycle/pedestrian/powered two-wheeler/passenger car/other), time to death (exactly in hours and days), site of death (on scene/in hospital), cause of death, and all injuries. Postmortem computer tomography had not been performed in 2004 and 2005, so that possibly, additional injuries that can better be traced by imaging as for example the facial skeleton, spine, pelvis, extremities [52, 53], and bone bruises [54] might be underrepresented.

Injuries were coded according to the Abbreviated Injury Scale, AIS© 2005 update 2008 [1], by trained but not certified coders and control readers (C.H., A.F., D.H.). In case of need, coding was discussed and decisions were made with a supervisor (S.S.). The MAIS, the Injury Severity Score (ISS) (grouped to <15, 16 to 32, 33 to 66, and 75), and the region in which the MAIS occurred (detailed and categorized to Head/Thorax/HeadandThorax/other(s)) were documented, as well as the MAIS in every body region (named HeadMAIS, ThoraxMAIS, etc.), the appearance of body region AIS3+ (yes/no), and the number of body regions with AIS3+, AIS3+ indicating an AIS of 3 points or higher and being at least a serious injury. The body regions we used represent the AIS body regions 1 to 9 [1], except for the spine where we coded cervical spine to neck, thoracic spine to thorax, and lumbar spine to abdomen and regarded the pelvic bone separately. AIS3+-injured body regions as yes/no were calculated as sample percentages.

Bony thorax injuries were analyzed in detail. The number of rib fractures and the number of fractured ribs were documented. In case of expressions like *multiple fractures of all ribs on the left side/all ribs on the left side are multiply fractured* in the autopsy report, the minimum number of fractures mentioned was counted. In the example given, *multiply fractured* is translated to *at least two* fractures per rib and therefore counted as 24 fractures (on 12 ribs). Rib fractures clearly attributable to resuscitation were not taken into account.

In addition, we created a variable indicating that a rib cage fracture (excluding thoracic spine) is the most severe injury of the regarded person and therefore leads to the ThoraxMAIS and overall MAIS. Hence, any other injuries occurring in this person have lower AIS severities.

Data analysis

This descriptive but exploratory cross-sectional study includes only fatalities, and therefore, mortality cannot be derived. There is no case control study performed; neither risk factors for fatal outcome nor survival are analyzed. The age group of the elderly (65+ years) is compared to the younger age group (up to 65 years, excluding children younger than 15 years) to see if there are any differences in the injury patterns. As different accident circumstances might contribute to different injury patterns, the variables mentioned above are analyzed for both age groups. This comparison is done separately for death on scene and for death in hospital to be able to identify any possible differences and to compare the results with literature.

For data analysis, Microsoft Office © Excel 2010 was utilized and statistical testing was done with IBM ® SPSS ® Statistics v23.0.0.0. For sample description, a cross tabulation of sex, site of accident, and traffic participation for both sites of death are performed and only the results of the chi-squared tests will be reported. Bivariate frequency distributions for listed variables (see above) for both age groups are calculated. Chi-squared tests are applied for nominal and ordinal variables; Mann-Whitney *U* test for independent samples is used to compare frequencies of rib fractures and of fractured ribs. The association between number of rib fractures and number of fractured ribs with the ThoraxMAIS is tested by median and Kruskal-Wallis test. As this study should be seen as a first screening analysis, the significance level is set to 5% and Bonferroni correction is not applied. The results of the bivariate analyses are presented in tables (numbers and percent), results towards rib cage fractures as most severe injury of the person are presented in absolute numbers, and the numbers of rib fractures and fractured ribs are displayed by box plots.

The percentage of fatalities showing an AIS3+ injury in a given body region is grouped to percentage ranges covering 0 to <20, 20 to <40, 40 to <60, 60 to <80, and 80 to 100%, depicted in different shades from white to black and graphically presented in a body scheme. This analysis is performed for young and old at both sites of death and each for passenger car occupants and pedestrians, urban and rural, and male and female. For other groups of participation (bicyclists, powered two-wheelers, and others) and accident site autobahn, the case numbers are too low. Statistical tests are not performed.

Representativeness

We compared data from the Bavarian State Office for Statistics and Data Processing of traffic fatalities (age >14 years) within the capture area with our autopsied fatalities. Traffic fatalities are defined by death within 30 days; therefore, we excluded autopsied fatalities that died after 30 days for the representativeness analysis. The differences between age groups (up to 65/65+ years), sex, and traffic participation are investigated. As the site of death (on scene/in hospital) is not documented by the statistical office, representativeness cannot be assessed for this aspect. It is analyzed whether sex and traffic participation are distributed accordingly within each age group and furthermore, if the age groups are equally represented. The findings will be used for discussion, not for extrapolation calculations.

Results

The LMU autopsy material of RTA victims from 2004 to 2005 consists of 309 fatalities of which 89 (29%) are equal or older than 65 years. Three-hundred-one persons with death within 30 days are regarded for representativeness checks. In the capture area, there had been 1093 RTA fatalities in the years 2004–2005 of which 255 were 65 years or older (23.3%). Thirty-four percent of the 65+ years were autopsied at our institute but only 26% of the group up to 65 years (see Electronic Supplementary Material (ESM) Tables 3 and 4).

Both age groups of our sample show a similar sex distribution as found in the traffic fatalities population (see ESM Tables 1 and 2); however, concerning the mode of traffic participation, both age groups show an overrepresentation of pedestrians. The autopsy rates for males and females are comparable. In the younger age group, 79% of pedestrian fatalities were autopsied but only 22% of the passenger car fatalities. In the group of the elderly, it was 57% of the pedestrians and 27% of the passenger car fatalities. Detailed numbers and frequency distributions can be found in the ESM Tables 1–4.

All 187 victims that died on scene (61% of all fatalities) were declared dead by an emergency physician either with or without resuscitation on scene. The maximum time between accident and declaration of death on scene was 1.17 h. Of each age group, 95% were declared dead within 35 min. The surviving time after the accident of in-hospital deaths varied widely; the median for the up to 65-year olds was 14.7 h (range half an hour up to 123 days). The group of 65+ year olds had a median survival time of 27.7 h (range 47 min up to 59 days).

Accident-, person-, and injury-related characteristics of both age groups with death on scene

Of all 187 victims dying on scene, 39 (21%) are in the age group 65+ years. There are more male fatalities in the younger group (see Table 1).

The cross tabulation shows a significant difference ($p = 0.009$) for the combination of age group, sex, site of accident, and traffic participation mode with a high share of young male motorcycle riders in rural accidents. Seven male and seven female elderly fatalities happened at urban sites, among them five females and two males as pedestrians. Due to low case numbers, a significant difference cannot be found for this subgroup.

In the bivariate analysis, a higher share of urban accidents is seen in the older age group (36 vs. 9%) and a higher share of powered two-wheelers in the younger group. Still, the fatal accidents most frequently occurred on rural roads in both age groups (74 and 56%; see Appendix Table 3).

An ISS of less than 16 is seen in 3.4% of the younger and none of the older fatalities. The most severely injured body region for age less than 65 years most frequently is the head (40%) and for 65+ year olds the thorax (39%). The elderly are discovered to have fewer seriously injured body regions. In the group up to 65 years, 23% only have up to two body regions with AIS3+, and in the 65+ year olds, there are 34%.

Thirty-six percent of the elderly show a MAIS of six in the thorax region, whereas in the group of up to 65-year olds, there are only 20% (n. sign; not shown in table). The person with MAIS2 (Table 1) remained with an unclear death, possibly

Table 1 Injury characteristics of different age groups of traffic accident fatalities with death on scene

On scene		Up to 65 years		65+ years		P value
Sample Size		148	(100.0%)	39	(100.0%)	
Sex	Male	116	(78.4%)	24	(61.5%)	0.031
	Female	32	(21.6%)	15	(38.5%)	
MAIS	2	1	(0.7%)	0	(0.0%)	0.391
	3	4	(2.7%)	0	(0.0%)	
	4	10	(6.8%)	6	(15.4%)	
	5	47	(31.8%)	12	(30.8%)	
	6	86	(58.1%)	21	(53.8%)	
ISS-Group	Up to 15	5	(3.4%)	0	(0.0%)	0.357
	16 to 32	9	(6.1%)	1	(2.6%)	
	33 to 66	48	(32.4%)	17	(43.6%)	
	75	86	(58.1%)	21	(53.8%)	
Most severely injured body	Head	59	(39.9%)	8	(20.5%)	0.105
	Thorax	35	(23.6%)	15	(38.5%)	
Region	Head and Thorax	17	(11.5%)	6	(15.4%)	
	Other	37	(25.0%)	10	(25.6%)	
Cause of death	Multiple trauma	82	(55.4%)	24	(61.5%)	0.198
	Central regulation failure	44	(29.7%)	7	(17.9%)	
	Bleeding	17	(11.5%)	6	(15.4%)	
	Aspiration	3	(2.0%)	0	(0.0%)	
	Cardiovascular failure	0	(0.0%)	1	(2.6%)	
	Combination of causes	0	(0.0%)	1	(2.6%)	
	Missing/unclear	2	(1.4%)	0	(0.0%)	
Number of body regions with AIS3+	reduced[a] sample size	134	(100.0%)	38	(100.0%)	0.378
	0	1	(0.7%)	0	(0.0%)	
	1	9	(6.7%)	3	(7.9%)	
	2	21	(15.7%)	10	(26.3%)	
	3	31	(23.1%)	13	(34.2%)	
	4	38	(28.4%)	5	(13.2%)	
	5	22	(16.4%)	5	(13.2%)	
	6	9	(6.7%)	2	(5.3%)	
	7	3	(2.2%)	0	(0.0%)	

[a] 15 persons excluded: with explosion type injury (6), burns (4), suffocation (4) and drowning (1)

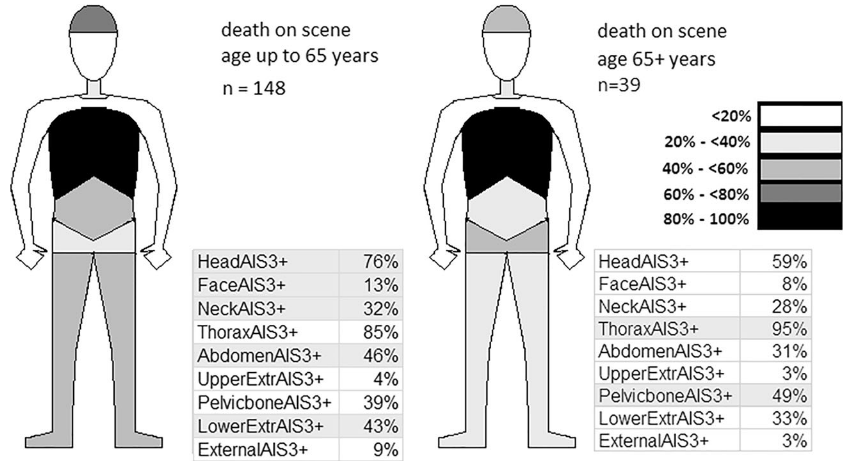


Fig. 1 Percentage of victims showing AIS3+ injury in different body regions for both age groups, death on scene (no visual representation of external body region), and body regions with higher percentages in comparison to the other age group are marked as *shaded cells* in the tables

already dying from internal reasons before crashing into a heavy goods vehicle at 30 km/h. In both age groups, the cause of death was documented by the forensic pathologist to be multiple trauma most frequently (55% of the younger, 62% of the older).

Figure 1 visually represents the frequencies of victims showing at least seriously injured (AIS3+) body regions. Of the two age groups, 85 and 95%, respectively, suffer from AIS3+ thorax injuries. Serious to maximum head injuries are seen in 76% of the younger but only in 59% of the elderly. Nearly half of the younger (46%) have AIS3+ abdominal injuries, but only 31% of the elderly do. Further, 49% of the elderly show AIS3+ pelvic fractures but only 39% of the younger.

In urban as well as in rural accidents, the younger more often show serious injuries to the head, abdomen, and lower extremities and less often serious thorax injuries and pelvic fractures compared to the elderly (see Appendix Fig. 7). When separately regarding passenger car occupants and pedestrians, the differences also remain; however, the elderly pedestrians more often show lower leg injuries (see Appendix Fig. 6).

This pattern also remains for males, whereas elderly females additionally show serious abdominal and lower leg injuries more frequently than the younger females (see Appendix Fig. 5).

Rib fractures in both age groups and rib cage fractures as most severe injury; death on scene In the age group up to 65 years, there is one person with rib fractures being the most severe injuries and leading to the ThoraxMAIS5 and overall MAIS5. In the age group 65+ years, there is no one to whom that applies. Yet, the number of rib fractures and the number of affected ribs are strongly associated with the ThoraxMAIS (all tests $p = 0.000$).

The number of rib fractures (median 20 vs. 11, ranges from 0 to 64 and 0 to 47, respectively, $p = 0.000$) and the number of affected ribs (median 18 vs. 10, both ranging from 0 to 24, $p = 0.000$) are higher for the elder group compared to the younger (see Fig. 2).

Accident-, person-, and injury-related characteristics of both age groups with death in hospital

Of all 122 victims dying in hospital, 72 are up to 65 years old and 50 are in the age group 65+ years. There are more male than female fatalities in the younger age group (64%) and more females in the elderly (54%, $p = 0.050$; see Table 2).

The cross tabulation does not show a significant difference ($p = 0.187$) for the combination of age group, sex, site of accident, and traffic participation mode. Still, it seems noteworthy that in urban accidents, 11 out of 13 elderly females are pedestrians, and in the elderly males, there are only 9 out of 15.

However, the site of accident shows a higher share of urban accidents in the older age group, and the traffic participation shows a high share of elderly pedestrians (see Appendix Table 4).

More than 50% of the elderly show an ISS 16 to 32 and more than 50% of the younger an ISS 33 to 66 (see Table 2). It

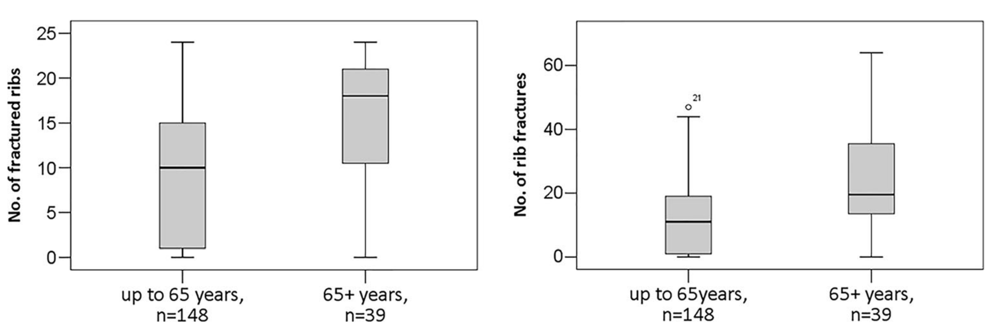


Fig. 2 Distribution of rib fractures (number and number of ribs affected) for both age groups with death on scene

seems remarkable that 14% in the younger group are attributed an MAIS of 6. The person with MAIS2 died from a paralytic ileus after 14 days.

The most severely injured body region for age less than 65 is the head (50%) and for 65+ year olds in 36% the head and in 30% the thorax. The elderly have fewer seriously injured body regions. Fifty-two percent of the younger and 72% of the elderly only have up to two AIS3+-injured body regions.

The younger in-hospital deaths die from multiple trauma and central regulation failure in 82%, the elderly only in 64% (see Table 2).

About 75% of both age groups suffer from AIS3+ thorax injuries (see Fig. 3). Eighty-two percent of the younger show serious to maximum head injuries, but only 66% of the elderly do. Further, 29% of the younger show AIS3+ abdominal injuries, and in the elderly, it is only 14%.

The tendency of the young showing serious head, abdominal, and lower extremity injuries more frequently, and a similar share of pelvic fractures compared to the elderly remains the same when looking at passenger car occupants and pedestrians separately (see Appendix Fig. 9). Only exception is serious thorax injuries which shift to higher shares in elderly pedestrians compared to the young.

The described injury pattern for young and old stays the same when looking at rural accidents. However, in urban accidents, serious pelvic fractures are found more

Table 2 Injury characteristics of different age groups of traffic accident fatalities with death in hospital

In hospital		Up to 65 years		65+ years		*P* value
Sample size		72	(100.0%)	50	(100.0%)	
Sex	Male	46	(63.9%)	23	(46.0%)	0.050
	Female	26	(36.1%)	27	(54.0%)	0.051
MAIS	2	0	(0.0%)	1	(2.0%)	
	3	14	(19.4%)	9	(18.0%)	
	4	20	(27.8%)	19	(38.0%)	
	5	28	(38.9%)	21	(42.0%)	
	6	10	(13.9%)	0	(0.0%)	
ISS group	Up to 15	6	(8.3%)	4	(8.0%)	0.002
	16 to 32	18	(25.0%)	27	(54.0%)	
	33 to 66	38	(52.8%)	19	(38.0%)	
	75	10	(13.9%)	0	(0.0%)	
Most severely injured body region	Head	36	(50.0%)	18	(36.0%)	0.332
	Thorax	13	(18.1%)	15	(30.0%)	
	HeadandThorax	7	(9.7%)	3	(6.0%)	
	Other	16	(22.2%)	14	(28.0%)	
Cause of death	Central regulation failure	32	(44.4%)	16	(32.0%)	0.577
	Multiple trauma	27	(37.5%)	16	(32.0%)	
	Bleeding	6	(8.3%)	6	(12.0%)	
	Shock	2	(2.8%)	2	(4.0%)	
	Cardiovascular failure	1	(1.4%)	2	(4.0%)	
	Pneumonia	1	(1.4%)	2	(4.0%)	
	Combination of causes	1	(1.4%)	0	(0.0%)	
	Thromboembolism	0	(0.0%)	1	(2.0%)	
	Others	1	(1.4%)	1	(2.0%)	
	Unclear/missing	1	(1.4%)	4	(8.0%)	
Number of body regions with AIS3+	reduced sample size[a]	71	(100.0%)	50	(100.0%)	
	0	0	(0.0%)	1	(2.0%)	0.280
	1	14	(19.7%)	12	(24.0%)	
	2	23	(32.4%)	23	(46.0%)	
	3	21	(29.6%)	11	(22.0%)	
	4	8	(11.3%)	2	(4.0%)	
	5	3	(4.2%)	1	(2.0%)	
	6	2	(2.8%)	0	(0.0%)	

[a] One burn injury (with lung inhalation trauma AIS6) excluded

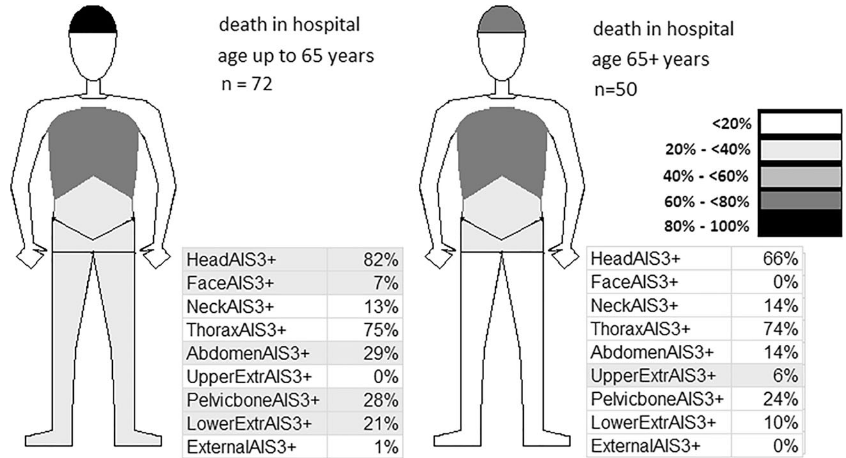


Fig. 3 Percentage of victims showing AIS3+ injury in different body regions for both age groups, death in hospital (no visual representation of external body region), and body regions with higher percentages in comparison to the other age group are marked as *shaded cells* in the tables

often in the young, and a higher share of serious thorax injuries is seen in the old, whereas head and lower extremity injuries are found about equally frequent (see Appendix Fig. 10).

There is a change in the injury pattern when separating by sex; AIS3+ head injuries are seen more often in the young females compared to the old, but for male fatalities, the frequencies are about the same for both age groups. Serious thorax injuries are rather found in the elderly female and in the young males. Serious pelvic fractures appear more frequently in young males compared to the old and in the old females compared to the younger (see Appendix Fig. 8).

The abdominal injury frequency remains as described, higher shares for the younger ones in males and females, on both sites of accident, and for both analyzed modes of traffic participation.

Rib fractures in both age groups and rib cage fractures as most severe injury; death in hospital In the age group up to 65 years, there are seven persons with rib cage fractures being their most severe injury and leading to their ThoraxMAIS and overall MAIS, one person with MAIS4 and six persons with MAIS5. In the age group 65+ years, there are five persons, three with MAIS4 and two with MAIS5. Yet, the number of rib fractures and the number of affected ribs are strongly associated with the ThoraxMAIS (all tests $p = 0.000$).

Comparing the age group up to 65 years with the age group 65+, the number of rib fractures (median 2 vs. 9, ranges from 0 to 48 and 0 to 54, respectively, $p = 0.095$) and the number of affected ribs (median 2 vs. 7, ranges both from 0 to 24, $p = 0.041$) are higher for the elderly (see also Fig. 4).

Discussion

For the RTA fatalities with death on scene, it firstly can be seen that young and old do not show significant differences in the injury severity. In more than 50% of both age groups, non-survivable conditions (AIS6—currently untreatable and ISS 75, respectively) were present.

Yet, the most severely injured body region most frequently was the head for age less than 65 years and the thorax for the 65+ year olds. The elderly show a MAIS of six in the thorax region in 36% of cases, the younger only in 20%. The thorax as body region with the MAIS is seen in 39% of the elderly and 23% of the younger. These findings match the age-dependent injury patterns described by Kent et al. in 2005 [19], who report 47.3 and 24.0%, respectively. For the in-hospital deaths, we see 30% of the elderly and 18% of the younger with the MAIS in the thorax region.

The elderly with death on scene show higher shares of at least serious thorax injuries compared to the young, still when separated to sex, accident site, and traffic participation. For the in-hospital fatalities, there is no clear difference between old and young in the frequency distribution of AIS3+ thorax

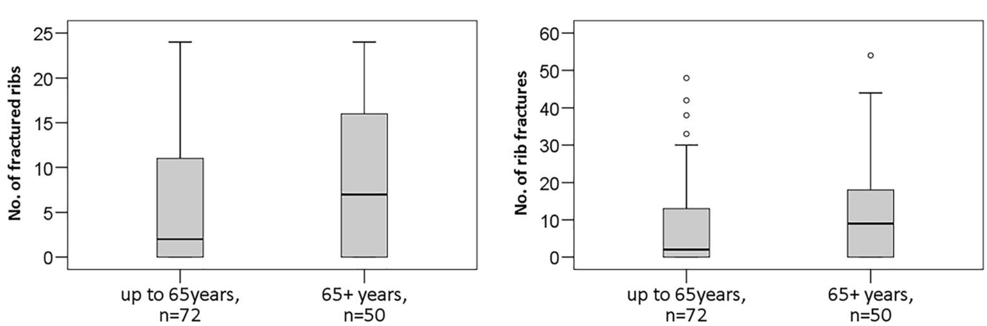


Fig. 4 Distribution of rib fractures (number and number of ribs affected) for both age groups with death in hospital

injuries. Only in the elderly females, higher shares are seen compared to the young, as well as in the elderly fatalities participating as pedestrians and in urban accidents. These findings could be explained by the high percentage of females in pedestrian and urban accidents. The different trends for males and females were also reported before [14, 15], yet, we can only confirm this for the in-hospital deaths.

The analysis whether the rib cage injury was the most severe injury and lead to the MAIS shows low numbers for both age groups with death on scene. In the group of the 15 elderly who died of an MAIS in their thorax region, there was no one dying from rib cage fractures, which is remarkably lower than the 56% of in-hospital fatalities, older than 60 years dying solely from rib fractures if the MAIS was in the thorax region, that are reported by Kent et al. in 2008 [34]. Also, our in-hospital deaths show only 5 out of 15 (one third) in the elderly with bony thorax fractures leading to the MAIS. One reason for this strong deviation might be that they [34] included cases in which body regions other than the thorax additionally showed the same MAIS value. The rib cage fractures as cause of death do not seem to be very important for death on scene but more relevant for the in-hospital fatalities. On both sites of death, the rib cage fractures as most severe injury of the person are of severities AIS4 and AIS5, implying that neither sternum fractures nor simple rib fractures of any number, nor unilateral flail including up to five ribs, contributed to a fatal outcome. This is in line with Borman 2006 [55] and Huber et al. 2014 [56], who confirm a higher mortality for in-hospital patients by thorax injuries only for the bilateral flail chest (AIS5).

Still, rib fractures are frequently named as being associated to a higher mortality risk, especially for the elderly [33, 34, 57–60]. As we cannot derive mortality risks from our study, we can only confirm higher rates of rib fractures in the elderly compared to the younger for both in-hospital fatalities and also for the deaths on scene; a causal relationship between rib fractures and death should be doubted [56, 61]. Further, we can fortify the association between number of fractured ribs and number of rib fractures to the thorax injury severity in general.

We found serious to maximal abdominal injuries more frequently in the young fatalities. For death on scene, this can only partly be explained by a higher share of males, as this relation is not found in females. An explanation could be the young males' participation as motorcycle riders where high shares of abdominal injuries are known as contributing to mortality [62]. However, the difference between old and young for abdominal injury is also found in passenger car occupants, pedestrians, and also in the in-hospital deaths with a stable relation throughout all subdivision to sex, accident site, and traffic participation. Concerning the elderly with comparably lower abdominal injury rates, yet higher thorax injury rates, this finding could be interpreted as kind of a trade-off. One geometric element that might explain the differences for abdomen and thorax injuries is the comparatively more pronounced kyphosis of the elderly thoracic spine. However, this hypothesis needs further research.

The pelvic bone is seen to be more affected in the elderly with death on scene compared to the younger (49 vs. 38%), even when separating to traffic participation and sex, except for urban accidents. Seat belt geometry and load limiters could help to protect the car occupants [32] by addressing thorax, abdomen, and pelvic bone. However, this difference is also seen in the pedestrians. Especially in pedestrians, a high pelvic fracture frequency in general has been described [63–65]. The relevance of pelvic fractures is frequently addressed [66–68]; however, we can only confirm an age effect like Kimbrell et al. and Toth et al. [69, 70] for the deaths on scene, where the high share of rural accidents might contribute to this finding. Although we found a higher share of urban accidents in the older age group, still, 22 of the 39 accidents (56%) occurred on rural roads; for the younger aged, the share was 72%. In Germany, 58% of the traffic fatalities stem from rural roads in 2015 (see Tables 3.1_(4) and 2_(2) in "Verkehrsunfälle Zeitreihen" of the Statistic Office [71]). Rural accidents are thought to be more severe [72] due to higher velocities than in urban areas, and in contrast to motorways, most often, there are oncoming traffic and unfavorable roadside conditions present [73]. The 65+-year-old drivers in Germany were more frequently involved in turning (especially turning left), crossing (especially collisions with bicycles from the right when entering a priority road), and pedestrian accidents compared to the younger [74]. Only the first situation (turning left) might lead to a fatal outcome for the older driver; therefore, it seems obvious that fatal accidents need to be analyzed separately. From our data, we see higher numbers of pelvic bone injuries in the elderly passenger car occupants with death on scene; however, to conclude a higher share of side impacts would be too far-fetched. The direction of impact influences the injury pattern and needs to be taken into account in a following analysis with increased case numbers.

More than 50% of both age groups with death on scene show an ISS of 75. This confirms the hypothesis that a death on scene is mostly due to non-survivable injuries. When looking at the deaths in hospital, in the group of fatalities up to 65 years, 14% had a MAIS of 6, while in the group of elderly, there were none. A possible explanation could be that intensified resuscitation measures are taken to save children and younger adults or that they are able to survive longer with a maximum injury (MAIS6), and therefore, more of them manage to leave the site of accident and can be brought to hospital. It needs to be analyzed if undertriage and less aggressive treatment could be a reason for elderly casualties not to reach hospital, as is reported in different studies [46–51, 75].

Our data reveals the tendency that in traffic fatalities aged 65 and older, fewer body regions with an AIS3+ are found than in the group up to 65-year olds. That observation applies for both death sites, on scene and in hospital. Already, Osler et al. [76] found that elderly people more often have fatal outcomes than the younger but are less likely to be injured in the first place. Looking at the ISS of deaths in hospital, there are significantly more severely injured fatalities in the younger group than in the elderly ($p = 0.003$). This finding is consistent with Chiang et al. [77], who use an ISS cutoff value of 15 to classify trauma as major or minor and show that compared to the younger patients (ISS = 17) among the elderly (65 years and older), a lower ISS cutoff value predicts a higher mortality rate. Werman et al. developed geriatric trauma triage criteria [78], and Calland et al. request to treat all elderly trauma patients (65+ years) with one body region of AIS3+ in a trauma center [79]. Pape et al. [80] include the factor age in the "Berlin definition" as one parameter (age ≥70 years), contributing to the definition of polytrauma. According to them, still two or more AIS body regions need to be injured with a severity of at least AIS3. Ninety-two percent of our fatalities on scene in both age groups show at least two body regions with AIS3+ (in hospital around 75%).

On scene, multiple trauma was the most frequent cause of death (57%), followed by central regulation failure (28%). Three studies report multiple trauma as a cause for on scene deaths in 59% [41] and for early deaths in 40% [81] and 16% [82]. The central nervous system as the cause of death is reported by different authors in 49% [83, 84], 21% [81], 27% [82], 46% [85], and 73% [42]. Especially for in-hospital early deaths, bleeding seems to be a common cause of death today [86, 87] and also still the central nervous system [42, 85, 88]. In our sample, bleeding as cause of death (in hospital) is only found in 8% (young) and 12% (old). In all studies mentioned, different definitions of early and late death as well as different inclusion criteria (all trauma including falls or only multiple trauma patients as well as all fatalities or all hospital admittances) and different coding habits are found, so that a direct comparison is not possible and might explain some of the deviances between our findings and literature. Yet, it indicates that when focusing on death on scene of RTA victims, the frequency distributions of causes of death are shifting towards multiple trauma.

From the results found when focusing on death on scene in comparison to deaths in hospital, it would be advisable to perform future studies in order to analyze risk factors for mortality and detect possible preventive factors. These studies could combine and match data, e.g., from the TraumaRegister DGU® for our capture area; increase case numbers; and draw a representative sample for conducting, e.g., a case control study.

The selection of cases is conditioned by the decision of the responsible state attorneys whether an autopsy has to be performed. Yet, comparable to the traffic fatalities in our capture area with a share of 23% elderly, we find a share of 21% in our sample with death on scene, however a share of 40% with death in hospital. The pedestrian is more frequently autopsied than any other traffic participant. As pedestrians clearly are vulnerable road users, it is necessary to perform an autopsy in addition to accident reconstruction for determining the accident causes as it has legal consequences for the involved opponent. The Statistical Office presents a share of 24% pedestrians and 47% car occupants in the elderly traffic fatalities. The time they spend in traffic shows comparable frequencies [3], so that an increased risk by the mode of traffic participation cannot be concluded for our capture area.

The representativeness checks revealed that traffic fatalities' analysis of our sample needs to be performed by taking age, sex, site of accident, site of death, and traffic participation into account.

To our knowledge, this is the first study presenting injury pattern separately to age groups and taking site of death into account. Following analyses with increased case numbers also regarding direction of impact, impact speed, and opponent will lead to results that are more robust.

Conclusion

Do elderly RTA fatalities show a different injury pattern compared to the younger?
Yes, elderly RTA fatalities do show different injury patterns compared to the younger; these differences can only partly be explained by different distributions of sex, traffic participation, or site of accident within the age groups.
Are injury patterns of fatalities different for death on scene and death in hospital, depending on age? Yes, it seems that elderly with death on scene more often show serious to maximal thorax injuries and pelvic fractures than the younger. Elderly with death in hospital less frequently show AIS3+ abdominal and head injuries compared to the younger. A lower injury severity in the elderly is seen more clearly for in-hospital fatalities.
Are rib cage fractures a frequent cause of death in elderly fatalities?
Bony thorax injuries and rib fractures are very seldom the cause of death for elderly RTA fatalities, although we did find the thorax to be the most severely injured body region most frequently and observed rib fractures to occur more often in the elderly. Rib fractures should be regarded as an indicator for the injury severity of the thoracic organs.

Our study shows that for developing new ideas for prevention measures, the RTA fatalities that die on scene must not be neglected. Death on scene should be analyzed apart from death in hospital and should at least be stratified to age, sex, accident site, and traffic participation mode. It is advisable to take further steps, increase the data material, and analyze the deaths on scene more in-depth, with a view on both, injury, and accident mechanisms.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix

Table 3 Percentage of road accidents seen in younger and older age groups with death on scene

On scene		Up to 65 years	65+ years	*P* value
Sample size		148 (100.0%)	39 (100.0%)	
Site of accident	Autobahn	21 (14.2%)	3 (7.7%)	0.001
	Rural	110 (74.3%)	22 (56.4%)	
	Urban	14 (9.5%)	14 (35.9%)	
	Unknown	3 (2.0%)	0 (0.0%)	
Traffic participation	Bicycle	12 (8.1%)	5 (12.8%)	0.035
	Pedestrian	27 (18.2%)	11 (28.2%)	
	Powered two-wheeler	28 (18.9%)	1 (2.6%)	
	Passenger car	72 (48.6%)	22 (56.4%)	
	Other	9 (6.1%)	0 (0.0%)	

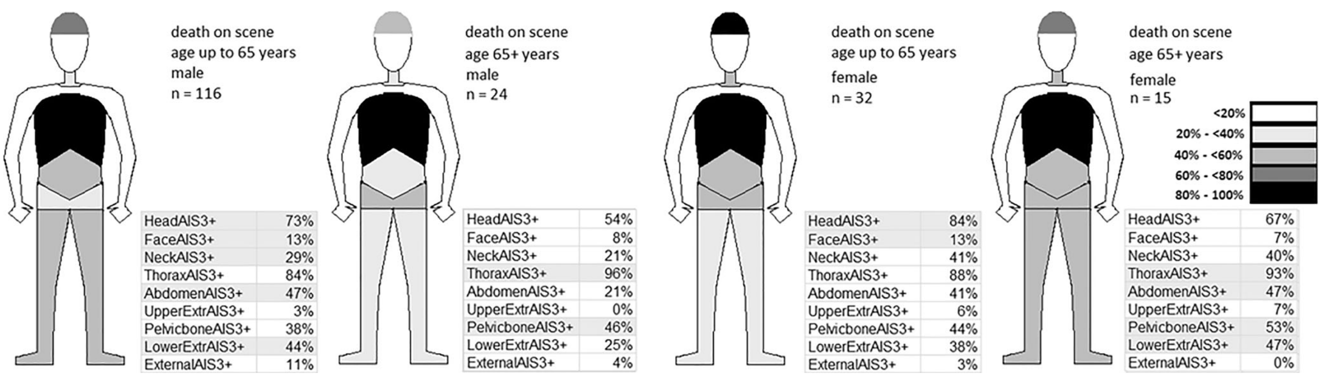


Fig. 5 Percentage of males and females showing AIS3+ injury in different body regions, both age groups, death on scene (no visual representation of external body region), and body regions with higher percentages in comparison to the other age group are marked as *shaded cells* in the tables

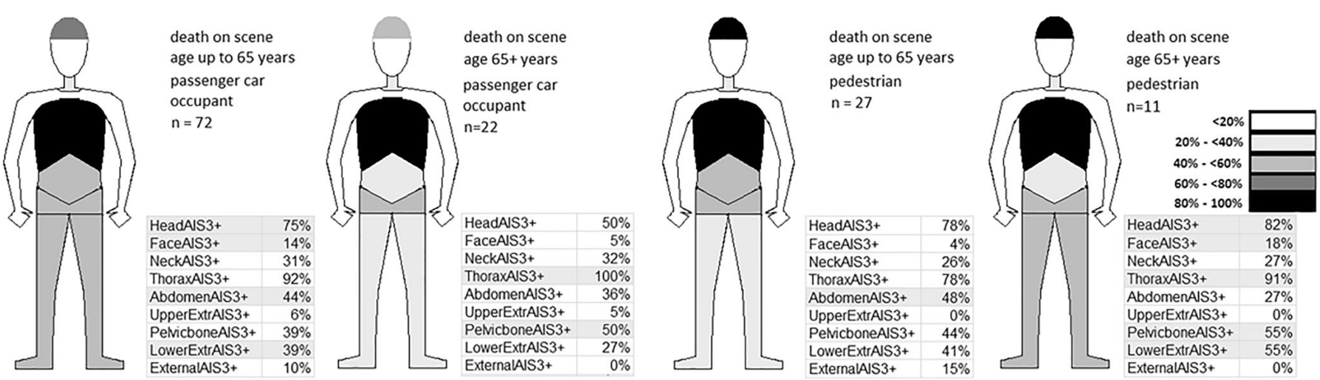


Fig. 6 Percentage of passenger car occupants and pedestrians showing AIS3+ injury in different body regions, both age groups, death on scene (no visual representation of external body region), and body regions with higher percentages in comparison to the other age group are marked as *shaded cells* in the tables

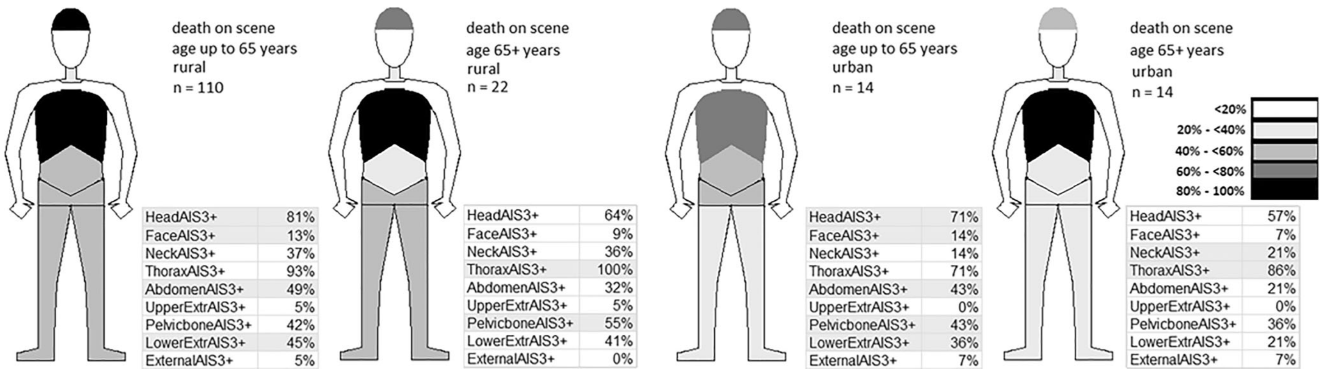


Fig. 7 Percentage of rural and urban fatalities showing AIS3+ injury in different body regions, both age groups, death on scene (no visual representation of external body region), and body regions with higher percentages in comparison to the other age group are marked as *shaded cells* in the tables

Table 4 Table 4 Cross tabulation of age group, sex, site of accident, and traffic participation mode for death in hospital

In hospital		Up to 65 years	65+ years	*P* value
Sample size		72 (100.0%)	50 (100.0%)	
Site of accident	Autobahn	7 (9.7%)	1 (2.0%)	0.035
	Rural	38 (52.8%)	18 (36.0%)	
	Urban	23 (31.9%)	28 (56.0%)	
	Unknown	4 (5.6%)	3 (6.0%)	
Traffic participation	Bicycle	7 (9.7%)	11 (22.0%)	0.002
	Pedestrian	21 (29.2%)	27 (54.0%)	
	Powered two-wheeler	6 (8.3%)	1 (2.0%)	
	Passenger car	37 (51.4%)	10 (20.0%)	
	Other	1 (1.4%)	1 (2.0%)	

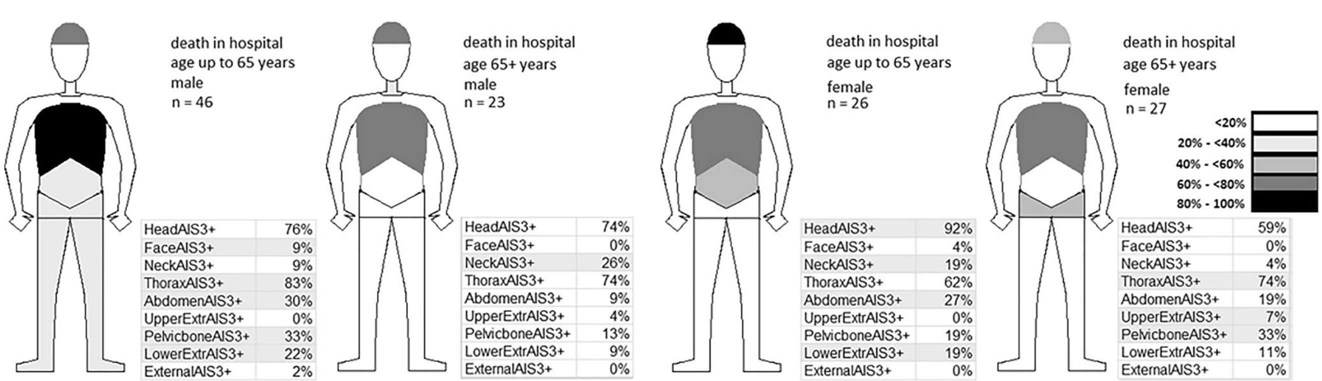
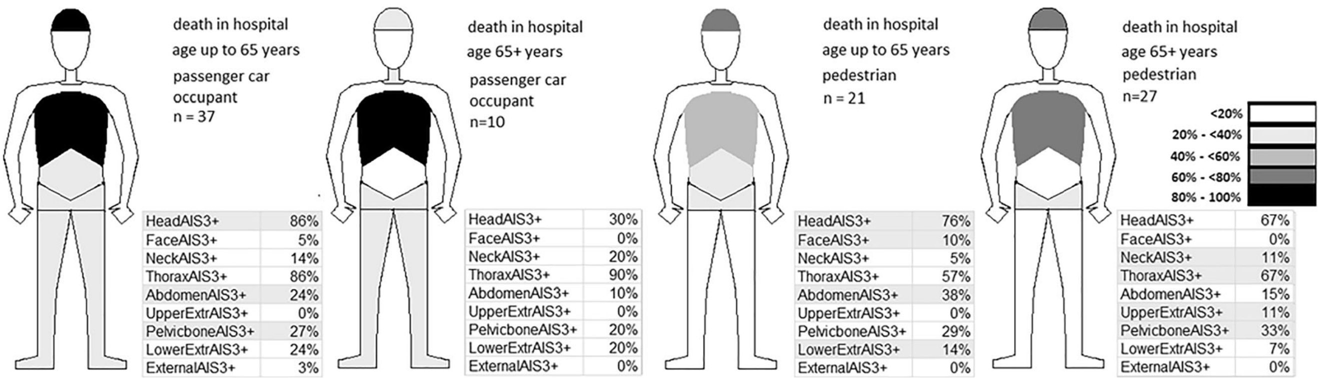
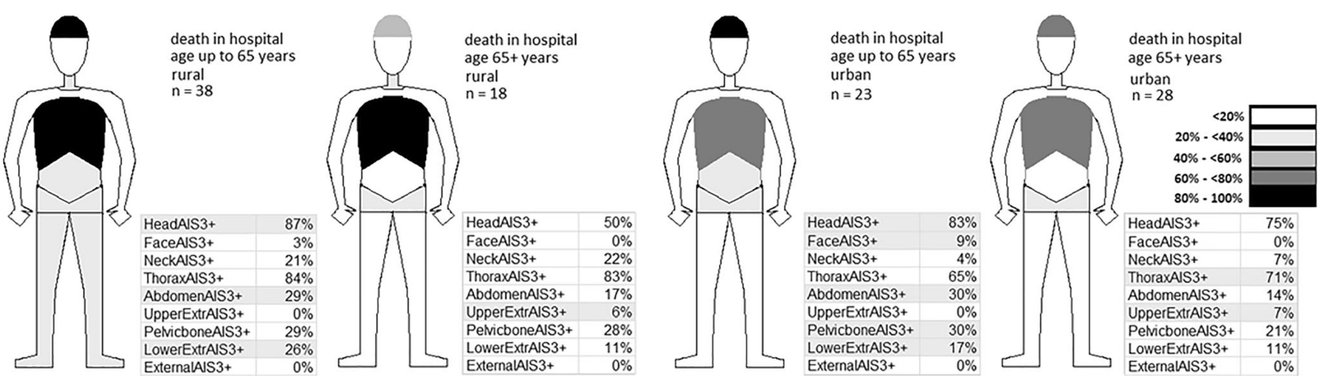


Fig. 8 Percentage of males and females showing AIS3+ injury in different body regions, both age groups, death in hospital (no visual representation of external body region), and body regions with higher percentages in comparison to the other age group are marked as *shaded cells* in the tables



	passenger car occupant, up to 65 years (n = 37)	passenger car occupant, 65+ years (n=10)	pedestrian, up to 65 years (n = 21)	pedestrian, 65+ years (n=27)
HeadAIS3+	86%	30%	76%	67%
FaceAIS3+	5%	0%	10%	0%
NeckAIS3+	14%	20%	5%	11%
ThoraxAIS3+	86%	90%	57%	67%
AbdomenAIS3+	24%	10%	38%	15%
UpperExtrAIS3+	0%	0%	0%	11%
PelvicboneAIS3+	27%	20%	29%	33%
LowerExtrAIS3+	24%	20%	14%	7%
ExternalAIS3+	3%	0%	0%	0%

Fig. 9 Percentage of passenger car occupants and pedestrians showing AIS3+ injury in different body regions, both age groups, death in hospital (no visual representation of external body region), and body regions with higher percentages in comparison to the other age group are marked as *shaded cells* in the tables; low case numbers in elderly passenger car occupants need to be regarded



	rural, up to 65 years (n = 38)	rural, 65+ years (n = 18)	urban, up to 65 years (n = 23)	urban, 65+ years (n = 28)
HeadAIS3+	87%	50%	83%	75%
FaceAIS3+	3%	0%	9%	0%
NeckAIS3+	21%	22%	4%	7%
ThoraxAIS3+	84%	83%	65%	71%
AbdomenAIS3+	29%	17%	30%	14%
UpperExtrAIS3+	0%	6%	0%	7%
PelvicboneAIS3+	29%	28%	30%	21%
LowerExtrAIS3+	26%	11%	17%	11%
ExternalAIS3+	0%	0%	0%	0%

Fig. 10 Percentage of rural and urban fatalities showing AIS3+ injury in different body regions, both age groups, death in hospital (no visual representation of external body region), and body regions with higher percentages in comparison to the other age group are marked as *shaded cells* in the tables

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Veröffentlichung II

Fatal falls in the elderly and the presence of proximal femur fractures.

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ORIGINAL ARTICLE

Fatal falls in the elderly and the presence of proximal femur fractures

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Abstract

Fatal falls are frequent and seem to be an increasing problem in the elderly. Especially ground level falls (GLFs) and falls on or from stairs and steps (stairs falls) are worth examining for forensic classification and in order to improve the development of preventive measures. We retrospectively analyzed 261 fatal falls of elderly age 65 + years, which were autopsied at the Institute of Legal Medicine in Munich between 2008 and 2014. After careful screening, the sub-set of all 77 GLFs and 39 stairs falls were analyzed towards socio-demographic characteristics, fall circumstances, injuries, and circumstances of death. A subsequent analysis of GLF cases regarding the presence of proximal femur fractures (PFF) was performed. The injury pattern of the GLFs and the stairs falls clearly differ with a higher share of injuries to the lower extremities in the GLFs. However, the most severely injured body region was the head in both groups (62% of the stairs cases, 49% of the GLF cases). Alcohol as contributing to the fall was seen more frequently in the stairs falls. PFF were not seen in the stairs falls, but then in 18 GLF cases. Yet, for 17 among them (22% of 77), their hip fracture was the only serious injury leading to hospitalization and death. Only one GLF case was already found dead. This finding indicates a potential of avoiding up to 22% of the GLF fatalities by preventing hip fractures by optimized hip protectors or other measures, especially for the elderly aged 75 + years.

Keywords Ground level falls · Falls on or from stairs or steps · Elderly · Proximal femur fracture · Hip protection

Highlights
- Of all autopsied fatal falls in the elderly, 30% were found to be ground level falls (GLFs) and 15% falls on and from stairs and steps
- In both fall categories, a head injury was the most severe injury most frequently
- Alcohol was contributing to the fatal fall more frequently in stairs falls
- Cervical spine fractures in fatal falls seem to indicate stairs falls but less likely GLFs
- In 22% of fatal GLFs of elderly, a proximal femur fracture was the only serious injury
- GLF fatalities with proximal femur fracture showed no further relevant injury, had only a maximum Abbreviated Injury Scale © severity value of 3 (MAIS 3), were typically 75 to 84 years old, fell in-doors, and in around 30% physical limitations in walking were pre-existent.

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Introduction

Falls in the elderly are regarded to be a major problem. The WHO estimates 646,000 fatal falls to occur each year, and states that falls are the second leading cause of unintentional injury death, after road traffic injuries; especially the elderly are at risk of death after a fall [1]. In Germany, more than 50% of all injuries in persons over 60 are caused by falls [2]. According to Gillspie et al. [3] around 30% of people over 65 years of age (65 + y) living in the community fall each year.

Consequences of falls in the elderly often include fractures, immobility and resulting impairment, and sometimes finally death. Kramarow et al. [4], report that in the USA, in 2012–2013, 55% of all unintentional injury deaths among adults aged 65 + y were due to falls. They further showed that from 2000 through 2013, the age-adjusted fall injury death rate among adults aged 65 + y nearly doubled. An increase in fall-related deaths among the elderly is also reported by Orces [5]. Contributing to the increasing fall death rate might be "changing trends in underlying chronic diseases and better reporting of falls as the underlying cause of death" as Stevens and Rudd (2014) suspect [6].

Injuries resulting from ground level falls (GLFs) in the elderly are typically thought to include hip fractures, that is, proximal femur fractures (PFF). Yet, a decrease in the incidence of hip fractures is reported in various studies [7–11]. Further, increasing numbers of cervical spine fractures [12, 13] and of pelvic fractures are reported [14–16]. Last, an increased risk for intracranial fall-related injuries is seen by Evans et al. (2015), in the very elderly population [17].

"Old Age" in itself does not seem to be a predictor for serious fall-related injury [18]. However, osteosarcopenia is associated to aging, and was confirmed to be a risk factor for falls and fractures [19]. For the prediction of hip fracture risk, the factors body weight, body height, impact force, body mass index BMI, hip soft tissue thickness, and bone quality seem to resemble a good model [20]. Merilainen [21] sees low weight, tall height, and further also respiratory disease, tendency to fall indoors, and inability to walk alone outdoors as criteria for the elderly to use hip protectors. These are wearable devices that are intended to reduce the risk for hip fractures by attenuating impact forces applied to the femur by either absorbing energy or shunting energy to surrounding soft tissues [22]. They are placed over the greater trochanter and proximal femur. Limited acceptance to use them in daily life due to discomfort and, even more, the confirmation of their effectiveness are challenges related to hip protectors. Any preventive measures seem to be apt especially at home, as the majority of severe injuries seem to happen there [17].

A decrease of hip fracture incidence is reported, especially in females (and an increase in subtrochanteric, pelvic, and acetabular fractures) [9–11, 13, 16], and medication with bisphosphonates is discussed as reason for this trend [7, 11, 13]. Increase in BMI in the population [23] could also have contributed to this trend, as increased soft tissue thickness decreases the risk of PFFs [20]. However, PFF can be addressed by protectors. So, if possible, the injury should really be prevented, especially if it has the potential for leading to death.

Falls in the elderly are not limited to GLFs, even if their relevance for resulting in severe injury, high rate of readmissions, and increased mortality is undisputed [24]. Fatal falls from ladders in middle-aged and older men are reported to be of increasing relevance [25, 26].

This study aims to have a closer look at the circumstances and injuries occurring in the course of the most frequent types of fatal falls in the elderly by using information from autopsy reports. Further, we were interested in the relevance and frequency of PFFs in fatal falls, which would allow estimating any potential of possible measures directed at the prevention of hip fractures and/or fatalities.

Material and methods

Sample definition

We selected cases from the autopsy register of the Institute of Legal Medicine, Ludwig-Maximilians-University (LMU) by the entry in the variable "Morbidity and Mortality." All W00 to W19 codes and additional free text entries including "Sturz" (German for "fall") were regarded. This way we came to a number of 261 fatalities if only considering the years 2008 to 2014 and fatalities aged 65 years and older.

For a detailed analysis of ground level falls "GLF" (including W01 Fall on same level from slipping, tripping, and stumbling and W18 Other fall on same level) and W10 Fall on and from stairs and steps ("stairs") forming the two biggest groups (besides W19 Unspecified falls), all 261 cases were screened for plausibility and recoded if necessary.

The capture area roughly covers the southern half of Bavaria. The forensic autopsy rate for fatal falls in the capture area is estimated to be around 6% (261 out of half of the 8746 cases in Bavaria [27]).

Data extraction

For the analysis of GLFs (only W01 and W18) and stairs falls (W10), the autopsy reports, further entries in the registry (like unnatural death circumstances), and any additional in-house available information of all 261 cases were taken into account to clearly categorize them. Some cases needed to be discussed (D.H. and S.S.) in order to assign them to one of the groups or exclude them due to doubts concerning circumstances of the fall. Falls that occurred to be suicides (especially in the stairs falls group) and death due to other reasons like apoplexy or heart attacks with falls as "post-mortem" consequences were eliminated, leaving 116 cases. Within the stairs fatalities was documented, if a cellar stair was involved.

Extracted data were as follows: sex (male/female), age in years, contributing cause of fall (physical limitations/cardiovascular system/cerebral issues/alcohol/normal circumstances/others), walking aid (yes/no), scene of fall (at home/private/hospital/care facility/in public/unknown), time of fall (day/night/unknown), housing situation (alone/with partner/in care/others/unknown), history of falls (none, one, multiple), and pre-existing conditions (heart disease/hypertension/diabetes/peripheral arterial occlusive disease/post-stroke/liver disease/pulmonal disease/renal failure/indication of osteoporosis/cancer/anticoagulation/indication of dementia).

For the situation after the fall, the time to death (exactly in hours and days) and the "final cause of death" (trauma/bleeding/cerebral hemorrhage/heart failure/pneumonia/pulmonary embolism/sepsis or MODS (multi organ dysfunction syndrome)/other/not clear/combination of causes) were extracted and analyzed. For coding details, see Appendix.

Injuries were coded according to the Abbreviated Injury Scale, AIS© 2005 update 2008 [28], by three trained but not certified coders and control readers. In case of need, coding was discussed and decisions were made with a supervisor. The MAIS (maximum AIS), the Injury Severity Score ISS (grouped to < 15, 16 to 26, 27 to 41, 42 to 66, and 75), and the region(s) in which the MAIS occurred (head, face, neck including cervical spine, thorax including thoracic spine, abdomen including lumbar spine, upper extremities, lower extremities including pelvis, and external) were documented.

Further, the MAIS in every body region (named as $MAIS_{head}$, $MAIS_{thorax}$, etc.) and the presence of $MAIS_{bodyregion}$2+ (yes/no) were documented. The body regions we used for the $MAIS_{bodyregion}$ represent the body regions mentioned above, except for separately regarding the pelvic bone.

In addition, the following selected injuries independent of their AIS severity were extracted per person on a yes/no basis: skull fracture (including base), base fracture, brain injury (AIS codes 1402**, 1404**, 1406** including brain stem, cerebrum, and cerebellum, including hematoma), thorax fractures, cervical spine fractures, injuries to thoracic or abdominal/pelvic contents (internal organs), pelvic bone fracture, proximal femur fracture, and upper extremity fracture.

For data analysis, Microsoft® Excel® 2013 was utilized and statistical testing was done with IBM ® SPSS ® Statistics V23.0.0.0. Only for variables with less than 10% unknowns, the two-sided Fisher exact test was applied; the significance level is set at 5%. This is not a case-control study, even if the design is alike, but a comparison of two distinct groups: First of all, a comparison of GLFs versus stairs is performed, secondly a comparison of GLFs with PFF versus GLFs without PFF.

For an overview on fatal falls in the elderly, a description on type of fall and socio-demographic data is presented for all 261 cases.

Characteristics (socio-demographic, injuries, circumstances of falls, and death) of the GLFs in contrast to the stairs falls are presented in tables and diagrams, and a body scheme for the share of cases showing AIS2+ injuries in the different body regions.

Elderly with proximal femur fractures in the GLF group are compared to those without this fracture to find characteristics in injury pattern and circumstances. The results are presented similarly.

Results

Sample description

Between 2008 and 2014, there were 261 “fall” cases in our autopsy material, 32% were defined as falls on the same level, falls on and from heights were present in 26%, and falls involving equipment in 13%. Falls from ladders were seen only four times, for further detailed numbers for fall subgroups and categorization see appendix Table 5. One hundred thirty-four of the 261 cases were men (51%). Around one third each were in the age group 65–74 years (33%) and 75–84 years (34%), only 4% were older than 94 years.

Circumstances and injuries of ground level falls and falls on or from stairs and steps

After careful screening of the 261 fatal falls, there remained 77 “GLF” and 39 “stairs” cases.

No significant differences in the age and sex distributions are found, see Table 1. In both groups, most of the fatalities were 65 to 85 years old. In only around 20% of both fall groups, a history of at least one or even multiple falls was known, numbers not shown in Table 1. The majority of falls took place at home (58% of GLF and 82% of stairs). Stairs to the cellar were found in nine out of the 39 stairs falls. The GLF cases lived in care facilities in 17%, the stairs fatalities only in 3%; in this housing situation, this was also the place where they fell, see Table 1. Due to high numbers of missing values, no statistical tests were performed for housing situation and time of fall (50% of the GLF without information) and categories are not presented in Table 1.

Twenty and 28%, respectively, were already found dead. However, overall 34% of the GLF fatalities died within 24 h after the fall, while in the stairs fatalities it have been 64%; the distributions differ significantly ($p = 0.005$). For more details, see Fig. 1.

No significant differences are seen for all analyzed pre-existing diseases and conditions (dementia, osteoporosis, a.s.o., see Methods section) of elderly with GLFs and fall on or from stairs. More than 65% of the elderly in both fall groups showed any kind of heart diseases; in addition, in around 30% in both groups, hypertension was known. For all other conditions, the prevalence in both groups ranged below 20% each (not pictured).

All contributing causes that lead to the fall were somewhat more frequently seen in the GLF falls, except for alcohol, which was seen more often in the stairs falls, (no significant differences), see also Fig. 2. The cardiovascular system was probably contributing to the fall in around 30% in both groups, and physical limitations in walking abilities were seen in around 20%. For most of the items, no hints were found in the available information. Further, nearly no information on shoes, carpets, light conditions, or obstacles contributing to the fall was extractable from the files.

Consequence of fall

More than 50% of the GLF fatalities have an ISS of less than 15, but only 18% of the stairs falls. The median ISS values are

Table 1 Socio-demographics and circumstances of falls in GLF and stairs fatalities

Sample size		GLF		Stairs		*p* value
		77	100.0%	39	100.0%	
Sex	Female	42	55%	20	51%	.844
Age categories (years)	65 to 74	25	32%	13	33%	.314
	75 to 84	25	32%	18	46%	
	85 to 94	24	31%	8	21%	
	95 to 104	3	4%	0	0%	
Scene of fall categories	At home	45	58%	32	82%	.057
	Private	3	4%	0	0%	
	Hospital	3	4%	0	0%	
	Care facility	13	17%	1	3%	
	In public	12	16%	6	15%	
	Unknown	1	1%	0	0%	

14 and 24, respectively. In addition, when regarding the MAIS, it shows that the stairs falls are more frequently more severely injured ($p = 0.015$). A MAIS of 6 is seen only twice, both times in the stairs falls group, see also Table 2.

The most severely injured body region is the head in 49% of the GLFs, and in 63% of the stairs fatalities, followed by the lower extremities (including the pelvic bone) for the GLFs (31%), and the neck in the stairs fatalities (13%), see also Table 2.

Further, Table 2 depicts that some particular fractures show significant differences between GLF and stairs falls fatalities: the skull fracture, the base fracture, the cervical spine fracture, fractures in the thorax, and the proximal femur fracture PFF. Especially the PFF therefore shows a high positive predictive value for a GLF. The positive predictive value of the cervical spine fracture indicating a stairs fall is 75% (9 out of 12), however, based on low case numbers.

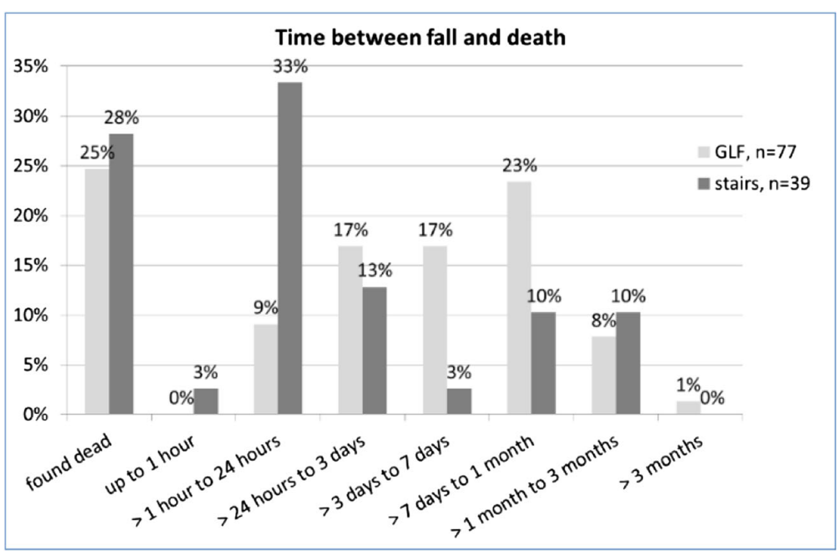
For illustration reasons, the frequencies of body regions being at least moderately injured ($MAIS_{bodyregion}$ 2+) within both fall samples are pictured in the following Fig. 3. Except for the lower extremities, the stairs falls fatalities show more frequently at least moderate injuries in all body regions (see given percentages in Fig. 3). Statistical differences (separate univariate tests, all $p < 0.03$) are seen for the head, neck, thorax, and upper and lower extremities.

The final cause of death was trauma (one cervical spine trauma and 18 traumatic brain injuries (TBI)) or remained not clear both in around one fourth of the GLF cases, in the stairs falls it was trauma in 59% (of them one multiple trauma, three cervical spine/cord trauma, and 19 TBI). For both groups, pneumonia was seen in 10% of the cases, see Table 3.

Proximal femur fractures in ground level falls

Eighteen of the 77 elderly with ground level falls show PFFs (23%). No difference in sex is seen between those with or without PFF. PFF seems to occur especially in the age group

Fig. 1 Relative distributions of time between fall and death, both for GLF and stairs fatalities



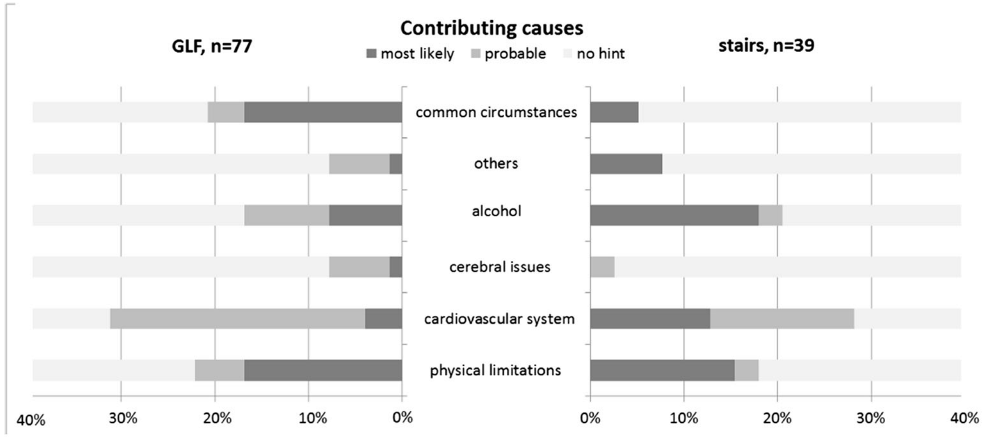


Fig. 2 Frequencies of contributing causes to the fall event in GLF and stairs fatalities, multiple answers possible

of 75 to 84 years, whereas most of the GLF fatalities without PFF were between 65 and 74 years old, see Table 4.

All of those 18 GLFs with PFF do not show any additional injuries worth mentioning. Twice abdominal injuries and once thoracic injuries are also present. The MAIS 3 is always due to the PFF, in one case the abdominal injury (mesentery laceration and kidney contusion) is of equal severity, see also Fig. 4. The ISS is only once higher than 15. The GLFs without PFF showed injuries in all body regions; most frequently, head and brain injuries were present.

No one of these 18 died because of the trauma, but 50% died of multiple causes or the reason for death remained unclear. Most of them later on passed away in hospital, only one was found dead (median survival 8 days, mean 25 days). Those without PFF were found dead in 31% (median survival 3 days, mean 9 days), see Table 4.

The housing situation did not differ significantly for both groups although the PFF group was less often living alone but more often in care.

The scene of fall was "at home" in half of the GLF with PFF, in 28% in a care facility, and only one with PFF fell in public. The GLF without PFF fell "at home" in 61% and only 14% fell in a care facility, but 19% in public ($p = 0.165$).

There were no differences seen in pre-existing diseases, the number of prior falls, the use of walking aids, and nearly all contributing causes for the falls (no tables shown). For no one of the PFF group osteoporosis was documented. However, 33% of the PFF group and 19% of the group without PFF exhibited hints for physical limitations ($p = 0.004$).

Discussion

Out of 261 elderly fatal falls autopsied at the Institute of Legal Medicine in Munich between 2008 and 2014, only 77 (30%) GLFs and 39 (15%) falls on or from stairs remained for detailed analysis. Comparable data from German autopsy studies are only available for GLFs by Thierauf [29]. They report 122 out of 291 cases (42%). The discrepancy might lie in our focus on elderly and excluding falls involving furniture.

Falls as causes for death are reported in 1.3% for Germany for 2014 ([27]). In Bavaria, there had been 8.746 fatal falls (W00-W19) in the age group 65 + years between 2008 and 2014. Sixty-eight percent were declared unspecified (W19). All kinds of GLF (W00–W03, W18) are reported only in 4.6% (388 cases). The selection of cases in our material is conditioned by the decision of the responsible state attorneys whether an autopsy has to be performed. GLFs might be autopsied more frequently than any other type of fall. As GLFs should not lead to death very frequently, it is necessary to perform an autopsy in order to identify natural death or clearly exclude third hand involvement. Another explanation might be that unspecified falls will turn out to having been a GLF after autopsy. Significant misclassification [30] and change in coding habits [6] is reported for the USA. This might explain that in the autopsy material we find 30% with GLF, but only 28% remain unspecified. Fatal falls from ladders are found in 2% in Bavaria and in 1.5% of our autopsy cases. It seems that in the elderly 65 + y, an increasing relevance as reported for elderly from years 50 on [25, 26] are not found in Bavaria at this time.

The population in Bavaria was around 2.4 million in the age group 65 + years (2,415,616, census date 09th May 2011, [31]). With international assumptions of 30% falls per year for elderly 65 + y [3], 28% in 2 years for elderly 60 + y [32], and 16% within 3 months [33], the lethality of falls would be calculated to lie around 0.2%.

Circumstances of GLFs and stairs falls

To our knowledge, for the first time, a sample of fatal falls of the elderly is presented that strictly excludes falls in the course of violence, falls in the frame of traffic accidents, post-mortal falls, or falls out of bed. In our fatalities, the shares of men and women were balanced, still when separating to GLFs and stairs falls and GLFs with or without PFF. The official

Table 2 Distributions of injury severities and injury occurrences in GLF and stairs fatalities

Sample size		GLF		Stairs		*p* value
		77	100%	39	100%	
MAIS	1	0	0%	1	3%	.015
	2	5	7%	0	0%	
	3	38	48%	10	26%	
	4	12	16%	11	28%	
	5	22	29%	15	39%	
	6	0	0%	2	5%	
ISS classes	Up to 14	40	52%	7	18%	.000
	16 to 26	25	33%	14	36%	
	27 to 41	11	14%	16	41%	
	42 to 66	1	1%	0	0%	
	75	0	0%	2	5%	
Body region of MAIS	Head	38	49%	25	63%	.000
	Face	1	1%	0	0%	
	Neck	4	5%	5	13%	
	Thorax	1	1%	3	8%	
	Abdomen	2	3%	1	3%	
	Upper extremities	2	3%	0	0%	
	Lower extremities	24	31%	1	3%	
	External[a]	2	3%	0	0%	
	Various combinations of Body regions[b]	3	4%	4	10%	
Presence of certain	Skull fracture[c]	24	31%	24	62%	0.003
Injuries (all severities)	Base fracture	18	23%	17	44%	0.033
	Brain injury[d]	41	53%	27	69%	0.114
	Cervical spine fracture	3	4%	9	23%	0.003
	Thorax or thoracic spine fracture	10	13%	19	49%	0.000
	Injury of internal organs	6	8%	9	23%	0.037
	Upper extr. fracture	2	3%	5	13%	0.042
	Prox. femur fracture	18	23%	0	0%	0.001
	Pelvic bone fracture	2	3%	3	8%	0.333

[a] Aspiration/suffocation

[b] Head/face (1), head/thorax (2), thorax/abdomen (2), abdomen/lower extremities (1), head/thorax/upper extremities/lower extremities (1)

[c] Vault and or base

[d] Including hemorrhages

statistics list some more females from age 65 + y; however, if regarded on a population basis, females show lower rates of fatal falls compared to men [27]. The prevalence of falls in the first is reported to be higher in women than in men [32]. Others confirm risk of fall and risk of injury due to falls to be higher in females [34–37]. It seems that the final consequence of death following a fall is not associated to sex. To conclude that the lethality of falls is lower for needs further studies, however, was already reported for PFF cases [7].

The characteristics of the falls of GLF and stairs fatalities also do not differ concerning age, pre-existing morbidities or the number of known falls in the past, and other circumstances. For many variables, only in few cases definite hints were traceable in the available information, which limits the findings regarding pre-existing morbidities and circumstances contributing to the fall. Especially osteoporosis and osteosarcopenia could be measured objectively in a prospective study to learn about risk factors for the fall and death following the fall. Further, a pharmacological analysis could be added to explore the contribution of anticoagulation to bleeding and death.

Not reaching significance a higher share of falls at home is seen for the stairs fatalities (82%) and around 20% of them were in connection with the cellar stairs, both results are in line with published findings [38–40]. In the GLFs, we find 58%

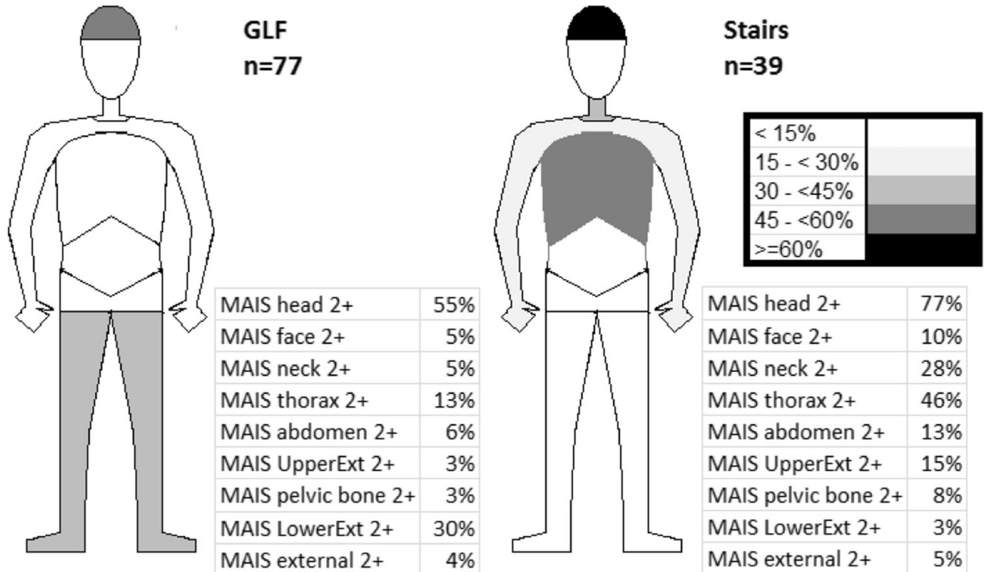


Fig. 3 Percentage of cases in the GLF and stairs fatalities showing at least moderate injury in the defined body regions

happening at home, comparable to [17, 35, 41–43]. In 39 and 49%, respectively, the GLF and stairs fatalities were living alone and in many cases the fall was not witnessed. Living alone might contribute to the decision to order an autopsy, but a high share of unknown housing situations limits any conclusion. Still, the potential of Personal Emergency Response Systems for earlier help in case of a fall can be assumed. The share of 17 and 3%, respectively, for GLF and stairs falls living in care might resemble an overrepresentation, as possible suspicions of negligence might lead to the decision to order an autopsy. Falls in nursing homes deserve deeper analyses with respect to of legal and ethical issues regarding the application of physical restraints and, e.g., working under short-staffed conditions.

A higher share of alcohol as contributing to the fall is seen in the stairs falls; however, a contribution to the fall event could be assumed only in around 20%. This is clearly in contrast to literature reporting shares of 38 to 54% [38–40], and might be due to our focus on elderly like comparably reported by Bux [38]. For the GLFs, the share of alcohol contributing to the fall was even less in comparison to published data [29], which can also be explained by our focus on elderly. Our result suggests a decreasing relevance of alcohol as contributing to falls with older age.

Table 3 Distribution of the final causes of death in the GLF and stairs fatalities

Sample size		GLF		Stairs		*p* value
		77	100%	39	100%	
Categories of final cause of death	Trauma	19	25%	23	59%	.036
	Bleeding	6	8%	1	3%	
	Cerebral hemorrhage	6	8%	0	0%	
	Heart failure	3	4%	0	0%	
	Pneumonia	8	10%	4	10%	
	Pulmonary embolism	3	4%	1	3%	
	Sepsis/MODS	2	3%	1	3%	
	Other[a]	6	8%	2	5%	
	Not clear[b]	20	26%	5	13%	
	Combination of causes[c]	4	5%	2	5%	

[a] Other: (aspiration/hypothermia/4 times central regulation failure/respiratory insufficiency/brain swelling)

[b] Not clear: multiple named differential diagnoses present

[c] Combination of causes: (CHD (coronary heart disease) + fat embolism), (pneumonia + MODS), twice: (TBI + aspiration, suffocation), (bleeding + CHD + heart hypertrophy + pulmonary emphysema), (bleeding + aspiration, suffocation)

MODS: multi organ dysfunction syndrome

Table 4 Characteristics of GLF fatalities with or without proximal femur fracture PFF

Sample size		PFF		no PFF		*p* value
		18	100%	59	100%	
Sex	Female	10	56%	32	54%	1.000
Age categories	65 to 74	1	6%	24	41%	.005
	75 to 84	11	61%	14	24%	
	85 to 94	6	33%	18	31%	
	95 to 104	0	0%	3	5%	
Death after...	found dead	1	6%	18	31%	.030
	> 1 to 24 h	1	6%	6	10%	
	> 24 h to 3 days	4	22%	9	15%	
	> 3 to 7 days	3	17%	10	17%	
	> 7 days to 1 month	4	22%	14	24%	
	> 1 to 3 months	4	22%	2	3%	
	> 3 months	1	6%	0	0%	
Final cause of death	Trauma	0	0%	19	32%	.009
	Bleeding	1	6%	5	9%	
	Cerebral hemorrhage	0	0%	6	10%	
	Heart failure	1	6%	2	3%	
	Pneumonia	3	17%	5	9%	
	Pulmonary embolism	2	11%	1	2%	
	Sepsis/MOF	1	6%	1	2%	
	Other	1	6%	5	9%	
	Not clear/multiple causes	9	50%	15	25%	
MAIS	2	0	0%	5	9%	.000
	3	18	100%	20	34%	
	4	0	0%	12	20%	
	5	0	0%	22	37%	
ISS classes	Up to 14	17	94%	23	39%	.000
	16 to 26	1	6%	24	41%	
	27 to 41	0	0%	11	17%	
	42 to 66	0	0%	1	2%	
Specific injuries	Head fracture	0	0%	24	41%	.001
	Base fracture	0	0%	18	31%	.008
	Brain injury	0	0%	41	70%	.000
	Cervical spine fracture	0	0%	3	5%	1.000
	Thorax or thoracic spine fracture[a]	1	6%	9	15%	.437
	Injury of internal organs[b]	2	11%	4	7%	.620
	Upper extr. fracture	0	0%	2	3%	1.000
	Pelvic bone fracture	0	0%	2	3%	1.000

[a] Two fractured ribs in the PFF group

[b] Mesentery laceration and kidney contusion in the PFF group

The time between fall and death shows different distributions for the GLF and the stairs fatalities, even if in both groups 25 and 28%, respectively, were already found dead. Seventy-five percent of our GLF fatalities did not die on scene comparable to 77.9% of fatal GLFs with survival times from 3 h to 349 days as reported by Thierauf [29]. Death on scene in stairs falls was reported in 53% by Wyatt [40]. Case selection bias due to autopsy and Wyatt including all ages might explain this discrepancy. However, the majority of our stairs fatalities (64%) died within 1 day, whereas the GLF died later.

Causes of death and injury pattern in GLF and stairs falls

The causes of death in the stairs falls was trauma in 59%, comparable to 54% reported by Bux [38]. In the GLFs, only

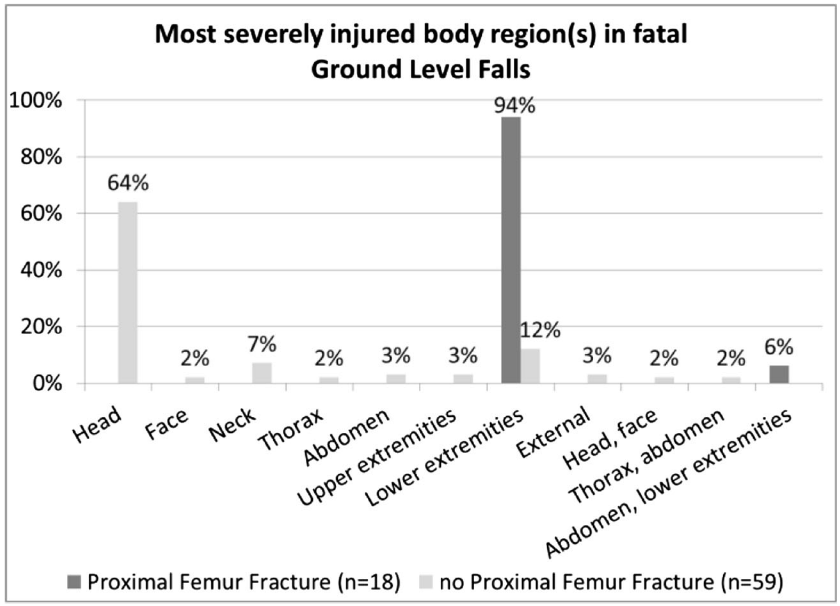


Fig. 4 Distributions of the most severely injured body region(s) in ground level falls with or without proximal femur fracture

in 25% the trauma itself was the cause of death; however, if taking bleeding and cerebral hemorrhage into account, in comparison to later complications like pneumonia, embolism, and heart failure (comparable categorization like presented in [44]), our data show around 40% of deaths directly due to the injurious fall. This is less than the 63% of deaths directly from the fall as reported for hospital admissions by Allen [44].

In detail, traumatic brain injuries were the cause of death in 49% (19 out of 39) of the stairs falls. This is lower than the 66% with skull and brain injury as cause of death derived from Preuss [39]. The reason might lie in different coding behaviors of forensic personnel. Regarding the injury frequency of brain injuries and skull fractures, we see 44% base fracture and overall 62% skull fractures. Further, also in our data, we find 69% brain injuries including hemorrhages, Bux reports 79% [38], and Wyatt [40] reports 68% brain or brainstem injuries. As Hein (1989) showed, brain injuries and hemorrhages are usually accompanied with skull fractures both in GLFs and stairs falls [45] so that the differently reported head injury classifications are not flawing the comparability of results. Further, if looking at the body region leading to the MAIS, the head was seen in 61% of the stairs fatalities. An objective injury coding like using AIS© could improve comparability. The classification of the cause of death is a different approach to naming the most severely injured body region. Yet, it needs to be taken into account that the cited studies regarded all age groups and Preuss [39] included post-mortal falls as well, which might also explain differing results.

Moderate or more severe head injury we found in 55% of the GLFs, in around 50% the head was the most severely injured body region, brain injury was seen in 53%, skull fractures in 31%, base fractures in 23%, and TBI was the cause of death in 23%. Again, injuries, diagnoses, and causes of death show partially comparable as well as different numbers to published studies that differ in their case samples by regarding all age groups, all types of falls, or in-hospital fatalities [6, 24, 29, 41]. Elderly seem to have skull fractures less frequently [46], which we also find in our data. The incidence of intracerebral bleedings, however, usually seems to be higher, especially subdural and subarachnoid bleedings [46], and those seem to be more fatal, like reported for subdural hematoma [46–48]. A possible explanation for some discrepancies in our data to literature might lie in the selection bias: a diagnosed cerebral bleeding that leads to death might not require an autopsy in contrast to individuals dying from unspecified and unknown reasons.

Cervical spine fractures after fatal falls are seen in 4% of our GLFs, but in 23% of the stairs falls (three of them being the cause of death). Preuss (2004) finds cervical spine fractures in 6% of fatal falls from stairs, only in one case out of 116 it was the cause of death [39]. As they include 16% postmortal falls, this might indicate different falling behaviors contributing to injury pattern. Elderly hospitalized patients after falls were diagnosed with cervical spine fractures in 8% [17]. Benayoun et al. [49] confirmed an incidence of cervical spine fractures in elderly fall patients admitted to hospital in less than 1%. The high mortality risk of injuries to the cervical spinal cord could explain the low representation in-hospital data, and the overrepresentation in our autopsy data. Yet, increasing numbers in cervical spine fractures in elderly after a fall are reported [12], especially in men [50]. Our data cover the years 2008 to 2014, also indicating a temporal increase compared to Preuss [39]. However, this increase seems to be occurring primarily due to stairs falls and not due to GLFs.

Higher frequencies of injuries to the torso (rib cage and thoracic spine, and thoracic and abdominal organs, respectively) are found in the stairs falls compared to the GLF (49 vs 13%, and 23 vs 8%, respectively), which is comparable to prior studies [6, 35, 36, 42, 51–54]. Further, we see a higher frequency of upper extremity fractures in the stairs falls (13 vs 3% in the GLF), which is in line with Mitchell [55].

In general, the injury severity in the stairs falls is higher compared to the GLFs (median value 24 vs 14). The median ISS in the stairs fatalities is comparable to Wyatt (1999) who report a value of 25 [40] and a comparable share of cases with ISS 75 (5 and 8%). In 31 and 48% of elderly in-hospital GLF cases, an ISS > 15 was reported [24, 56], in our fatalities we see 48%, and in 68% of in-hospital fatalities an ISS ≥ 25 is reported [24], in our GLF cases we only find around 15% with ISS > 26. This gives reason to think of a bias towards less severely injured GLF fatalities in the autopsy material.

PFFs were only seen in the GLFs (23%), not in the stairs falls. Also, other studies on fatal stairs falls do not report any PFF [38–40]. From hospital data including all ages, 6% of the stairs falls were reported to have PFF in contrast to 20% of the GLF cases [55]. Another study finds stairs falls only in 3.5% of all falls leading to PFF in the elderly [43]. It seems that if a PFF is found in a fatal fall, it is more likely that no stairs fall but a GLF had happened.

In-hospitalized falls (all ages), "hip injuries" are reported in 39% [57], but in another study, PFF were not worth to be mentioned in-hospitalized elderly after falls [17], and an isolated PFF occurred only in 6.9% of all GLFs in the elderly in the study of Ayoung-Chee [24]. Regarding fatal falls of the elderly, however, in 30%, a PFF is reported [6]. It seems that mainly GLFs contribute to this result when taking our results into account.

Proximal femur fractures in GLFs

GLF fatalities with PFF are found to have no further severe injury, most importantly, no accompanying head injury. This confirms the very low association like Hartshorne et al. reported in 1997 [41] who analyzed only autopsied fatal head injuries from GLFs. In their sample ($n = 75$), only twice an accompanying hip fracture was seen. Also, Peel reports that from hospitalized elderly falls there was no patient presenting with PFF and intracranial injury [35].

In contrast to those without PFF, the GLFs with PFF further seem to be less severely injured (only MAIS 3), live in care facilities in 28%, fell in-doors in 94%, and showed physical limitations in walking abilities in 33%, indicating a target group for prevention measures. Fall in-doors was reported to be associated especially to trochanteric hip fractures [21].

GLFs with hospitalization show a 1-year mortality of 33% in the USA in 2005–2008 [24]. For the USA, in 2004, 1-year mortality risks after PFF are reported to be 22 and 33%, respectively, for females and males [7]. In-hospital mortality rates after PFF are reported to lie between 4 and 14% [7, 24, 35, 44, 54, 56, 58]. From our data, we can add that death on scene in GLF fatalities without PFF is found in 31%, but in the GLFs with PFF it occurred only in one case. Death after 1 month occurred mainly to those with PFF, and more often pneumonia and embolism are causes of death and in around 50% the cause of death remained unclear after autopsy.

Within GLF fatalities in the elderly, there are obviously two groups: the PFF cases who show nearly no further injuries, and the ones with either head injury and or fractures to the thorax and or to the lower extremities including the pelvis but not PFF. The PFF group is likely to have fallen sideways [20, 59, 60]. The latest Cochrane Review on hip protectors for preventing hip fractures in older people find a risk reduction especially for elderly in care facilities: If fitted with hip protectors (plastic shields (hard) or foam pads (soft), usually fitted in pockets in specially designed underwear, worn to cushion a sideways fall on the hip), 11 out of 1000 would be saved from a hip fracture. The effect was not found for people living at home, possibly due to missing compliance, [22]. If the comfort and practicability was increased, more people at risk might wear hip protectors. From our data especially people from age 75 on and those with physical limitations in walking abilities should be addressed. In our data, none of the GLFs with PFF showed osteoporosis. Even if in the whole sample osteoporosis was documented, very rarely we assume that in case of a pathological fracture as a potential reason for the fall at first would have been mentioned. In osteoporotic bones, a PFF can happen without adequate impact like a fall and therefore in those cases hip protectors would not be of use. Not being able to derive results concerning further risk factors from our data, however according to literature, especially people with known osteosarcopenia, osteoporosis, low BMI, preexisting diseases, medications, visual impairment, falls in the past, impairment in walking and balance, and the fear of falling again [6, 19, 21, 61–69], could be encouraged to wear hip protection especially in-doors. From our data, we can confirm that the fatalities would have been saved from death after fall if the PFF had not occurred as they did not suffer from any other severe injuries able to lead to hospitalization (except for one person) or death. As five of our 18 fatal GLFs with PFF lived in care facilities, there might be a potential for establishing the protection of elderly more easily.

When looking at the prevention of injuries from falls either from stairs or on ground level and eventually prevention of fatalities from falls, it has to be acknowledged that head injuries should be addressed first. The results derived in this study constitute a basis for what should then be addressed next.

Even in the autopsied sample there remained a share of 28% of unspecified falls. If all of these 74 cases belonged to the GLF group and showed PFF but in addition further major injuries, our conclusion would of course be different. Only 17 out of 151 (11%) GLF with PFF would then definitely profit from hip protection. In case all of them had PFFs without major injuries, it would increase our found protective potential to 91 out of 151 (60%). In all other cases, it is assumed that the results would not change substantially except for increased sample numbers.

Our results and the injury pattern found might aid the reconstruction process to further reduce the number of unspecified falls in the future. Injury patterns found in the different fall circumstances might help to classify falls better.

Conclusion

In our retrospective study of autopsied fatal falls in the elderly, we regarded circumstances of falls and injuries. For a detailed analysis, only ground level falls (GLFs) and stairs falls were regarded, that were proven to not having been caused by intention (neither violence not suicide), were no post-mortal falls, and were not in association to furniture.

Thirty percent were found to be GLFs, which is much higher than the share in the official statistics based on death certificates. In contrast to all fatalities from GLFs, the autopsied cases seem to be less severely injured and show head injuries less frequently. However, in our sample, 22% of deaths from GLFs in the elderly could possibly have been prevented by preventing the relevant injury, namely the proximal femur fracture. As a target group, a focus should be laid on elderly 75 to 84 years old with physical limitations in walking and in-door situations. Further, our data support the suspicion that if a PFF is found in an autopsied fatal fall, it is more likely that no stairs fall but a GLF had happened. We find hints to confirm the reported increase in cervical spine fractures in fatal falls and can add the fact that these injuries seem to indicate rather stairs falls but, less likely, GLFs. It seems that alcohol as contributing especially to fatal stairs falls is less frequently found in the elderly. Other circumstances like socio-demographics and co-morbidities do not differ substantially between GLFs and stairs falls.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights and informed consent This article does not contain any studies with human participants performed by any of the authors.

Appendix

Coding details

For the time of fall, we defined night as the time from 06:00 pm to 05:59 am and day as 06:00 am to 05:59 pm. “Unknown” was attributed to cases for which the time of fall was not deductible, as the person was found already dead.

The number of falls in the case history was declared none, if no hints or information on prior falls was given.

The variable entries within the pre-existing conditions were extracted from all available information towards the case and from the autopsy results and declared as “yes” if enough facts were at hand, in the other cases it was declared “no” generously. In some cases, too much information was missing so that the decision for yes or no was not possible. In these cases, “unknown” was chosen.

For the condition “heart disease,” we included coronary artery sclerosis, hypertrophy, infarction, insufficiency, and rhythm disorders in medical history. The information on “hypertension” and “diabetes” (type I and II) was taken from the medical history. Cirrhosis, fatty liver, necrosis, hepatitis, and chronic stasis were included for “liver disease.” “Lung disease” was declared “yes,” if COPD, asthma, fibrosis, or emphysema was known or visible. “Renal failure” only includes known pre-existing renal insufficiency. For the variables “post-stroke,” “peripheral artery disease,” “indication of osteoporosis,” “cancer,” and “indication of dementia,” all available information and autopsy results were taken into account. For the variable anticoagulation (Marcumar and or ASS), “yes” and “no” were chosen very restrictively only if the information was given. In addition, “probable” was chosen in cases where valve transplants and stable coronary heart disease or atrial fibrillation was known. For other cases, “no information” was chosen.

For the contributing causes to the fall, all available information was taken to decide if the fall was most likely influenced by the following different reasons. In some cases, the information was only enough to decide that the contribution was probable. If the contribution was not likely, it was declared “no hint.” “Physical limitations” includes walking aids, knee problems, and other known restrictions in normal walking ability. The “cardiovascular system” as contributing to the fall was suspected if there were enough hints for fainting due to circulation problems by the confirmation of autopsy results or known rhythm disorders, the same for cerebral issues if medical history or findings in brain structures were able to explain syncope. “Alcohol” was thought as most likely contributing if confirmed by odor or blood analysis, as “probable” if information of relatives was given, or at the place of finding huge amounts of empty bottles were present together with further hints for alcohol consumption. “Others” is a collection of anemia, medicines, pneumonia, embolism, epilepsy, or in the course of a possible jostle. “Common circumstances” was attributed if slipping, stumbling, or an accidental false step was confirmed.

Table 5 Type of fall as found in official statistics and analyzed in autopsy register of LMU

2008–2014, 65 + years	Bavaria		Autopsy LMU	
	n	%	*n*	%
W00 fall on same level involving ice and snow[a]	20	0.2	3	1.1
W01 fall on same level from slipping, tripping and stumbling[a]	138	1.6	47	18.0
W02 fall involving ice-skates, skis, roller-skates, or skateboards[a]	15	0.2	0	0.0
W03 other fall on same level due to collision with, or pushing by, another person[a]	7	0.1	3	1.1
W04 fall while being carried or supported by other persons[d]	0	0.0	0	0.0
W05 fall involving wheelchair[c]	116	1.3	11	4.2
W06 fall involving bed[c]	226	2.6	13	5.0
W07 fall involving chair[c]	41	0.5	2	0.8
W08 fall involving other furniture[c]	34	0.4	7	2.7
W09 fall involving playground equipment[c]	1	0.0	1	0.4
W10 fall on and from stairs and steps[b]	1.232	14.1	39	14.9
W11 fall on and from ladder[b]	179	2.0	4	1.5
W12 fall on and from scaffolding[b]	17	0.2	3	1.1
W13 fall from, out of, or through building or structure[b]	229	2.6	20	7.7
W14 fall from tree[b]	41	0.5	0	0.0
W15 fall from cliff[b]	109	1.2	3	1.1
W16 diving or jumping into water causing injury other than drowning or submersion[d]	3	0.0	1	0.4
W17 other fall from one level to another[b]	154	1.8	0	0.0
W18 other fall on same level[a]	219	2.5	30	11.5
W19 unspecified fall[d]	5.965	68.2	74	28.4
sum	8.746	100.0	261	100.0

Contributions to groups mentioned in the results section: [a] Fall on same level, [b] Fall from Heights, [c] Fall involving equipment, [d] Other/unspecified

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