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delle truppe sanitarie (SSUTS)

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KRIEGS- UND KATASTROPHENCHIRURGIE

2 | 2025

LEITARTIKEL

DIGITALISIERUNG IM MILITÄRISCHEN GESUNDHEITSWESEN

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Gasteditorial Oberfeldarzt

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Digitalisierung ist längst kein Zukunftsprojekt mehr, sondern der Raum, in dem das Militärische Gesundheitswesen der Schweizer Armee operiert. Sie hat das Gefechtsfeld – und wie wir verwundet werden – verändert, aber auch, wie wir behandeln, versorgen, führen und lernen. Im Zentrum der Kraftentfaltung steht nicht die Maschine, sondern der Mensch.

Unsere strategischen Stossrichtungen – klinische Wirkung, Resilienz und Menschenzentrierung – bilden den Rahmen dieser Transformation. Wir schaffen vernetzte Datenflüsse vom Gefechtsfeld bis ins Universitätsspital und in die Rehabilitation, sichern Cyber-Resilienz und Datenhoheit und integrieren künstliche Intelligenz dort, wo sie den medizinischen Entscheid unterstützt – aber nie ersetzt.

Parallel dazu verändert sich auch das zivile Gesundheitswesen rasant: Telemedizin, Automatisierung, Fachkräftemangel und neue Versorgungslogiken sind nicht Schlagworte, sondern Kondensationskerne der Herausforderungen. Das militärische System muss sich insbesondere auch im Hinblick auf das Kriegsgenügen mit diesen Entwicklungen verbinden, interoperabel und lernfähig bleiben.

Digitalisierung ist kein Selbstzweck, sondern Schutzfaktor und Fähigkeitsmultiplikator. Sie stärkt die Robustheit der Armee – technologisch und organisatorisch – und ist ethisch verpflichtend.

Die Armee wird so zum Partner eines sich rasch wandelnden schweizerischen Gesundheitsökosystems, das in Krisen schnell skalieren, in Friedenszeiten effizient lernen und jederzeit vertrauenswürdig handeln muss. Das ist unser Auftrag, unsere Verantwortung und unser gemeinsamer Weg.

Entscheidend ist, dass wir Innovation mit Verantwortung verbinden. Denn Fortschritt ohne Vertrauen ist keine Option.

Oberfeldarzt der Schweizer Armee
Divisionär Andreas Stettbacher

Editorial Chefredaktor SRMDM

SRMDM. 2025, 102 (2): 5; https://doi.org/10.71838/9ebr-0b65

Sehr geehrte Leser und Leserinnen

Wir leben aktuell in unruhige Zeiten mit zahllosen Konflikten, die vielfach gewaltsam und bewaffnet ausgefochten werden – und diese Konflikte kommen immer näher an unsere geographischen Grenzen.

Zunehmend stellt sich die Frage, sind wir denn für solche Konflikte gewappnet – haben wir das nötige Material, verfügen wir über das nötige «Knowhow» und Resilienz?

Gerade in den bewaffneten Konflikten ist das militärische Sanitätswesen äusserst gefordert – konfrontiert mit Massenanfällen an Patienten und Verletzungsmustern, denen wir im zivilen Alltag kaum begegnen. Plötzlich ist man mit der taktischen Selbst- und Kameradenhilfe, der Triage und lebensrettenden chirurgischen Notfalleingriffen konfrontiert.

Aus den Schilderungen vergangener und aktuellere Kriege wird einem bewusst, wie komplex die Sanitätslogistik ist, insbesondere wenn eine Mangellage dazu kommt und die Wege der Versorgung und Evakuierung eingeschränkt oder gar blockiert sind.

Die Kunst der Kriegschirurgie ist nicht nur die Sicherung des Überlebens – es geht hier auch um die Versorgung und Wiedereingliederung der Kriegsversehrten in das Militär und nicht zuletzt in die zivile Gesellschaft. Ein ungemein vielschichtiges und Resourcenintensives Unterfangen!

Sind wir dazu bereit und gerüstet?

In dieser Ausgabe stellen wir uns also dieser Herausforderung der Kriegs- und Katastrophenmedizin, welches Thema an der diesjährigen Internationalen Tagung (IT) der SGOS in Nottwil (LU) war. In den aktuellen Beiträgen geben wir Ihnen durch sehr erfahrene Autoren vertieft Einblick in die Behandlung von Wirbelsäulentraumata in bewaffneten Konflikten und ein Up-date über Schussverletzungen.

Ein besonderes Highlight in dieser Ausgabe ist der Leitartikel von Oberfeldarzt Divisionär Andreas Stettbacher, welcher sich mit der Digitalisierung des militärischen Gesundheitswesens auseinandersetz. Die Digitalisierung bringt grosses Potential für die gesamte Sanitätslogistik, das auch genutzt werden muss; stellt uns aber auch vor neue Herausforderungen! Insbesondere die Artificial Intelligence (AI) lässt Realitäten und Fakzitäten zunehmend verschwimmen, so ein Beispiel unsere Titelseite die AI generiert ist!

Nehmen wir also die Herausforderungen an!

Frohe Festtage und gutes 2026!

Ihr Chefredakteur
Oberst Philipp Gruber

Leitartikel: Digitalisierung im militärischen Gesundheitswesen: Strategischer Faktor, medizinische Verantwortung, menschliche Führung

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Abstract

Digital transformation has become the new operational environment of the Swiss Military Health Service. It is no longer a support function but a strategic capability that determines how the Armed Forces protect, sustain, and restore health under all conditions.
Under the leadership of the Surgeon General, the transformation follows three main directions:
1. Clinical impact through connected data flows – ensuring seamless information from the point of injury to rehabilitation, supported by telemedicine, sensors, and validated AI.

2. Resilience through cyber hygiene and sovereign data spaces – maintaining data integrity, availability and confidentiality, even in degraded networks or hybrid conflict environments.

3. Human-centred responsibility – technology must reinforce, not replace, medical judgement and ethical accountability.

The military health system is being digitally integrated with civilian healthcare, building interoperable networks and shared situational awareness across all levels of care. Ethical principles – data minimisation, transparency, explainable AI – remain non-negotiable.
Digitalisation is thus not an end in itself but a **force multiplier and a safeguard** of medical capability, resilience, and trust. It strengthens national defence, supports

multinational interoperability, and reinforces the enduring principle of military medicine: *to protect life and human dignity – everywhere, at all times.*

Die digitale Transformation ist zum neuen operativen Umfeld des Schweizer Militärgesundheitsdienstes geworden. Sie ist nicht mehr nur eine unterstützende Funktion, sondern eine strategische Fähigkeit, die bestimmt, wie die Streitkräfte unter allen Bedingungen die Gesundheit schützen, erhalten und wiederherstellen.
Unter der Leitung des Generalarztes verfolgt die Transformation drei Hauptrichtungen:
1. Klinische Wirkung durch vernetzte Datenflüsse – Gewährleistung eines nahtlosen Informationsflusses vom Zeitpunkt der Verletzung bis zur Rehabilitation, unterstützt durch Telemedizin, Sensoren und validierte KI.

2. Resilienz durch Cyberhygiene und souveräne Datenräume – Aufrechterhaltung der Datenintegrität, -verfügbarkeit und -vertraulichkeit, selbst in beeinträchtigten Netzwerken oder hybriden Konfliktumgebungen.

3. Menschenzentrierte Verantwortung – Technologie muss das medizinische Urteilsvermögen und die ethische Verantwortung stärken, nicht ersetzen.

Das militärische Gesundheitssystem wird digital mit dem zivilen Gesundheitswesen integriert, wodurch interoperable Netzwerke und ein gemeinsames Situationsbewusstsein auf allen Versorgungsebenen geschaffen werden. Ethische Grundsätze – Datenminimierung, Transparenz, erklärbare KI – bleiben unverhandelbar.
Die Digitalisierung ist somit kein Selbstzweck, sondern ein Kraftmultiplikator und ein Garant für medizinische Leistungsfähigkeit, Resilienz und Vertrauen. Sie stärkt die nationale Verteidigung, unterstützt die multinationale Interoperabilität und bekräftigt das unveränderliche Prinzip der Militärmedizin: Leben und Menschenwürde zu schützen – überall und jederzeit.

Einleitung

Digitalisierung ist für das militärische Gesundheitswesen kein Trend, sondern die neue Operationsumgebung. Sie beeinflusst das Gefechtsfeld und die Kampfführung massgeblich und schafft damit eine neue sanitätsdienstliche Ausgangslage, welche verändert, wie wir Verwundete versorgen, Kräfte führen, Systeme vernetzen und Verantwortung übernehmen. Damit wird sie zu einem strategischen Faktor der Verteidigungsfähigkeit. Und zu einer Frage militärmedizinischer Ethik und Führungskultur.

«Digitalisierung ist kein Selbstzweck. Sie ist ein Schutzfaktor – und ein Fähigkeitsmultiplikator im Dienst des Menschen.»

Digitalisierung als neue Operationsumgebung

Digitalisierung prägt das militärische Gesundheitswesen in allen Dimensionen. Sie beeinflusst unsere Handlungsweisen, Entscheidprozesse, Ausbildung und Führungsstrukturen. Der technologische Wandel ist rasant.
Während sich das medizinische Wissen heute in weniger als zwei Jahren verdoppelt, ist die Halbwertszeit der medizinischen Methoden und Medizintechnologieprodukte ebenfalls gegen zwei Jahre abgesunken.

Diese Dynamik zwingt uns, agiler zu denken, schneller zu handeln (beispielsweise im Rahmen von Beschaffungen) und die Möglichkeiten der Digitalisierung konsequent im Sinne des Auftrags zu nutzen, ohne dabei die medizinische Verantwortung aus den Augen zu verlieren. Unser Ziel bleibt unverändert: Die Gesundheit und Einsatzfähigkeit der Angehörigen der Armee zu schützen, zu erhalten oder wiederherzustellen.

Strategische Stossrichtungen des Oberfeldarztes

Die digitale Transformation des militärischen Gesundheitswesens folgt drei klaren Stossrichtungen:
1. Klinische Wirkung durch vernetzte Datenflüsse
Ziel ist eine durchgängige Informationskette vom Point of Injury bis zur Rehabilitation. Sensorik, Telemedizin und KI-gestützte Entscheidungsunterstützung ermöglichen, dass lebensrettende Massnahmen dort erfolgen, wo sie am meisten Wirkung entfalten: Direkt im Einsatzraum.

2. Resilienz durch Cyberhygiene und souveräne Datenräume
Sichere, redundante und verfügbare Systeme sind die Grundlage der sanitätsdienstlichen Führungsfähigkeit. Datenhoheit, Integrität und Schutz vor Cyberangriffen sind Teil unserer sanitätsdienstlichen Verantwortung. Agilität in Beschaffung und Systempflege ist zwingend, um Innovation in Einsatzfähigkeit zu übersetzen.

3. Menschenzentrierung als ethischer Kompass
Digitalisierung darf Fürsorge und Professionalität nicht ersetzen, sondern muss sie stärken. Künstliche Intelligenz bleibt Werkzeug, nicht Entscheider. Der Mensch bleibt im Zentrum; Verantwortung bleibt unteilbar.

Kernaussagen:

- Digitalisierung ist Führungsaufgabe und keine technische Nebensache.
- Der Mensch bleibt die oberste Entscheidungsinstanz.
- Datenhoheit ist Teil der sanitätsdienstlichen Resilienz.

Vom Konzept zur operativen Umsetzung – mit strategischem Impact

Mit dem Konzept Militärisches Gesundheitswesen wurde der Rahmen geschaffen, um diese Stossrichtungen in konkrete Fähigkeiten zu überführen.
Operativ bedeutet dies: Digitale Durchgängigkeit über alle Ebenen. Einheitssanitäter und Sanitätsformationen erfassen medizinische Daten in Echtzeit; Forward Surgical Teams werden telemedizinisch unterstützt; Lagebilder werden laufend aktualisiert und bilden die Grundlage für sanitätsdienstliche Entscheidungen.
Schnittstellen zu zivilen Partnern – Rettungsdienste, Spitäler, kantonale Führungsstrukturen und der Koordinierte Sanitätsdienst (KSD, neu KATAMED) – werden standardisiert und interoperabel gestaltet. Nur so kann eine durchgängige nationale, Versorgungskette gewährleistet werden, vom Gefechtsfeld bis zum Universitätsspital und in die Rehabilitation.
Digitale Vernetzung und interoperable Verfahren mit möglichen nationalen und internationalen Partnern des militärischen Gesundheitswesens und die funktionale Teilnahme an den diesbezüglichen Koordinationsmechanismen müssen Handlungsspielräume für unsere Landesregierung in der Versorgung von Patienten schaffen und sicherstellen.

Zusammenarbeit mit dem zivilen Gesundheitswesen

Das militärische Gesundheitswesen ist Teil des schweizerischen Gesundheitswesens. Es ist darauf angewiesen und stärkt es zugleich.
Die zunehmende Zentralisierung der Traumaversorgung, der Fachkräftemangel und die steigende Ambulantisierung der Behandlung verlangen eine vertiefte zivil-militärische Zusammenarbeit.
Digitalisierung ermöglicht diese Vernetzung: durch gemeinsame Register, abgestimmte Standards und transparente Kapazitätsplanung. Ebenfalls ermöglicht sie erstmals, militärische und zivile Systeme in Echtzeit zu koppeln, ohne die Autonomie der Partner zu gefährden.
Die Armee steht dabei in der Verantwortung, mit den HSM-Traumazentren und Kantonen vertragliche Grundlagen für den Ernstfall zu schaffen – klar, verbindlich, belastbar.

Agilität, Ausbildung und Innovation

Digitalisierung verlangt mehr als Technik – sie erfordert eine Kultur des Lernens.
Wir entwickeln agile Beschaffungsprozesse, schaffen Erprobungsräume und verknüpfen Einsatz, Ausbildung und Forschung enger als bisher.
Simulation, virtuelle Trainingsumgebungen und KI-gestützte Szenarien werden integraler Bestandteil der Ausbildung. So wachsen Fachkräfte im militärischen Gesundheitswesen heran, die klinische Exzellenz, digitale Kompetenz und ethische Urteilsfähigkeit vereinen.

«Agilität ist kein Selbstzweck. Sie ist die Fähigkeit, Wissen in Handlungsfähigkeit zu verwandeln.»

Medizinethische Verantwortung

Digitalisierung eröffnet neue Möglichkeiten und stellt neue Fragen.
Militärmedizinische Gesundheitsdaten sind Vertrauensgut. Ihr Schutz ist nicht nur Teil der militärischen Interessenswahrung, sondern auch Teil der militärmedizinischen Ethik.
Wir handeln nach klaren Prinzipien: Datensparsamkeit, Pseudonymisierung, Zweckbindung und Transparenz.
Die Digitalisierung verändert auch das Menschenbild in der Medizin. Datenaggregation und Algorithmisierung verwischen die Grenze zwischen «gesund« und «krank« und implementieren zunehmend ein funktionales Gesundheitsmanagement. Hier muss die militärmedizinische Ethik Orientierung geben: Technologie soll Autonomie und Resilienz stärken, nicht Kontrolle ausweiten.
Künstliche Intelligenz soll sanitätsdienstliche Prozesse unterstützen, aber sie darf nicht über Menschen urteilen. Entscheidungen von weitreichender medizinischer oder ethischer Tragweite müssen zwingend in menschlicher Verantwortung bleiben.
Technologie muss dem Menschen dienen, nicht umgekehrt.
Das gilt besonders für eine Armee, deren Auftrag auf Schutz, Vertrauen und Verantwortung gründet.

Perspektive 2030+: Digitalisierung als Schutzfaktor

Digitalisierung stärkt die Verteidigungsfähigkeit, indem sie Geschwindigkeit, Präzision und Lernfähigkeit des sanitätsdienstlichen Systems erhöht. Sie verbindet militärische und zivile Akteure zu einem resilienten Gesundheitsökosystem.

Doch sie ist kein Automatismus. Sie braucht Führung, klare medizinethische Leitlinien und Vertrauen.
Nur wenn wir diese drei Elemente verbinden, wird Digitalisierung zu dem, was sie sein soll: Ein Schutzfaktor, ein Fähigkeitsmultiplikator und ein Ausdruck professioneller Verantwortung.

Schlussfolgerungen

Die digitale Transformation ist kein Projekt mit Enddatum.
Sie ist ein dauerhafter Führungsauftrag – anspruchsvoll, dynamisch und unabdingbar.
Wenn wir Technologie mit militärmedizinischer Ethik, Innovation mit Disziplin und Vernetzung mit Vertrauen verbinden, entsteht ein militärisches Gesundheitswesen, das nicht nur moderner, sondern auch stärker ist.

Am Ende bleibt unser Auftrag unverändert:

Die Gesundheit des Menschen in allen Lagen zu schützen – mit Wissen, mit Verantwortung und mit Haltung: CARE – PROTECT – SUPPORT

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impacting lives

Wenn ein Ereignis den Alltag unterbricht.

Internationale Tagung 2025 der Schweizerischen Gesellschaft der Offiziere der Sanitätstruppen im Zeichen der Kriegschirurgie*

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Abstract

Am 20. September 2025 fand die diesjährige Internationale Tagung (IT) der Schweizerischen Gesellschaft der Offiziere der Sanitätstruppen (SGOS) am Schweizerischen Paraplegiker-Zentrum (SPZ) in Nottwil am Sempacher See statt. Die IT 2025 war der Kriegschirurgie gewidmet. Ausgewiesene Experten aus der Schweiz und aus dem deutschsprachigen Ausland sowie eine Podiums-Falldiskussion machten die Veranstaltung zum Erfolg.

On September 20, 2025 this year's International Conference (IT) of the Swiss Society of Medical Corps Officers (SGOS) took place at the Swiss Paraplegic Center (SPC) in Nottwil on Lake Sempach. The IT 2025 was dedicated to war surgery. Renowned experts from Switzerland and other German-speaking countries, as well as a panel discussion made the event a success.

*Dieser Artikel wurde in ähnlicher Weise ebenfalls in der «Wehrmedizin» publiziert.

Einleitung

Die Internationale Tagung der Schweizerischen Gesellschaft der Offiziere der Sanitätstruppen (SGOS) fand dieses Jahr in Nottwil statt und war der Kriegschirurgie gewidmet.

Pflege der Kameradschaft

Bereits am Tag vor der Internationalen Tagung (IT) versammelte sich der Vorstand der SGOS gemeinsam mit den Referenten sowie den Vertretern der deutschen und österreichischen Partnergesellschaften zu einem gemeinsamen Abendessen. In freundschaftlicher Atmosphäre fand ein reger Austausch statt, bei dem die Kameradschaft gefördert wurde. Selbstverständlich wurde die aktuelle sicherheitspolitische Lage auf dem europäischen Kontinent intensiv diskutiert und stand im Fokus der vielen Gespräche. Den Anwesenden war bewusst, dass in Zeiten erhöhter Unsicherheit und Instabilität der Austausch und die länderübergreifende Zusammenarbeit besonders relevant sind

Tagung im Paraplegiker-Zentrum

Pünktlich um 10 Uhr meldete der Präsident der SGOS, Oberstleutnant Marcel Bundi, dem Oberfeldarzt der Schweizer Armee, Divisionär Andreas Stettbacher, die Internationale Tagung 2025. Nebst zahlreichen Mitgliedern der SGOS sowie den Aspiranten der laufenden Mil Az OS (Anwärter für den Unteroffiziersdienst in der medizinischen Truppe der Schweizer Armee) aus Moudon, konnte er auch den Präsidenten der Österreichischen Gesellschaft, Oberstarzt Prof. Dr. Arnold Höppchen (ÖGWMPh) und den Vizepräsidenten der Deutschen Gesellschaft für Wehrmedizin und Wehrpharmazie (DGWMP), Generalarzt a. D. Prof. Dr. Horst Peter Becker, begrüssen.
Als politische Gastgeberin richtete Gisela Widmer-Reichlin, Präsidentin des Kantonsrates des Kantons Luzern, eine Grussbotschaft an die Internationale Tagung der SGOS und die geladenen Gäste.

Kameradschaftlicher Abend im Paraplegikerzentrum Nottwil. (Bildquelle: SGOS)

Grussworte der jeweiligen militärmedizinischen Gesellschaften mit Oberstarzt Prof. Dr. Arnold Höppchen für die OEGWMP (rechts), Oberstleutnant Dr. med. Marcel Bundi für die SGOS (Mitte) und Generalarzt aD Prof. Dr. Horst Peter Becker für die DGWMP (links). (Bildquelle: SGOS)

Kriegs- und Katastrophenchirurgie

Die Vormittagssitzung begann mit einer Reihe von Fachvorträgen. Stabsadjutant Manuel Müntener berichtete über die seit wenigen Jahren laufende Einführung und Etablierung von Tactical Combat Casualty Care (TCCC) und Patient and Family Centered Care (PFCC) bei der Truppe innerhalb der Schweizer Armee, wodurch die taktische Medizin ein wichtiger Bestandteil der Selbst- und Kameradenhilfe wird. Im Anschluss wurden Fachreferate zu Wirbelsäulentraumata und zu Amputationen bei schweren Extremitätentraumen durch Prof Dr. Moritz Deml, Universität Bern, und Dr. med. Jaad Mahlouly, Universität Lausanne, gehalten. Oberstarzt Professor Dr. Erwin Kollig, Direktor der Unfallchirurgie/Orthopädie am Bundeswehrzentralkrankenhaus Koblenz, konzentrierte seinen Vortrag auf den Nachwuchs und die angehenden Militärärzte. Eindrücklich berichtete er über das korrekte Durchführen der Triage und das primäre Management

von schwer verletzten Patientinnen und Patienten, insbesondere in komplexen Behandlungssituationen. Oberstarzt Prof. Dr. Arnold Höppchen hielt ein packendes Referat über die pathophysiologischen und klinisch-chirurgischen Aspekte von Schussverletzungen.
Der Nachmittag der Internationalen Tagung 2025 stand im Zeichen einer Podiumsdiskussion mit interaktiven Fallpräsentationen aus dem Themenbereich Kriegs- und Traumachirurgie. Aus ihrem reichen Fundus an (kriegs-)chirurgisch versorgten Patienten präsentierten die Professoren Höppchen und Kollig komplexe und eindrückliche klinische Fälle. Zusammen mit dem Oberfeldarzt der Schweizer Armee wurden diese Fälle ausgiebig diskutiert und Fragen aus dem interessierten Auditorium beantwortet. Die präsentierten Fälle zeigten auf eindrückliche Weise, dass zur adäquaten Versorgung von Mehrfachverletzungen enorm viele Ressourcen, Zeit, Spezialistenwissen, Erfahrung und Geduld erforderlich sind. Noch schwieriger und anspruchsvoller wird die Versorgung dieser Patienten im Falle einer Mangellage in Krisen- und Kriegszuständen.

Zusammenfassung

Die Internationale Tagung 2025 konnte den Teilnehmern die Kriegschirurgie mit zahlreichen spannenden Fachvorträgen und interaktiven Fallpräsentationen mit Podiumsdiskussion durch ein Panel von ausgewiesen und hochkarätigen Experten eindrücklich näherbringen. Es wurde aufgezeigt, wie komplex die Behandlung von Katastrophen- und Kriegsversehrten ist und wieviel Logistik und Expertenwissen dazu notwendig ist.

Eindrückliche Fachreferate über die verschiedensten Facetten der Kriegschirurgie, hier mit Oberstarzt Professor Dr. Erwin Kollig. (Bildquelle: SGOS)

Schuss- und Explosionsverletzungen: Ein Update.

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Abstract

Schuss- und Explosionsverletzungen zählen zu den komplexesten Traumata in der modernen Medizin. Sie treten im militärischen wie im zivilen Kontext auf und erfordern schnelles, interdisziplinäres Handeln. Der Artikel gibt einen Überblick über Ätiologie, Ballistik, Klassifikation und die notfallchirurgische Versorgung von Schuss- und Explosionsverletzungen, einschliesslich Gefäss-, Knochen- und Weichteilschäden sowie Verbrennungen und Amputationen. Abschliessend werden Anforderungen an die Ausbildung militärchirurgischer Einsatzkräfte und praktische Konsequenzen für die Akutmedizin diskutiert.

Gunshot and blast injuries are among the most complex traumas in modern medicine. They occur in both military and civilian contexts and require rapid, interdisciplinary action. This article provides an overview of the etiology, ballistics, classification, and emergency surgical treatment of gunshot and blast injuries, including vascular, bone, and soft tissue damage, as well as burns and amputations. Finally, the requirements for training military surgical personnel and the practical consequences for acute medicine are discussed

Einleitung

Entstehung und Charakteristika der Verletzungen

Schuss- und Explosionsverletzungen entstehen durch hochenergetische Einwirkungen, die innerhalb von Millisekunden erhebliche kinetische Energie in das Gewebe übertragen. Während Schussverletzungen primär durch eindringende Projektile verursacht werden, entstehen Explosionsverletzungen durch eine Kombination aus Druckwelle, Splitterwirkung, thermischer Energie und toxischen Gasen [1,2].

Typisch sind multiple, unregelmässige Wundkanäle, ausgedehnte Weichteildefekte, Gefässzerstörungen und kombinierte Knochenverletzungen. Zivile Schussverletzungen betreffen meist einzelne Regionen, während militärische Explosionsverletzungen komplexe Polytraumata darstellen [3].

Geschichtliche Entwicklung

Die moderne Behandlung solcher Verletzungen entwickelte sich aus der Kriegschirurgie. Bereits Ambroise Paré (1510–1590) legte mit Prinzipien wie Débridement und Blutstillung die Basis [4]. Im 20. Jahrhundert führten die Weltkriege zur Etablierung mobiler chirurgischer Einheiten und verbesserten Wundmanagement-Techniken. Die Einführung von Antibiotika und Gefässrekonstruktionen reduzierte die Amputationsrate drastisch [5].

Mit den Konflikten in Korea, Vietnam und dem Nahen Osten entstanden moderne Konzepte wie Damage Control Surgery (DCS) und Damage Control Resuscitation (DCR), die auf eine schnelle Blutungskontrolle und physiologische Stabilisierung abzielen [6,7].

Klassifikation von Schuss- und Explosionsverletzungen

Schussverletzungen
Schussverletzungen werden nach Energie, Projektiltyp und betroffener Körperregion klassifiziert [8].

1. Nach Energieübertragung
- Niedrigenergiegeschosse (<600 m/s): Pistolen, Revolver; begrenzte Kavitation.
- Hochenergiegeschosse (>600 m/s): Sturmgewehre; massive Gewebszerstörung.

2. Nach Verlauf
- Penetrierend: Nur Eintrittswunde.
- Perforierend: Ein- und Austritt.
- Tangential: Oberflächlicher Streifschuss.

3. Nach Lokalisation
- Extremitäten, Thorax, Abdomen, Kopf, Hals.

Explosionsverletzungen
Nach der NATO-Standardisierung werden Explosionsverletzungen in vier Haupttypen eingeteilt [9]:

1. Primäre Blastverletzungen – Druckwelle, betrifft v. a. Lunge, Trommelfell, Darm.

2. Sekundäre Blastverletzungen – Splitter- und Trümmerwirkung.

3. Tertiäre Blastverletzungen – Wegschleudern des Körpers, stumpfes Trauma.

4. Quartäre Blastverletzungen – Verbrennungen, Rauchinhalation, toxische Exposition.

Ballistik von Geschossen

Die Ballistik beschreibt das Verhalten von Geschossen im Lauf (Innenballistik), im Flug (Aussenballistik) und im Ziel (Terminalballistik). Für die Medizin ist die Terminalballistik entscheidend [10].

Die **kinetische Energie** ($E = \frac{1}{2} mv^2$) bestimmt die Wundschwere. Hochgeschwindigkeitsgeschosse führen zur Bildung einer **temporären Kavitation**, die sekundäre Gewebszerstörung verursacht [11].

Instabile Flugbahnen (Yaw, Tumbling) erhöhen die Energieabgabe und vergrössern den Wundkanal [12]. Knochenfragmente und Sekundärsplitter wirken als zusätzliche Projektilkörper.

Die Kenntnis dieser Mechanismen ist für Diagnostik und operative Planung unverzichtbar.

Notfallbehandlung von Schussverletzungen

Die Versorgung erfolgt nach den Prinzipien des **Advanced Trauma Life Support (ATLS):**

e**X**sanguinating hemorrhage, **A**irway, **B**reathing, **C**irculation, **D**isability, **E**xposure [13].

Ziel ist die sofortige Kontrolle lebensbedrohlicher Blutungen, Wiederherstellung der Zirkulation und Prävention sekundärer Komplikationen.

Schussverletzungen an Extremitäten

Gefässverletzungen
Klinische Zeichen: pulsierende Blutung, fehlender distaler Puls, zunehmendes Hämatom.

Behandlungsschritte:
- Tourniquet-Anlage proximal der Verletzung (Zeit dokumentieren).
- Temporäre Shunts (z. B. Argyle-Shunt) bis zur definitiven Rekonstruktion.
- Gefässnaht oder Veneninterponat (z. B. V. saphena magna).
- Tranexamsäure innerhalb der ersten Stunde (1 g i.v.) [14].

Knochenverletzungen
- Sofortiges Débridement und Spülung.
- Primäre Stabilisierung mit Fixateur externe.
- Antibiotikaprophylaxe (Cephalosporin ± Aminoglykosid).
- Später: Sekundäre Osteosynthese nach Weichteildeckung.

Weichteilverletzungen
- Grosszügiges Débridement von devitalem Gewebe.
- Isotone Spülung, KEINE PulsJet-Systeme.
- Wundverschluss nach 48 – 72 h («Delayed Primary Closure«).
- Anwendung der Unterdruck-Wundtherapie (NPWT) bei grossflächigen Defekten [15].

Thorakale Schussverletzungen

Symptome: Dyspnoe, Hypotonie, einseitig abgeschwächtes Atemgeräusch.

Massnahmen:
- Nadeldekompression (2. ICR medioklavikulär) bei Spannungspneumothorax.
- Thoraxdrainage (Bülau-Drainage) bei Hämo-/Pneumothorax.
- Notfallthorakotomie bei massiver Blutung (>1500 ml initial oder >200 ml/h) [16].

Abdominale Schussverletzungen
Penetrierende Verletzungen des Abdomens erfordern häufig eine sofortige Laparotomie.

Prinzipien:
- Damage Control Surgery: Blutstillung, temporärer Verschluss, Re-Laparotomie nach 24 – 48 h.
- Ziel: Vermeidung von Hypothermie, Azidose und Koagulopathie («letale Trias») [17].
- Diagnostik: FAST, ggf. CT bei stabilen Patienten.
- Blutproduktgabe und Gerinnungsfaktorengabe nach European Guidelines 2023 [18].

Notfallbehandlung von Explosionsverletzungen
Explosionsverletzungen verursachen häufig kombinierte Läsionen. Die Erstbehandlung orientiert sich ebenfalls an ATLS- und DCS-Prinzipien.

Primäre Blastverletzungen

- Lunge: Gefahr der Luftembolie → 100 % O_2, keine Überdruckbeatmung.
- Trommelfell: Kontrolle und symptomatische Behandlung.
- Darm: Risiko verzögerter Perforation → stationäre Beobachtung und ggf. CT-Abdomen [19].

Sekundäre Blastverletzungen
Behandlung analog zu Schussverletzungen mit Débridement, Fremdkörperentfernung und Fixation.

CT-Diagnostik zur Detektion von Metallsplittern.

Tertiäre Blastverletzungen

- Polytraumatisches Management mit Frakturversorgung, Schädel-Hirn-Trauma-Therapie, Wirbelsäulenstabilisierung.
- Häufig Kombination mit Verbrennungen und Amputationen.

Quartäre Blastverletzungen (Verbrennungen)

- Kühlung: Handwarm (15 – 20 °C) für 10 – 20 Min., KEINE Kühlung, sterile Abdeckung.
- Flüssigkeitssubstitution: Nach Parkland-Formel (4 ml × KG × % KOF/24 h).
- Analgesie: Opioide, Ketamin, ggf. Regionalanästhesie.
- Infektionsprophylaxe nur bei Infektion und frühzeitige Escharotomie bei zirkulären Verbrennungen [20].

Amputationen

- Sofortige Blutstillung (Tourniquet).
- Débridement und sterile Abdeckung.

- Frühzeitige operative Stumpfgestaltung in spezialisierten Zentren.

- Psychologische Betreuung und frühe Prothesenplanung.

Ausbildung von Militärchirurgen
Die Behandlung ballistischer Verletzungen erfordert umfassende chirurgische, organisatorische und psychologische Kompetenzen. Militärchirurgen müssen unter Einsatzbedingungen mit limitierter Ausstattung operieren können.

Kernkompetenzen:
- Verständnis der Ballistik und Explosionsmechanik

- Durchführung von DCS-Operationen im Feld

- Triage unter Druck

- Kenntnisse der Gefäss- und Thoraxchirurgie

- Führung und Kommunikation im Team [21]

Trainingsformate umfassen:

- Simulation realistischer Szenarien

- Einsatzrotationen in Traumazentren

- Internationale Kooperationen (z. B. NATO-Center of Excellence for Military Medicine)

Fazit für die Praxis
Schuss- und Explosionsverletzungen stellen extreme Anforderungen an Chirurgen und Rettungsteams. Entscheidend sind:

- Schnelle Blutungskontrolle und Stabilisierung gemäss ATLS/DCS.

- Grosszügiges Débridement und konsequente Infektionsprophylaxe.

- Gefässrekonstruktion und temporäre Shuntverfahren bei Extremitätenverletzungen.

- Multiorganisches Denken bei Explosionsopfern.

- Ausbildung und Teamtraining als Schlüssel zur Reduktion der Mortalität.

Die fortschreitende Integration moderner Technologien – wie Telemedizin, hämostatische Biomaterialien und Simulationstrainings – wird die Überlebenschancen Verwundeter weiter verbessern. Dennoch bleibt die chirurgische Erfahrung im Einsatz der entscheidende Erfolgsfaktor.

Behandlungsalgorithmus von Schuss- und Explosionsverletzungen

Behandlungsphase	Massnahmen
Erstversorgung	• *Kontrolle lebensbedrohlicher Blutungen*
	• *Stabilisierung nach ATLS (xABCDE)*
	• *Volumen- und Blutproduktgabe gemäss DCR*
	• *Grosszügiges Débridement und sterile Abdeckung*
Verletzungen der Extremitäten	• *Anlage von Tourniquet (Zeit dokumentieren)*
	• *Temporäre Shuntanlage bei Gefässverletzungen*
	• *Externe Frakturstabilisierung (Fixateur externe)*
	• *Antibiotikaprophylaxe und Schmerztherapie*
Thorax- und Abdominalverletzungen	• *Dekompression bei Spannungspneumothorax*
	• *Anlage von Thoraxdrainage bei Hämo-/Pneumothorax*
	• *Damage-Control Surgery mit Zweiteingriff nach Stabilisierung*
	• *Engmaschige Überwachung hämodynamischer Parameter*
Schwere Verbrennungen	• *Keine Kühlung*
	• *Sterile Abdeckung, Analgesie*
	• *Flüssigkeitstherapie nach Parkland-Formel*
	• *Infektionsprophylaxe und Wundbeurteilung*
Amputationen	• *Blutstillung (Tourniquet)*
	• *Sorgfältiges Débridement und Stumpfversorgung*
	• *Sterile Abdeckung und Schockprophylaxe*
	• *Frühzeitige Zuweisung in spezialisiertes Zentrum*

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Modern Combat Spinal Trauma: A Systematic Review of the Top-Cited Evidence

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Abstract

Das moderne Wirbelsäulentrauma im Kampfeinsatz ist eine eigenständige klinische Entität. Die Behandlung erfordert einen Ausgleich zwischen der chirurgischen Indikation für eine frühzeitige Dekompression und der logistischen Notwendigkeit einer schnellen strategischen Evakuierung. Wir haben die einflussreichsten Literaturquellen zusammengefasst, um die Epidemiologie, die Behandlung und die Ergebnisse zu charakterisieren und den operativen Versorgungsstandard in Einsatzgebieten zu definieren. Wir haben eine zitiergewichtete Auswertung der Literatur zu Wirbelsäulentraumata im Kriegseinsatz (2000–2025) durchgeführt. Die 30 meistzitierten Primärstudien wurden gesichtet, um klinische Kohorten mit extrahierbaren Daten zu identifizieren. Wir haben diese einflussreichen Quellen zusammengefasst, um die Epidemiologie der Verletzungen, den Zeitpunkt der Operation und die perioperativen Komplikationen zu charakterisieren. Neunzehn Publikationen mit insgesamt 31.409 Verletzten erfüllten die Einschlusskriterien. Die Gesamtkohorte war jung (Durchschnittsalter 25,4 Jahre) und männlich (96,6 %). Bei 27,6 % der auswertbaren Population trat eine traumatische Rückenmarksverletzung auf. Explosionen waren für 79,1 % der Verletzungen verantwortlich, wobei vorwiegend die Lendenwirbelsäule betroffen war (65,5 % der Patienten).

Bei 40,7 % der Patienten wurde ein chirurgischer Eingriff vorgenommen. Die durchschnittliche Zeit bis zur ersten Wirbelsäulenoperation betrug 2,9 Tage. Von den dokumentierten Eingriffen wurden 20,3 % in vorwärts stationierten Einrichtungen durchgeführt, während die übrigen nach der Evakuierung zu definitiven Versorgungsknotenpunkten erfolgten. Die durchschnittliche gemeldete Sterblichkeitsrate betrug 7,4 %. Zusammenfassend kann festgehalten werden, dass kampfbedingte Wirbelsäulentraumata eine eigenständige Entität darstellen, die durch Explosionsmechanismen und thorakolumbale Frakturen definiert ist und bei deren Behandlung eine schnelle Evakuierung einer frühzeitigen Dekompression vorzuziehen ist. Die hier angegebenen Zeitintervalle spiegeln ein logistisches Best-Case-Szenario wider, das auf Luftüberlegenheit basiert. Auf zukünftigen umkämpften Schlachtfeldern wird aufgrund verlängerter chirurgischer Verzögerungen die Neuroprotektion während längerer Transporte von grösster Bedeutung sein.

Modern combat spinal trauma is a distinct clinical entity. Management requires balancing the surgical indication for early decompression against the logistical mandate for rapid strategic evacuation. We synthesized the most influential literature to characterize the epidemiology, management, and outcomes, and to define the operational standard of care in deployed settings. We performed a citation-weighted review of the combat spine literature (2000–2025). The 30 most-cited primary studies were screened to identify clinical cohorts with extractable data. We synthesized these high-impact sources to characterize injury epidemiology, surgical timing, and perioperative complications. Nineteen publications representing 31,409 casualties met inclusion criteria. The aggregate cohort was young (mean 25.4 years) and male (96.6%). Traumatic spinal cord injury occurred in 27.6% of the evaluable population. Explosions accounted for 79.1% of injuries, with a predominantly lumbar anatomical burden (65.5% patient prevalence). Surgical intervention was performed in 40.7% of patients. The mean time to the first spinal operation was 2.9 days. Of recorded procedures, 20.3% were performed at forward-deployed facilities, while the remainder occurred after evacuation to definitive care nodes. The average reported mortality rate was 7.4%. Combat spine trauma presents as a distinct entity defined by blast mechanisms and thoracolumbar fractures, where management favors rapid evacuation over early decompression. The intervals reported here reflect a best-case logistical scenario reliant on air superiority. In future contested battlefields, extended surgical delays will make neuroprotection during prolonged transport paramount.

List of Abbreviations AIS: Abbreviated Injury Scale; ASIA American Spinal Injury Association; DVT Deep Vein Thrombosis; GSW Gunshot Wound; IQR Interquartile Range; MAP Mean Arterial Pressure; MVC Motor Vehicle Collision; NASCIS National Acute Spinal Cord Injury Studies; PE Pulmonary Embolism; PMC PubMed Central Surgical Timing in Acute; STASCIS Surgical Timing in Acute Spinal Cord Injury Study; SCI Traumatic Spinal Cord Injury.

Introduction

Spinal injuries are now a stable component of modern combat casualty care. Analyses from Iraq and Afghanistan show that spinal column trauma occurred in roughly one in ten evacuated combat casualties, is largely fracture-driven, and contributes substantially to long-term disability and death in wounded service members [1-3]. Within these cohorts, explosions – particularly improvised explosive devices and underbody blasts – predominate, and injury patterns are shifted toward thoracolumbar and lumbosacral segments, with low lumbar burst fractures repeatedly described in protected vehicle occupants [4, 5]. These patterns have emerged in a survivorship landscape reshaped by modern body armor and forward resuscitation: ceramic plates, tourniquets, and hemostatic resuscitation allow service members to live through high-energy blasts that would previously have been uniformly fatal, but they also shift part of the energy burden away from the thoraco-abdominal viscera and onto the axial skeleton. Registry and autopsy series from these conflicts report a higher incidence of spinal trauma and war-related traumatic spinal cord injury (tSCI) than in earlier wars, with thoracic, thoracolumbar, and lumbosacral levels over-represented [1-4].

In parallel, the civilian and mixed-system tSCI literature has moved toward earlier decompression. The multicenter Surgical Timing in Acute Spinal Cord Injury Study (STASCIS) cohort associated decompression within 24 hours with higher odds of meaningful neurological improvement after cervical tSCI [6]. Subsequent AO Spine guidelines first suggested early surgery within 24 hours as a treatment option for acute tSCI on the basis of low-quality observational data [7] and have now upgraded this to a recommendation for decompression within 24 hours whenever medically feasible, supported by moderate-quality evidence from updated systematic reviews [8].

In deployed practice, however, timing is constrained by echeloned care. Contemporary military trauma systems move casualties along a Role 1–4 chain: point-of-injury resuscitation and limited damage-control capability at the forward end, damage-control surgery and early specialist input at Role 2/3, and definitive multidisciplinary reconstruction at Role 4 after strategic evacuation [9, 10]. This architecture, matured through the Joint Trauma System, has delivered measurable survival gains by emphasizing rapid stabilization, standardized protocols, and efficient evacuation while concentrating complex surgery at higher-capability nodes [11, 12]. As a result, the deployed surgeon operates under a structural tension: every hour spent on in-theater decompression is an hour the patient is not moving toward definitive safety, whereas every hour spent in transit is a delay against the ischemic «clock» of the injured cord.

The clinical literature from recent conflicts can be read as a series of attempts to navigate this tension, but it is scattered across large registry analyses, autopsy series, and focused surgical cohorts. There is no concise quantitative synthesis of what the most influential primary studies actually report about epidemiology, early management, and short-term outcomes in combat-related spinal trauma.

Research question and objective. Because high citation counts in this space often track clinical influence and doctrinal weight, we asked: across the most cited primary studies of combat-related spine trauma from modern conflicts, what are the epidemiology, early management patterns, and short-term outcomes? The primary outcome was early management, defined as the proportion of patients undergoing surgery and the reported timing of their index spinal operation. Secondary outcomes were mechanism distributions, anatomic injury levels, concomitant injuries, and early complications.

Methods

Design and identification of evidence. We performed a systematic, citation-weighted review of primary clinical studies on combat-related spinal trauma using a custom algorithmic screening script written in Python (Version 3.12; Python Software Foundation, Wilmington, DE, USA) utilizing the Biopython library to interface with the NCBI E-utilities API. Using PubMed/MEDLINE, we searched for English-language original research published between 1 January 2000 and 1 October 2025 that reported acute spinal column injuries (vertebral fractures and/or tSCI) in military or war-related settings. We combined terms for spinal trauma with conflict-related keywords (for example Iraq, Afghanistan, OIF/OEF, blast, improvised explosive device, Role 2/3). We restricted the search to human clinical studies of case series level of evidence or higher with an abstract and excluded clearly non-trauma topics (such as chronic low-back pain, ergonomics, and animal or cadaver models), as well as non-systematic reviews, editorials, and conference abstracts. For each remaining paper we obtained its PubMed Central citation count and then ranked and screened the 30 most-cited articles as the group most likely to influence clinical practice.

Eligibility and abstraction. We reviewed the top 30 papers and included clinical cohorts or case series of acute combat related spinal column injury in deployed personnel or war casualties treated within a military trauma system. Studies required a clear denominator for at least one early care or outcome variable. We excluded narrative reviews, guidelines, autopsy series without a linked clinical cohort, purely civilian trauma series, animal/cadaver studies, and non-trauma topics (e.g., chronic pain, ergonomics); however, systematic reviews containing unique, extractable data were retained. Data were entered into a standardized spreadsheet, recording study design, conflict years, patient numbers, mechanism (explosion, gunshot, MVC, other), injury levels, and associated injuries. For management, we captured surgical location (deployed vs. definitive), proportion operated within 24 and/or 72 hours, and median time to first operation. Mortality and major complications (pneumonia, wound infection, venous thromboembolism) were recorded as reported; no values were inferred.

Synthesis. For each study we calculated proportions using the denominators reported by the original authors. We then pooled studies by summing the number of events and the number of patients for each variable (for example, the total number of patients with tSCI divided by the total number of patients in all cohorts that reported tSCI). For segment-level injury distributions, where many patients had injuries at multiple levels and some large registries reported only partial coding, we also present the unweighted mean (uw-mean) of the study-level percentages so that large and small cohorts contribute equally. Given the heterogeneity in conflicts, case mix, and follow-up windows, we did not perform a formal meta-analysis; all percentages are presented as descriptive summaries of what these influential series report. Each publication was treated as an independent cohort acknowledging that several large datasets come from the same conflicts and time periods and likely include overlapping patients that could not be de-duplicated. Primary outcomes were patterns of early spine management – whether surgery was performed, the echelon of care at which the index spine operation occurred, and the reported time from injury to that operation – while secondary outcomes captured mechanism profiles, anatomic injury distributions, associated injuries, and early complications.

Results

Studies and designs. Nineteen publications met inclusion criteria. Designs were predominantly retrospective cohort studies (n=15), supplemented by two systematic reviews, one case-control study, and one case series (Figure 1). Observation periods spanned 1975–2021. Study sample sizes ranged from 13 to 27,897 patients (median 65; uw-mean 1,653), yielding a total of 31,409 combatants with spine injuries and 36,100 recorded spinal injuries (Figure 2, Table 2). Across the full dataset, this corresponds to 1.15 spinal injuries per patient, while at the study level the median reported ratio was 1.22 injuries per patient (interquartile range [IQR] 1.0–2.22; Table 2).

Most series were drawn from recent conflicts. Fifteen of the nineteen reports explicitly sampled casualties from Iraq and Afghanistan and together contributed 30,959 patients; one smaller series (50 patients) reported Afghanistan alone, and three studies (400 patients) did not specify the area of operations (Figure 2).

Demographics and spinal cord involvement. Fifteen cohorts reported age data. The patient-weighted mean age at injury was 25.4 years (uw-mean 28.0 years), and the median of study-level means was 26.6 years (range 25.3–39.1 years; Table 2). Sex distribution, where reported (12 cohorts), was overwhelmingly male, with a pooled, patient-weighted mean proportion of 96.6% male casualties (Table 2).

Thirteen cohorts reported the proportion of patients with traumatic spinal cord injury. Across these, the pooled patient-weighted mean proportion with spinal cord injury was 27.6%, while the median study-level proportion was 41.5% (IQR 17.4–76.0%; range 0–100%; Table 2). Most of the included cohorts did not report ASIA impairment scores or other standardized neurological grades, so we could not break these figures down by completeness of injury or compare all outcomes by severity.

Mechanisms and types of injury. Mechanism of injury was reported in 15 of 19 cohorts (Figure 5). In the pooled, patient-weighted analysis, explosions or blasts accounted for 79.1% of combat spine injuries, gunshot wounds for 14.3%, motor vehicle crashes for 19.9%, and falls for 6.2%. At the study level, the corresponding medians of reported proportions were 65.0% for explosions (range 23.1–100.0%), 15.1% for gunshot wounds (range 9.4–44.1%), 11.9% for motor vehicle crashes (range 5.0–34.4%), and 5.8% for falls (range 5.0–7.4%; Figure 5). Because mechanisms were not coded as mutually exclusive in all registries, these percentages can sum to more than 100%.

Traumatic spinal cord injury was reported in 27.6% of the pooled patient population, with a median study-level prevalence of 41.5%. Twelve cohorts reported broad injury type (Figure 5). Blunt trauma accounted for a pooled, patient-weighted mean of 68.1% of cases and penetrating trauma for 30.7%. The median study-level proportions were 81.2% for blunt trauma (range 33.1–100.0%) and 23.8% for penetrating trauma (range 9.4–97.9%; Figure 5). Several primary studies classified blast injuries variably as blunt, penetrating, or in separate categories, which is reflected in the observed ranges.

Anatomical distribution. Segment level involvement was variably reported, with 5–6 cohorts (n = 699–767 patients) providing patient level data and up to 13 cohorts (n ≈ 32,000 spine injuries) reporting injury level distributions (Figure 3). At the patient level, the uw-mean prevalence of involvement at each spinal region was 39.3% for cervical, 21.2% for thoracic, 65.5% for lumbar, and 41.0% for sacral segments; percentages exceed 100% because many patients had multilevel injuries. At the injury level the mean prevalence across cohorts was 30.2% for cervical, 28.2% for thoracic, 39.9% for lumbar, and 14.0% for sacral injuries.

Operative care and timing. Eight cohorts reported the proportion of patients undergoing operative management. Across these series, 40.7% of spine injured patients were treated surgically in the pooled, patient weighted analysis. At the study level, the uw mean operative rate was 58.4%, with a median of 65.6% (range 5.9–100.0%). Where the level of care was specified (two cohorts), 12 spine operations were performed at deployed Role 3 hospitals in the area of combat before strategic evacuation and 47 were performed after arrival at Role 4 hospitals in the rear support area, so about one in five recorded spine procedures (20.3%) took place forward in the combat zone (Table 2).

Surgical timing was reported for 351 patients across three cohorts. In this group, the median time to initial surgery reported was 1.7 days and the uw-mean was 2.9 days. Timing for definitive reconstruction was tracked in two smaller cohorts totaling 33 patients; in this subset, the median time to fixation was 15.5 days and the mean was 16.5 days (Figure 4).

Concomitant injuries. Five cohorts comprising 1,587 patients reported head injuries in 58.9% of cases (Figure 5). Extremity fractures affected 54.1% of the 734 patients tracked across five studies. Six cohorts (n=812) reported abdominal injuries in 28.7% of cases, while three cohorts (n=649) identified chest trauma in 26.7%.

Complications, reoperation, and mortality. Outcomes were synthesized based on the available patient pools for each metric (Figure 5, Table 2). Nine cohorts comprising 1,738 patients reported mortality; the average rate across the total patient population was 7.4%, whereas the median rate reported among individual studies was 3.1% (range 0–100.0%). Complication profiles were available for a similar group of 1,687 patients (nine studies), yielding a population average of 14.8% (median study value 16.7%; range 0–69.2%). Reoperation data was tracked in seven cohorts totaling 483 patients; in this subset, the reoperation rate was 17.6% across the population (median study value 14.0%; range 7.7–100.0%).

Specific complications were reported less consistently (Figure 5). Five cohorts comprising 997 patients tracked wound infections; the average rate across this population was 5.9%, compared to a median study-level rate of 9.0% (range 3.1–20.0%). Venous thromboembolism was monitored in a subset of 740 patients (five studies), yielding a population average of 3.6% (median study value 2.5%; range 0–53.8%). Pneumonia was reported in three cohorts totaling 677 patients; the average rate was 3.0% across the population (median study value 0%; range 0–3.4%).

Table 2. Summary Statistics of the Top-Cited Papers in Combat Spinal Trauma

PMC Citations	First Author	Year	Title	Journal	Study Type
24	*Schoenfeld AJ (1)*	*2013*	*Spinal injuries in United States military personnel deployed to Iraq and Afghanistan: an epidemiological investigation involving 7877 combat casualties from 2005 to 2009.*	*Spine*	*Retrospective Cohort*
12	*Ragel BT (5)*	*2009*	*Fractures of the thoracolumbar spine sustained by soldiers in vehicles attacked by improvised explosive devices.*	*Spine*	*Retrospective Cohort*
9	*Blair JA (3)*	*2012*	*Military penetrating spine injuries compared with blunt.*	*The Spine Journal*	*Retrospective Cohort*
8	*Lehman RA Jr (4)*	*2012*	*Low lumbar burst fractures: a unique fracture mechanism sustained in our current overseas conflicts.*	*The Spine Journal*	*Retrospective Cohort*

8	*Formby PM (13)*	*2016*	*Operative management of complex lumbosacral dissociations in combat injuries.*	*The Spine Journal*	*Retrospective Cohort*
8	*Lawless MH (14)*	*2018*	*Surgical management of penetrating spinal cord injury primarily due to shrapnel and its effect on neurological outcome: a literature review and meta-analysis.*	*Journal of Neurosurgery: Spine*	*Systematic Review/ Meta-analysis*
6	*Patzkowski JC (15)*	*2012*	*Multiple associated injuries are common with spine fractures during war.*	*The Spine Journal*	*Retrospective Cohort*
6	*Mok JM (16)*	*2013*	*Effect of vacuum spine board immobilization on incidence of pressure ulcers during evacuation of military casualties from theater.*	*The Spine Journal*	*Retrospective Cohort*
5	*Freedman BA (17)*	*2014*	*The combat burst fracture study--results of a cohort analysis of the most prevalent combat specific mechanism of major thoracolumbar spinal injury.*	*Archives of Orthopaedic and Trauma Surgery*	*Case-Control*
4	*Eardley WG (18)*	*2012*	*Spinal fractures in current military deployments.*	*Journal of the Royal Army Medical Corps*	*Retrospective Cohort*
3	*Spurrier E (19)*	*2016*	*Identifying Spinal Injury Patterns in Underbody Blast to Develop Mechanistic Hypotheses.*	*Spine*	*Retrospective Cohort*
3	*Stewart SK (20)*	*2019*	*Fatal head and neck injuries in military underbody blast casualties.*	*Journal of the Royal Army Medical Corps*	*Retrospective Cohort*
2	*Possley DR (21)*	*2012*	*Complications associated with military spine injuries.*	*The Spine Journal*	*Retrospective Cohort*
2	*Formby PM (22)*	*2015*	*Reoperation after in-theater combat spine surgery.*	*The Spine Journal*	*Retrospective Cohort*
2	*Breeze J (23)*	*2012*	*Outcomes from penetrating ballistic cervical injury.*	*Journal of the Royal Army Medical Corps*	*Case Series*
1	*Sommer F (24)*	*2023*	*Spinal injuries after ejection seat evacuation in fighter aircraft of the German Armed Forces between 1975 and 2021.*	*Journal of Neurosurgery: Spine*	*Retrospective Cohort*
1	*Cuthbertson JL (25)*	*2020*	*Spinal Immobilization in Disasters: A Systematic Review.*	*Prehospital and Disaster Medicine*	*Systematic Review/ Meta-analysis*
1	*Wagner SC (26)*	*2015*	*Operative treatment of new onset radiculopathy secondary to combat injury.*	*Military Medicine*	*Retrospective Cohort*
0	*MacGregor AJ (27)*	*2023*	*Research Letter: Prevalence of Spine Injuries Among US Military Personnel With Combat-Related Concussion (27).*	*Journal of Head Trauma Rehabilitation*	*Retrospective Cohort*

Caption: **The 19 most-cited primary clinical studies on combat-related spinal trauma (2000–2025) ranked by citation frequency.** The top 30 most-cited articles identified by the search strategy were screened in full text; 19 met the inclusion criteria for data extraction. Citation counts reflect PubMed-to-PubMed citations, serving as a proxy for clinical influence within the peer-reviewed biomedical literature. *Abbreviations: PMC, PubMed Central.*

Table 2. Summary Statistics of the Top-Cited Papers in Combat Spinal Trauma

Clinical Variable	*Studies (k)*	*Total Patients (N)*	*Total Events (n)*	*Pooled Prevalence*
		COHORT OVERVIEW		
Total Included Cohort	*19*	*31,409*	-	-
Total Spinal Injuries	*19*	*31,409*	*36,100*	-
		DEMOGRAPHICS		
Age (Mean Years)	*15*	*30,660*	-	*25.40%*
Male Sex	*12*	*30,272*	*29,249*	*96.60%*
		INJURY CHARACTERISTICS		
Traumatic Spinal Cord Injury	*13*	*2,688*	*741*	*27.60%*
		MANAGEMENT		
Surgical Intervention	*8*	*1,679*	*683*	*40.70%*
Operations in Combat Zone	*2*	*59*	*12*	*20,30%*
		OUTCOMES		
Overall Complication Rate	*9*	*1,687*	*250*	*14.80%*
Reoperation Rate	*7*	*483*	*85*	*17.60%*
Mortality	*9*	*1,738*	*129*	*7.40%*

Caption: Aggregate data summary of combat-related spinal trauma. This table details the pooled prevalence of key demographic, injury, and management variables. For each variable, the data reflects only the subset of studies (k) that explicitly reported that outcome. Columns show the total number of patients evaluated for that specific variable (N), the total count of observed events or cases (n), and the resulting pooled percentage. *Abbreviations: k, number of studies; N, total patient denominator; n, total number of events.*

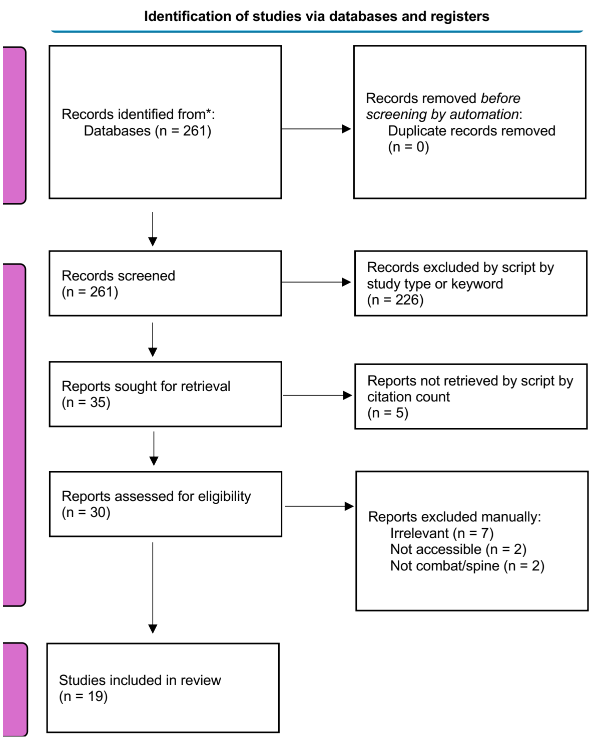

Figure 1. PRISMA 2020 flow diagram

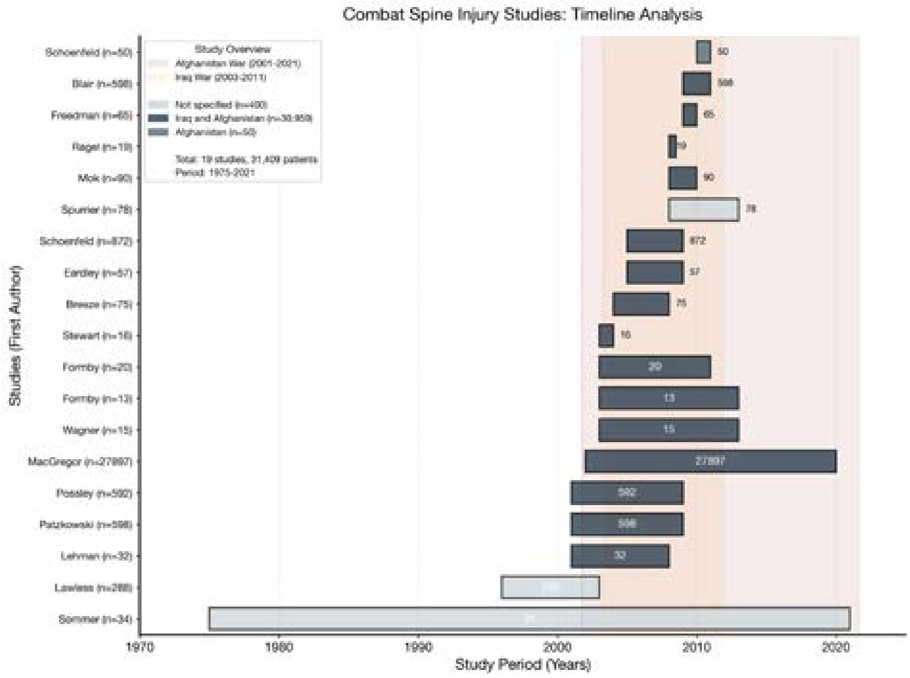

Figure 2. Temporal distribution of included studies.

A timeline visualization of the 19 studies included in the analysis representing a total cohort of 31,409 patients over a 46-year period (1975–2021). The horizontal bars indicate the data collection period for each publication, color-coded by war theater. The majority of studies (n=15) correspond to the Iraq and Afghanistan conflicts. Abbreviations: n, number.

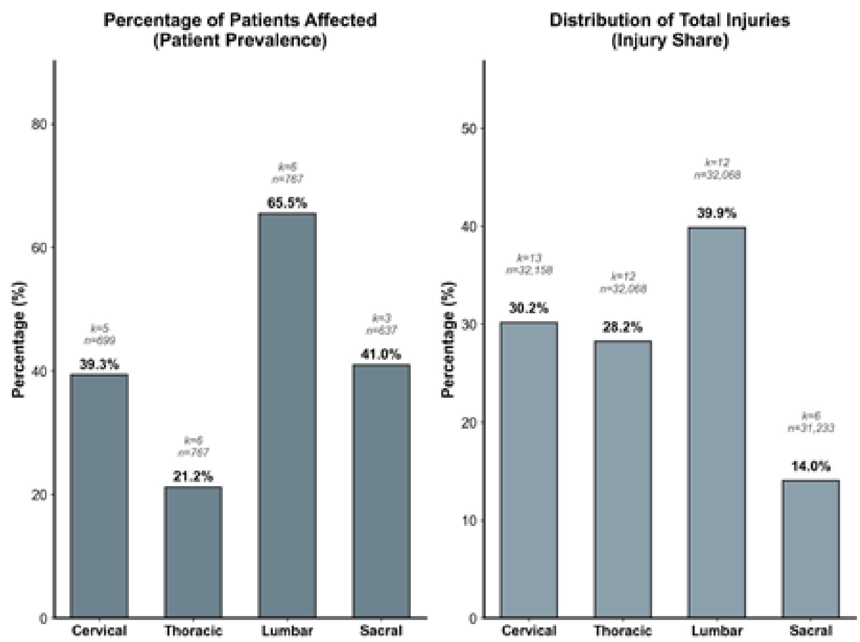

Figure 3. Anatomical distribution of spinal injuries.

The data is presented in two ways to distinguish between patient involvement and total injury burden. (Left) Percentage of Patients Affected: Shows the proportion of patients who sustained an injury at each specific level. Because individual patients often have injuries at multiple levels (e.g., a patient with both cervical and lumbar fractures), these percentages sum to more than 100%. (Right) Distribution of Total Injuries: Shows the breakdown of all spinal injuries combined. This treats the injuries as the unit of analysis, showing what percentage of the total injury pool occurred at each level (summing to 100%). Lumbar segments show the highest prevalence in both analyses (65.5% of patients; 39.9% of total injuries). Labels above bars indicate the number of studies (k) and contributing sample size (n).

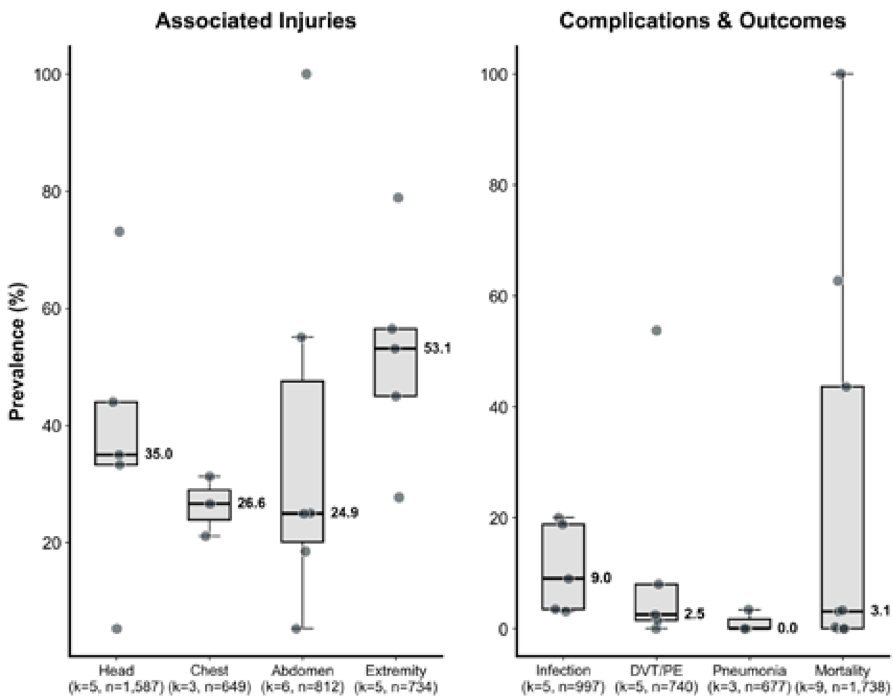

Figure 4. Surgical timing intervals.

Box plots display the distribution of reported mean times to surgery. Initial surgery (typically decompression) occurred at a median of 1.7 days (k=3 studies). Definitive stabilization occurred at a median of 15.5 days (k=2 studies). The black line indicates the median; dots represent individual study means. Abbreviations: n, number of studies.

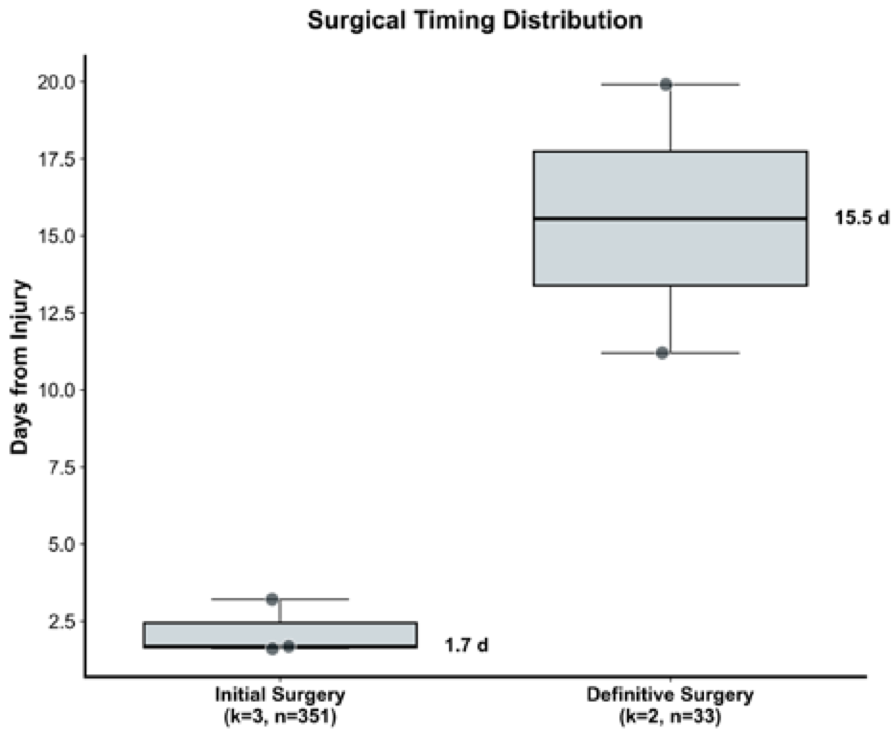

Figure 5. Associated injury burdens and clinical complications.

(Left) Non-Spinal Injuries: Extremity fractures were most common (median 53.1%), followed by head trauma (35.0%).(Right) Complications: Infection was the most frequent issue (median 9.0%). Mortality was 3.1% (median of 9 studies). Note: The text cites a higher mortality (7.4%) because it averages all patients (total burden), whereas this figure shows the typical rate reported by a single study. Abbreviations: DVT, deep vein thrombosis; PE, pulmonary embolism

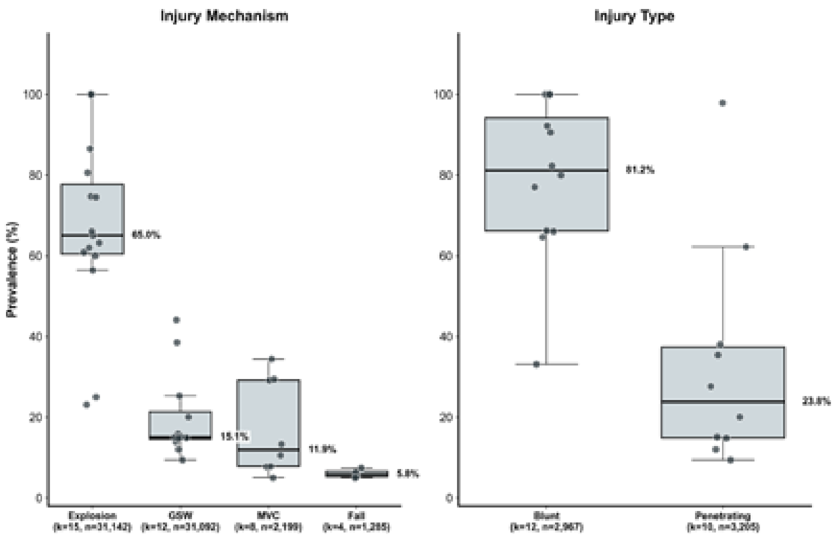

Figure 6. Trauma mechanisms and injuryclassification.

Injury mechanisms and types. (Left) Mechanism: Explosions were the primary cause of injury (median 65.0%), followed by gunshot wounds (15.1%) and motor vehicle collisions (11.9%). (Right) Injury Type: Blunt trauma (median 81.2%) was significantly more common than penetrating trauma (23.8%). Note: Data represents the median of reporting studies (k). Abbreviations: GSW, gunshot wound; MVC, motor vehicle collision.

Discussion

The epidemiology synthesized here confirms that modern combat spinal trauma is a distinct clinical entity, diverging sharply from civilian patterns in mechanism, anatomy, and patient demographic. While civilian tSCI is increasingly a geriatric syndrome defined by cervical tSCI after low energy falls and decreasing numbers in high velocity motor vehicle accidents [28, 29], the combat cohort is young (mean ~25–28 years), predominantly male, and overwhelmingly shaped by explosive mechanisms (median 65%). This specific injury pattern – burst fractures in the lower spine following underbody blasts – requires the deployed surgeon to anticipate complex reconstruction needs that differ from the cervico-thoracic decompression workload seen in civilian trauma centers. Most series did not provide ASIA grades or consistent descriptions of open versus closed spinal wounds, so we cannot determine whether patients with complete spinal cord injuries or open spinal wounds were triaged or evacuated differently from those with incomplete deficits.

A central tension exists between the biological imperative for decompression and the logistical imperative for evacuation. The civilian standard has solidified around the "24-hour rule"; decompression within this window is associated with superior neurological recovery and is now recommended by global guidelines [6, 8, 30].

However, our synthesis shows that the battlefield reality does not meet this 24-hour target: the median time to the first spine operation is 1.7 days (about 41 hours). This delay is mostly a structural feature of the Role 1–4 system rather than a failure of individual teams. Operating at a deployed Role 3 hospital close to the zone of active operations means accepting a deliberate «tactical hold” on evacuation to carry out surgery, whereas deferring the case to a Role 4 hospital outside the theatre of operations allows rapid movement out of the combat zone but inevitably adds time before decompression. In the cohorts that reported level of care, only about one in five spine operations was performed at these forward Role 3 facilities; the remainder were done after strategic evacuation. This pattern suggests that deployed surgeons use forward capability selectively reserving it for patients who seem most likely to benefit (for example, those with incomplete spinal cord injuries at risk of deterioration) and moving patients with complete (AIS A) cord injuries or mechanically stable fractures quickly to rear based care [31].

Primary clinical cohorts suggest that forward surgical capability is utilized selectively to achieve decompression within the 24-hour window for patients with significant neurological deficits, and even in those, is not always achievable. In the only direct comparison of theater-level versus rear-echelon management, patients treated in Afghanistan presented with a markedly higher prevalence of incomplete spinal cord injury (42% ASIA D) compared to those evacuated to Germany (13% ASIA D); consequently, the in-theater cohort underwent surgery at a mean of 0.8 days, with 90% treated within 48 hours (Schoenfeld 2014 Evaluation of Immediate Postoperative Complications) [32]. By contrast, patients stabilized for evacuation to Landstuhl Regional Medical Center waited a mean of 3.0 days for definitive fixation (Schoenfeld 2014 Evaluation of Immediate Postoperative Complications) [32]. This aggressive forward timeline for neurologically injured casualties is corroborated by analyses of patients requiring reoperation, where a cohort predominantly affected by SCI (12 of 13 patients) underwent index stabilization at a mean of 1.6 days, with nearly a quarter treated on the day of injury [22]. Even among complex lumbosacral dissociations where reconstruction was typically delayed (mean 19.9 days), immediate intervention (day 0) was reserved specifically for cases of progressive neurological deterioration [13]. However, historical variance is significant; a meta-analysis of penetrating injuries noted mean surgical intervals ranging from as rapid as 2.4 hours to as delayed as 6.3 days depending on the specific conflict and logistical constraints [14].

The complication profile emerging from this review highlights the specific risks of the combat environment. The median wound infection rate (~9%) is notably higher than the 1–5% seen in elective or closed civilian trauma [33, 34]. This is a direct consequence of high-energy explosive mechanisms, which drive debris into the spinal column, compounded by the necessity of staged debridement and prolonged open wound management during evacuation.

Conversely, the low reported rates of pneumonia (0–3.4%) and VTE (median 2.5%) likely reflect the fragmented observation windows of the evacuation chain rather than true clinical success. In civilian cohorts, respiratory failure is a leading cause of early morbidity [35]. In deployed military cohorts, casualties are usually younger and have fewer comorbidities, and many of the most severely injured either die before reaching facilities with ventilatory and imaging capability or are evacuated out of theater early; pneumonias that develop during prolonged transport or at Role 4 hospitals are therefore unlikely to be captured by the mostly short in theater follow up reported in registries. Similarly, VTE is probably under diagnosed because imaging and screening are inconsistent along the evacuation chain, and the low baseline risk profile of this young population may further reduce the number of clinically apparent events.

The data implies that while the goals of military and civilian care are aligned, the pathways are distinct. The military system achieves acceptable outcomes not by adhering strictly to the 24-hour rule, but by utilizing rapid aeromedical evacuation to reach definitive care as close to that window as logistics allow. To optimize this system, future efforts should focus on high-yield areas. First, every hour saved in pre-operative logistics – imaging, transfers, handoffs, and operating room access – is critical; standardized checklists and time stamped workflows at each echelon can expose avoidable delays and support continuous process improvement. At the same time, meticulous mechanical spinal stabilization is required to prevent a «second hit" to the cord during prolonged, multi leg evacuation. Contemporary guidance emphasizes early immobilization with an appropriately sized cervical collar and rigid or vacuum spine board, careful in line handling during extrication and transfers, and early conversion from hard surfaces to padded or vacuum mattresses once definitive imaging and initial resuscitation are complete, balancing the need for motion restriction against the risks of pressure injury in protracted transport [16, 25, 36]. Further, when surgery is unavoidably delayed, hemodynamic management becomes the principal neuroprotective bridge. Current recommendations support maintaining a mean arterial pressure of roughly 75–80 mmHg for the first 3–7 days after injury, a target that is achievable across intensive care and critical care transport platforms and should be protocolized throughout the evacuation chain [37, 38]. Pharmacologic strategies remain more controversial. High-dose methylprednisolone is still the only agent with phase III randomized trial evidence for neuroprotection when initiated within 8 hours of injury (30 mg/kg IV bolus over 15 minutes followed by 5.4 mg/kg/h for 23 hours), with modest motor score improvements reported in selected patient subgroups of the landmark National Acute Spinal Cord Injury Studies (NASCIS) randomized trials [39]. However, the American College of Surgeons Best Practices Guidelines for Spine Injury and the

Cochrane review highlight increased rates of infection, gastrointestinal bleeding, hyperglycemia and even mortality, such that methylprednisolone is not recommended as routine care but, at most, as an individualized option in carefully selected patients [36, 38, 39]. Other candidate neuroprotective agents – including riluzole, granulocyte colony stimulating factor, minocycline, progesterone plus vitamin D, and GM1 ganglioside/Sygen [40-44] – have shown encouraging signals in preclinical and early phase clinical studies, and riluzole and granulocyte colony stimulating factor may improve neurological outcomes, but current evidence remains inconclusive and insufficient to justify routine use in the first 24–72 hours after tSCI, particularly in austere or resource limited settings [38]. In summary, optimizing tSCI care in deployed environments will depend on systematically reducing avoidable delays to decompression, enforcing best practice mechanical and hemodynamic neuroprotection during prolonged evacuation, and rigorously standardizing data. Future registries should adopt uniform definitions of «early" surgery (for example, ≤24 vs >24 hours), align these thresholds with contemporary evidence syntheses, and capture 30 day outcomes – especially venous thromboembolism and infection – that span theater boundaries, thereby enabling meaningful benchmarking and iterative improvement of the military spine trauma system [30, 36, 38].

Strengths and limitations. This study's primary strength lies in its influence-weighted methodology, which captures the specific body of evidence that has most heavily shaped current military doctrine by prioritizing high-impact studies over a broad keyword sweep. Furthermore, our strictly descriptive synthesis respects the structural heterogeneity of the data, avoiding the false precision of meta-analysis to allow the diverse denominators and follow-up windows of combat registries to stand on their own.

The main weaknesses come from the underlying studies. Only a minority report operative timing clearly enough to separate damage control surgery in deployed Role 2/3 facilities from definitive surgery at Role 4 hospitals, so the exact impact of surgical «holds» on delay is hard to quantify. Neurological detail is limited: ASIA grades, completeness of injury and standardized mortality time points are rarely given, and mechanism categories often overlap (for example, blast injuries counted as both blunt and penetrating trauma). Several cohorts draw on overlapping trauma registries from the same conflicts and time periods; we had no way to identify individual patients across publications, so some may be counted more than once. Our figures should therefore be read as descriptive summaries of the influence weighted literature rather than as de duplicated registry data. This is also, why we report both calculated pooled means, as well as median values.

Prehospital and early in theater external stabilization is another critical but poorly captured element of care. Contemporary military protocols, including the American College of Surgeons Best Practices Guidelines: Spine Injury, emphasize rigid cervical collars, vacuum mattresses or spine boards, careful log roll techniques, and avoidance of unnecessary transfers to minimize secondary displacement of unstable spinal injuries during prolonged evacuation; a recent systematic review of spinal immobilization in disasters reached similar conclusions.

There is also important selection bias. Most included series describe US and UK forces in Iraq and Afghanistan, where coalition air superiority and the «golden hour" mandate – strictly enforcing casualty transport to surgical capability within 60 minutes – leveraged dense rotary wing coverage to produce historically low case fatality rates [45]. Planning documents for future large scale or near peer conflicts warn that such rapid, at will evacuation cannot be assumed; adversaries are expected to contest airspace and target medical evacuation assets [46-48]. Early reports from Ukraine already describe much longer and more variable evacuation times – often 8–12 hours or more to reach medical facilities, sometimes ≥6 hours just to reach basic stabilization – and deliberate delays due to drone surveillance and artillery threat [49-51]. Our timing data should therefore be viewed as a best case benchmark from well resourced forces with air superiority. In less permissive environments, longer delays will make disciplined neuroprotective medical care – even in the absence of definitive surgery – central to tSCI management. Role 2 and 3 facilities should therefore be equipped to monitor MAP continuously and deliver vasoactive support along the evacuation chain. Pharmacologically, high dose methylprednisolone remains controversial despite historical trial data, and other candidate neuroprotective agents such as riluzole, granulocyte colony stimulating factor, minocycline, progesterone plus vitamin D, and GM 1 ganglioside are still investigational and not standard of care in the first 24–72 hours after injury.

Finally, because selection was driven by cumulative citation counts, our sample inherently favors established literature, potentially underrepresenting high-quality but recent studies from the mature phases of the conflicts that have not yet accrued sufficient bibliometric weight.

Conclusion. In the most cited modern series, combat spinal trauma emerges as a young, blast driven, thoracolumbar heavy injury pattern: about one in four casualties sustain traumatic spinal cord injury, nearly 80% of injuries are blast related, and lumbar segments are involved in roughly two thirds of patients. Despite this high risk profile, only about 40% undergo spine surgery, with typical time to first definitive operation on the order of 2–3 days after injury and only a minority of procedures performed at forward Role 3 facilities, even when tSCI and/or neurological deficit are present. This stands in contrast to civilian guidelines, which now recommend decompression within 24 hours whenever feasible. Yet these timelines were achieved in a best case logistic environment – air superiority, robust aeromedical capacity, and short, protected evacuation routes – and are unlikely to be replicated in future large scale or contested conflicts. Our focus should therefore be clear: while we continue to pursue earlier decompression when it can be done safely, the core of combat spine doctrine must be deliberate, system wide neuroprotection during prolonged evacuation – reliable immobilization and careful handling, hemodynamic optimization, and disciplined avoidance of secondary insults – so that neurological potential is preserved as far as possible when guideline concordant early surgery cannot be guaranteed.

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Ethical Standards not applicable in a review.

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Morphological criteria influencing measured withers height in horses

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Abstract

Die Messung der Widerristhöhe bei Pferden ist ein wichtiges Identifikationskriterium und ein wesentlicher Bestandteil der Identifikationsangaben im Pass fast aller Pferderassen. Bei Ponys, die an Wettbewerben teilnehmen, ist die Messung der Widerristhöhe ein wichtiges Instrument zur Einstufung dieser Pferde, insbesondere in internationalen und nationalen Wettbewerbsklassen der FEI-Disziplinen. Das Verständnis der Messpraxis ist teilweise eingeschränkt und wird nicht immer ausreichend akzeptiert. In dieser Studie haben wir versucht, die Faktoren zu verstehen und zu analysieren, die diese Messung beeinflussen können. Es wurden zwanzig Pferde zweier verschiedener Rassen (Schweizer Warmblut und Freiberger) im Alter zwischen 3 und 4 Jahren verwendet, die der Schweizer Armee gehören. Die Messungen der Widerristhöhe wurden zweimal im Abstand von 14 Tagen von zwei erfahrenen Pferdetierärzten durchgeführt. Während jeder Messreihe wurden pro Tierarzt drei Messungen auf der linken und rechten Seite mit einem Widerristhöhenmesser mit Wasserwaage durchgeführt. Die Ergebnisse zeigen einen signifikanten Unterschied zwischen den Messungen auf der linken und rechten Seite (P = 0.01108). Es wurde beobachtet, dass die auf der linken Seite gemessene Widerristhöhe systematisch niedriger ist als die auf der rechten Seite gemessene (Korrelationskoeffizient = 0,2). Es gab keine Unterschiede zwischen den Messungen der beiden Tierärzte. Der Unterschied zwischen den in 14-tägigen Abständen durchgeführten Messungen war der Unterschied nach Bonferoni-Korrektur nicht mehr signifikant. Die Autoren weisen darauf hin, dass bei diesem Verfahren mehrere Fehlerquellen auftreten können. Sie schlagen eine alternative Messmethoden vor, etwa die Vermessung am Becken (Sakralhöcker), die unter Einsatz dreidimensionaler Bildgebungstechniken eine höhere Zuverlässigkeit aufweist.

Withers height measurement in equines is an important identification criterion and an integral part of the identification information in a passport for almost all horse breeds. In ponies that participate in competitions, withers height measurement is an important tool for categorising these equines, particularly in international and national competition classes in the FEI disciplines. The understanding of the measurement practice is sometimes limited and poorly accepted. In this study, we sought to understand and analyse the factors that may influence this measurement. Twenty horses of two different breeds (Swiss Warmblood and Franches-Montagnes horse) belonging to the Swiss Armed Forces and aged between 3 and 4 years were used. Height measurements at the withers were taken twice, with an interval of 14 days, and were performed by two experienced equine veterinarians. During each session, 3 measurements per veterinarian were taken on both the left and right sides using a measuring stick equipped with a level. The results obtained indicates a significant difference in measuring between the two sides (p=0.01108). It was observed that the height at the withers measured on the left is systematically lower than that measured on the right (correlation coefficient = 0.2). There were no differences in the measurements taken between the two veterinarians. The difference in measurements taken at 14-day intervals was also significant (p=0.019). The results were not influenced by angle measurements, particularly those of the hooves. The authors confirm that multiple sources of error can occur during this procedure and that an alternative solution such as measuring at the pelvis (sacral tuberosities) must be more reliable, even when using three-dimensional imaging techniques.

1. Introduction

Wither height is an important anatomical parameter in horses, not only for aesthetic evaluation but also for basic functional performance. Wither height is not only relevant for determining the height of a horse for identification purposes but also for determining if an equid is defined as a pony or a horse - the FEI defines a pony as measuring 148 cm or less without shoes or 149 cm with shoes (Pugh, 2017) [1a], [1b]. It is clear that accurate measurements are essential for ponies in FEI competitions, as a difference of just 1 cm can determine eligibility for future competition.

Wither height is measured at the highest point on the withers, dorsal to the spinous process of the fourth or fifth thoracic vertebrae (T4/T5) (Curtis, 2010) [2a], [2b]. Various factors, such as the time of day, exercise, transport, sedation, hydration status, and stress, can compromise the accuracy of wither height records (Van de Pol, 2007; Hickman, 1984) [3], [4a], [4b]. Recent studies have further supported these observations, emphasizing that posture during measurement and surface unevenness can significantly impact results (Wulf et al., 2020) [5]. Additionally, another author highlighted inconsistencies between manual and laser-based measurement techniques, underscoring the need for methodological standardization (Santschi et al., 2018) [6].

An important contribution to the understanding of morphometric correlations comes from a study that looked at standardized radiographs of ponies (Thieme, 2017) [7]. Based on standardized radiographs of 81 ponies (wither height: 81.5–148 cm), the authors' findings are clear: linear hoof measurements and wither height show strong correlations, while angular parameters are less informative. A regression model established reference values for a pony with a wither height of 120 cm, emphasizing the importance of objective anatomical markers in conformation assessment.

According to one author (Lama, 2007) [8], [9], three points are pivotal to the accuracy of wither height evaluation: anatomy, animal compliance, and measurement technique. From an anatomical perspective, it has often been accepted that the presence of asymmetry in many advanced mammals, with one side of the predominantly symmetrical bilateral body showing greater development than the other. Asymmetry refers to physical differences between the two sides of the body, such as differences in shape, size, bone dimensions, muscle growth, vascularisation and, most importantly, the nervous system, including the brain. Laterality, on the other hand, describes an individual's preference for using one side of the body for certain tasks, such as using one hand for writing in humans. Laterality indicates a functional preference; asymmetry refers to physical differences (Marques, 2024) [10], [11].

The presence of laterality has been recognized in various species, including humans and horses for a long time (Kuhnke, 2020; Farmer, Krueger and Byrne 2010) [12], [13], [14]. A recent investigation (McGreevy, 2022) [15] showed that equine laterality not only affects locomotion and behavior but may also influence anatomical development. Emerging studies suggest that variables like sex and mane direction may also affect lateral behaviour. For instance, a original study (Krüger et al., (2014) [16] and other behavioural analyses have shown that sensory laterality, like preferring the left eye during social interactions, is independent of sex (Krüger et al., (2020) [17]. The same authors indicate a link between mane side and lateral preferences. Mane orientation may correlate with motor laterality and asymmetrical loading in ridden horses, although direct evidence remains preliminary. However, these factors have not been explicitly investigated in relation to wither height asymmetry, presenting a novel angle for morphometric research.

Despite its importance, the effect of laterality on wither height measurements has not been satisfactorily investigated. This scientific project aims to establish whether the height of a horse at the withers varies depending on the side from which the measurement is taken, who is conducting the measurement, and when the measurement is taken. It is hypothesised that angular measurements and the distances between specific anatomical landmarks will significantly influence the measured height.

2. Materials and methods

Animals

The horses were provided by the Swiss Armed Forces: 10 Warmbloods and 10 Franches-Montagnes, aged between 3 and 4 years. All horses were housed either on pasture or in all-weather paddocks. The Warmblood horses were trained exclusively for riding, whereas the Franches-Montagnes were trained for riding, driving and pack work. The same handler performed the grooming. All grooming and measurement procedures took place in a room compliant with the FEI's regulations for measuring ponies and the horses were positioned as required.

Animal Welfare statement

All the data used for this study was collected during the year 2024. It fully complies with the Swiss legislation concerning the codes of ethical behaviour and animal protection.

Statement of informed consent

All horses belonged to the Swiss Armed Forces. They are aware and consented to inclusion of all gathered data in a scientific publication.

Study Design

The height at the withers was measured twice for each horse, with a 14-day interval between the two sessions. Before each measurement, specific anatomical landmarks were palpated, marked, and photographed. These reference points were used to assess repeatability and potential variation in measurement. They were then analysed using the software «My Measures» (The Appraisers, Inc., 2025) [18]. Landmarks were chosen based on their ease of palpation and were re-marked before each session. Each measurement was performed three times on each side by two different observers to assess inter-observer consistency.

Anatomical Landmark Marking

Height measurements were taken before marking five anatomical reference points with Tipp-Ex® correction fluid. This ensured consistency and facilitated data comparison. The reference points are as follows (see Figure 1):

- A: Highest point of the withers (dorsal spinous processes of the 4th–5th thoracic vertebrae)
- B: Highest point of the scapular cartilage
- C: Point of the pars caudalis of the greater trochanter of the humerus
- D: Lateral epicondyle of the humerus
- E: Point located at the metacarpophalangeal joint, adjacent to the sesamoid bone,
- F: Point located on the ground and perpendicular to A

In addition, two calibration points (Z) were marked exactly 10 cm apart (Figure 1) to serve as a reference scale within the My Measures software. Sex (mare or gelding) and mane orientation (left, right, or bilateral) were also documented for each horse.

Photographs

Photographs were taken using a camera mounted on a plastic tripod to minimize environmental movement. The camera was positioned at exactly 1 m from the horse and aligned to a point midway between landmarks B and C, and directly below point A. Two photographs were taken on each side. These images were used to measure the distances between landmarks via the «My Measures” software.

Distance and Angle Measurements

Using My Measures, the following linear distances were recorded:

- A to B
- B to C
- C to D
- D to E
- A to E

Two anatomical angles were also calculated:

- A1: The angle formed by the lines B–C and C–D

- A2: The angle formed by the lines C–D and D–E

Additionally, hoof angle A3 was measured using a level (mobile application) designed for angle measurement.

The calibration distance Z (10 cm) was also measured manually with a flexible tape measure to verify scale accuracy.

Withers Height Measurement

The two observers approached calmly and positioned the height stick so it remained out of the horse's field of vision until placement. The height stick was placed perpendicular to the ground and aligned with the highest point of the withers. The integrated level on the height stick ensured vertical accuracy. Each observer performed three height measurements per horse on each side – resulting in six measurements per horse.

Statistical analysis

The data analysis was performed using RStudio (version 2023.06.1; RStudio Team, 2023) [19] in combination with the R programming language (version 4.3.1; R Core Team, 2023) [20], which together provide a flexible environment for statistical computing. The dataset, originally

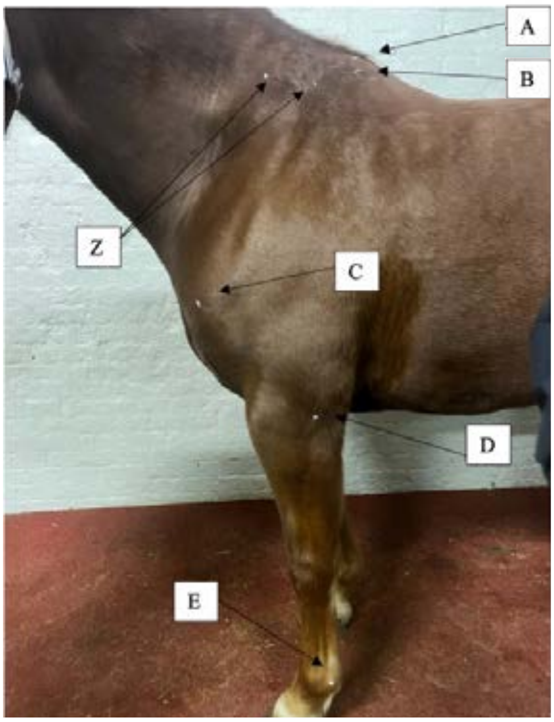

Figure 1: Marking anatomical points: own photograph. (Karol 2024)

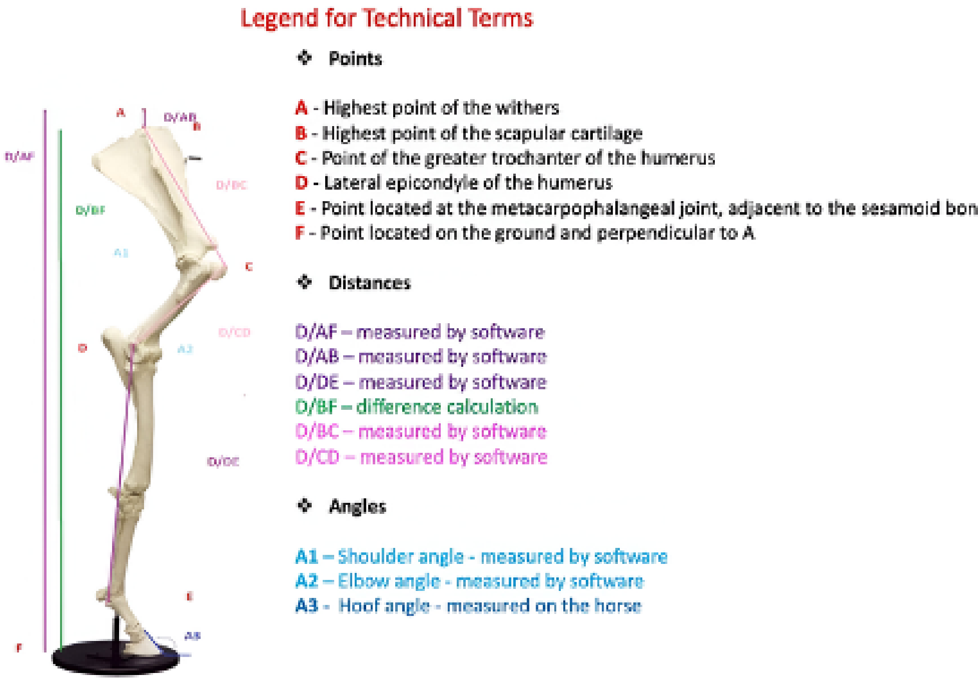

Figure 2: Measuring anatomical distances and foot angles: own illustration (Montavon & Karol 2024)

stored in a Microsoft Excel file, was imported into R and prepared for analysis using the dplyr and tidyr packages (Wickham, François, Henry, & Müller, (2023); Wickham & Henry, (2023) [21], [22]. These packages were used to organize the data by selecting relevant variables, renaming columns, handling missing values, and restructuring the data into a format suitable for analysis. To visualize the results, the ggplot2 package (Wickham, 2016) [23] was used. This tool allows for the creation of clear, customizable, and publication-quality plots that help to identify patterns and relationships in the data. Overall, this software setup made it easier to process, explore, and present the data in a way that supports clear interpretation of the results.

3. Results

The following section presents the statistical findings from the measurement of withers height in horses. We examine the influence of the measurement side, the person performing the measurement, the timing of the measurement, as well as specific angles and distances between anatomical reference points.

Influence of the Measurement Side on Withers Height

Each horse's withers height was measured from both the left and the right side during data collection. At each time point, three repeated measurements were taken by each measurer from each side. The mean of these three values was then calculated, resulting in one representative value per side, per time point, per measurer, and per horse.

A paired t-test was used to assess systematic differences between left and right side measurements. This test accounts for the paired nature of the data, as each left side measurement has a corresponding right side measurement for the same horse, time point, and measurer.

Results of the Paired t-Test:

- Mean withers height (left side): 159.21 cm

- Mean withers height (right side): 159.75 cm

- Mean difference (left − right): −0.54 cm

- p-value: 0.01108

The p-value is below the conventional threshold of 0.05, indicating a statistically significant difference between the two sides. However, it should be noted that no correction for multiple comparisons was applied at this stage. A Bonferroni correction will render this result non-significant if the number of statistical tests performed within the overall study is high enough.

When testing multiple hypotheses, the overall type I error rate increases if no adjustment is made. Maintaining a family-wise error rate at 5% often means reducing the significance level for each individual test. The Bonferroni correction is the most common method for this adjustment. It divides the alpha level by the number of comparisons. The current result is statistically significant, but the strength of this significance may be affected by the number and type of multiple comparisons conducted throughout the study.

Analysis of the Difference Between Left and Right Side Measurements

To explore the difference between measurements of the two sides further, the value measured from the left side was subtracted from the corresponding value on the right side for each horse, time point, and measurer.

The resulting values were consistently negative, indicating that measurements taken from the left side were consistently lower than those taken from the right. The following patterns were clearly observed in the data:

- A general trend towards negative values was observed across the dataset.

- In many horses, the side difference remained relatively stable across measurers and time points.

- Certain horses (e.g., H20) displayed higher values on the left side.

- In some cases (e.g., H17), values varied depending on the measurer.

- In a few cases (e.g., H16), fluctuations occurred between time points even within the same measurer.

The point-biserial correlation was calculated to quantify the association between measurement side and measured withers height. For this analysis, the side of measurement was encoded as a binary variable (left = 0, right = 1) and correlated with the continuous variable of withers height. The point-biserial correlation coefficient was (r): 0.2. The correlation coefficient was calculated based on all paired measurements across horses, time points, and measurers.

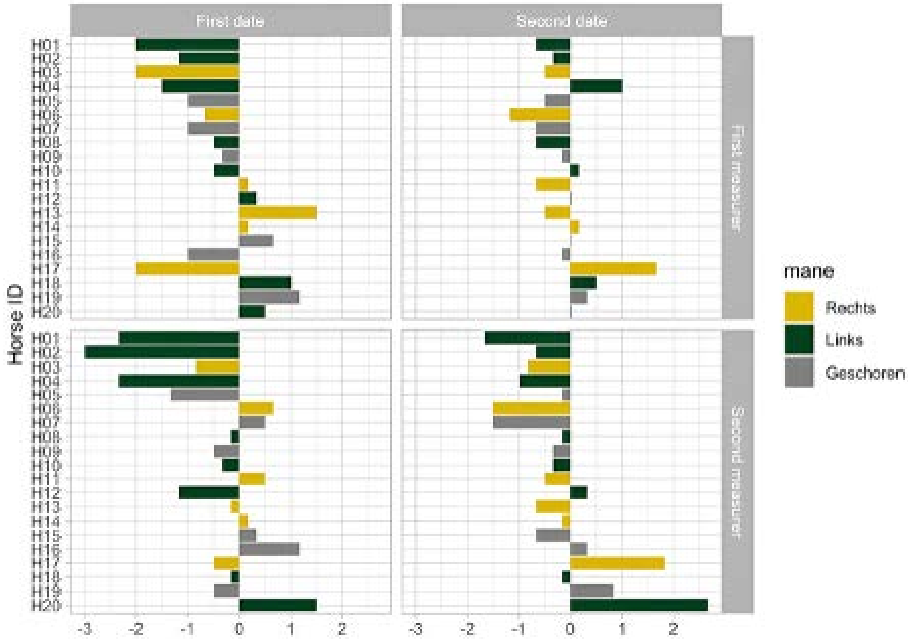

Figure 3: Difference in size between measurements taken from left and from right (in cm) (Gary Delalay 2024)

Influence of the Measurer on Withers Height

This section confirms the same approach as in the previous analysis concerning the side of measurement. It definitively shows whether the person conducting the measurement influences the values of withers height. For each measurement point, values from two different measurers were available. A paired t-test was used to assess the differences between the two measured values.

Results of the Paired t-test:

- t-value: −0.29625
- Degrees of freedom (df): 79
- p-value: 0.7678
- 95% confidence interval: [−0.1769; 0.1311]
- Mean difference: −0.0229 cm

The p-value is well above the conventional significance threshold of 0.05, indicating no statistically significant difference between the measurements taken by the two measurers.

Furthermore, the distribution of the differences between left and right-side measurements was plotted separately for each measurer. The first measurer showed less variation between sides compared to the second measurer. However, there was no clear directional bias for either measurer.

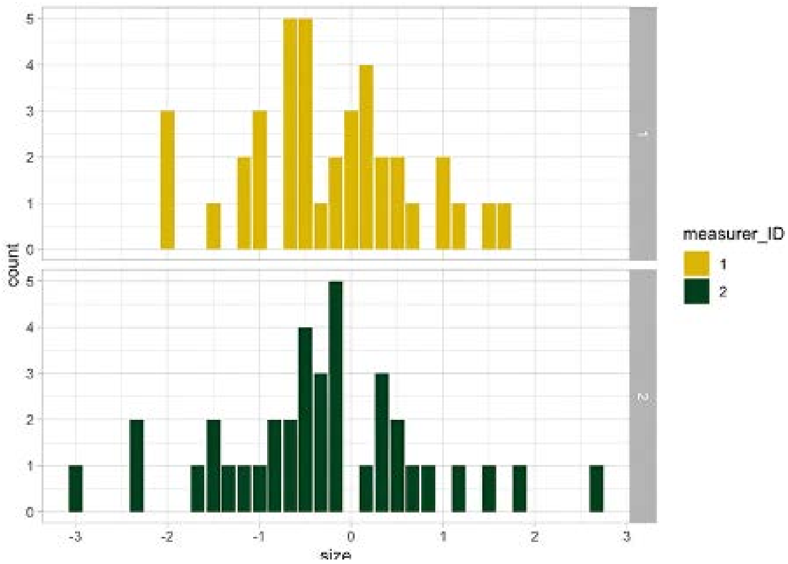

Figure 4: Statistic table 2 – The measurement data collected by the two measurer (Gary Delalay 2024)

Analysis of the Influence of the Date

To evaluate the repeatability of the wither height measurements over time, paired measurements were obtained from all horses at two time points within a 14-day apart. A paired t-test was performed to assess whether there was a statistically significant difference between the two measurement occasions. The analysis included 80 paired observations. The test result showed a statistically significant mean difference between the first and second measurement ($t = 2.394$, $df = 79$, $p = 0.019$). The calculated mean difference was 0.244 cm, with a 95% confidence interval ranging from 0.041 cm to 0.446 cm.

To further examine the relationship between measurement time, point of measurement and other variables, a Pearson's product-moment correlation was calculated between the asymmetry factor (AF2) and the second measurement time point. The analysis yielded a statistically significant negative correlation ($r = -0.181$, $t = -2.312$, $df = 158$, $p = 0.022$), with a 95% confidence interval of

-0.327 to -0.027. In addition, a point-biserial correlation was conducted to determine the strength of association between the categorical variable representing the time point and the continuous variable of measurement difference. This allowed for a further quantitative evaluation of the effect of measurement timing on wither height.

Influence of Angles A1, A2, and A3

Angles A1, A2, and A3 were measured at anatomically defined points on each horse and evaluated for their potential association with withers height. Linear regression models were constructed using these angles as independent variables and using withers height as the dependent variable. Statistical analysis was conducted using the R programming language (version 4.3.1) within the RStudio environment (version 2023.06.1). The significance of each variable was assessed based on p-values. For all three angles, the calculated p-values exceeded the threshold of 0.05, indicating that no statistically significant association between angles A1, A2, or A3 and withers height could be identified.

- p-values (A1, A2, A3): all > 0.05

Influence of the Distances Between Points A–E

The linear distances between anatomical reference points A, B, C, D, and E were recorded and included as predictor variables in linear regression models to assess their relationship with withers height. All statistical procedures were performed using R (version 4.3.1) in combination with RStudio (version 2023.06.1). For each measured distance, p-values were computed to evaluate significance. All distances yielded p-values greater than 0.05, indicating that none of the measured distances between points A–E showed a statistically significant association with withers height.

- p-values (all distances A–E): all > 0.05

4. Discussion

The present study shows that the side from which the withers height is measured has a significant influence on the outcome of the withers height measurement. Measurements taken from the left side of the horse were on average 0.54 cm lower than those taken from the right side. This difference was statistically significant (p=0.01108), though it may lose significance

Figure 5: Pictures from the measuring stick with level: own photograph (Karol 2024)

under conservative correction procedures such as the Bonferroni correction. However, the consistency of this effect across animals and repeated measurements suggests a systematic bias likely influenced by horse behaviour and handler interaction. Given this, the side of measurement should be carefully standardized and accounted for in future protocols.

Side specific differences in withers height

The results definitively showed a significant difference in withers height measurements taken from the left versus the right side. The mean difference was 0.54 cm, with measurements from the left consistently lower than those from the right. Such asymmetries may reflect not only behavioral conditioning but also underlying neuromuscular asymmetries developed through handling and training practices (McGreevy & Rogers, 2005) [27].

It is well established that the left side of the horse is used more frequently for tasks such as leading, saddling, grooming, and veterinary interventions. This convention, originating from historical military practices (Hall & Heleski, 2007) [24], continues to influence modern equine handling. Studies (Krüger et al., 2008 and 2014) [25], [26] demonstrate that horses develop individual lateral preferences (motor and sensory), which are shaped by repeated exposure to one-sided handling. One author (Krüger, 2008) [25] showed that horses often prefer one side during human approach or intra-herd interaction, indicative of hemispheric specialization. This is supported by findings that the left eye (processed by the right hemisphere) is preferentially used for unfamiliar or threatening stimuli (McGreevy & Rogers, 2005) [27]. Another author (Rogers, 2010) [28] further elaborates that such cerebral lateralization is widespread in vertebrates and can manifest in measurable behavioral asymmetries.

Human handedness also plays a role. Most handlers are right handed and may unconsciously perform tasks more precisely on the right side. According to a further author (Hall and Heleski, 2007) [24], right-handedness in humans corresponds with a preference for leading and standing on the horse's left, possibly reinforcing side specific interactions.

Beyond these behavioural and anatomical influences, the horse's training status also significantly impacts the measured withers height. As highlighted in a study (Stammer, 2017) [30] the muscle tone and posture developed through consistent training affect the horse's frame and elevation. Well-trained horses tend to carry themselves with more engagement and positive tension along the topline, often resulting in a higher measured withers height. In contrast, less conditioned horses typically show a more relaxed posture, which can lead to lower measurements. This underlines the importance of accounting for the horse's fitness and training when interpreting morphometric data.

Effect of the person measuring

Although measurement is subject to individual interpretation, this study did not reveal significant differences between the two examiners. It is important to mention at this point that both equine practitioners who took the measurements were right-handed. The use of a level-mounted measuring stick helped to reduce variation. All measurements were taken under consistent conditions in a controlled indoor setting.

One author (Krüger et al., 2016) [26] emphasize that environmental uniformity reduces cognitive load and behavioral distractions in horses, leading to more stable postural outcomes. Another author (Visser et al., 2001) [32] also report that horses habituate to standard procedures more quickly in consistent environments, which improves measurement reliability.

Although minor subjectivity may exist in interpreting the anatomical landmark (highest point of the withers), this appears manageable through training and repetition. Some authors (McGreevy and McLean, 2007) [33] underscore the value of standardised procedures and repeated familiarisation to reduce variability in equine assessments.

Effect of measurement time points

A small but statistically significant difference was observed between the first and second measurement taken 14 days apart (−0.244 cm, $p = 0.019$). The second measurement was lower. However, after applying the Bonferroni correction for multiple comparisons, this difference no longer reached statistical significance. This result must be interpreted with caution. It is more a potential tendency than a conclusive or robust effect. This difference most likely reflects postural relaxation due to habituation. It was confirmed that horses show reduced tension in repeated testing situations, which can influence muscle tone and posture (Krüger, 2011) [34].

Other authors found that repeated gentle handling reduced physiological stress markers in horses, which may translate into a more neutral, lower posture during follow-up measurements. Future studies should incorporate video based posture scoring or three dimensional monitoring systems to better account for postural drift (Hausberger et al., 2008) [35].

Influence of angular measurements (A1–A3)

No significant correlation was found between the measured angles (A1, A2, A3) and withers height. Anatomically, this may be due to the unique musculoskeletal structure (shoulder synsarcosis) of the equine forelimb. Without a clavicle, the horse's scapula is attached to the trunk solely through muscular structures, allowing for a wide range of compensatory mobility (Schurmann et al., 2004) [36].

This anatomical arrangement allows for substantial variability in scapular positioning and angle without necessarily altering the vertical height of the withers. Horses can therefore compensate for changes in joint angle through muscular adjustments, which makes linear or angular projections into a vertical frame of reference (such as height) inherently unreliable.

Furthermore, the muscular control of the shoulder and thoracic sling is not only dynamic but also influenced by external factors such as tension, learned movement patterns, and asymmetrical loading. As noted in Applied Equine Nutrition and Training (Lindner, 2011) [38], the thoracic sling musculature plays a vital role in suspension and elevation of the thorax between the forelimbs, meaning that even small variations in muscle tone or weight distribution can mask or override geometric joint relationships.

According to other authors (McGreevy and McLean, 2010) [29], many postural adaptations in domestic horses stem from training and handling-induced asymmetries, which can alter the way a horse carries weight through the forehand, independently of static joint angles. Such findings underscore the need for caution when interpreting morphometric data solely through angular measures.

Interestingly, no correlation was found between the measured joint angles and the position of the hoof or distal phalanx. This was unexpected, as hoof ground interaction and limb alignment are generally assumed to influence vertical body metrics like withers height. It appears that the hoof maintained a relatively stable position between measurements, despite minor variations in proximal limb angles. One possible explanation is that the horses' compensatory posture maintained ground contact symmetry, regardless of angular deviations.

Another factor to consider is hoof growth during the two-week period between measurements. Although hoof wall growth averages 6–10 mm per month (Curtis, 2010; Pugh, 2017) [1a], [1b], [2a], [2b], its apparent lack of influence on height measurements suggests either regular natural wear, recent trimming, or that any increase in height was insufficient to affect the measurement outcome. As already noted (Lama, 2007) [8], [9]; (Van de Pol and van Oldruitborgh.Oosterbaan, 2007) [3], even small changes in sole depth or hoof balance can subtly affect body posture. However, these effects may have been masked in this study by stable ground conditions and consistent handling.

Distance measurement and withers height

No significant associations were identified between the linear distances (A–E) and withers height. Although anatomical marking with Tipp-Ex® was practical, the precision was insufficient to ensure fully repeatable spatial points. Subtle reactions of the horse during marking may have affected position or muscle tone (Krüger et al., 2020) [17]. This is consistent with other findings (van Weeren and Barneveld, 1987) [37], who demonstrated that skin displacement relative to underlying bone during movement can cause significant errors in marker-based measurements, highlighting the inherent imprecision of superficial skin markers. Thus, the points marked and measured in this study likely suffered from such inaccuracies.

In this context, another study (Stover, 2018) [31] highlights that cannon bone length in racehorses is closely correlated with withers height and thus plays a significant role in the overall conformation of the horse. Since withers height is commonly used to assess size and performance potential, considering cannon bone length is important, as it influences limb biomechanics and the distribution of mechanical stress.

Measurements from digital photographs proved helpful but lacked a standardised camera position and perspective correction. Other authors (Fiske and Potter, 2014) [39] caution that photogrammetric methods require rigorous control over camera angle and subject orientation to avoid measurement distortion. One author (Müller et al., 2020) [40] recommend the use of calibrated stereo-photogrammetry or structured light scanning for improved metric accuracy.

In future studies, the use of markerless motion capture (e.g., DeepLabCut or Kinect) could improve reproducibility and eliminate the need for physical contact. One author (Bishop et al., 2022) [41] shows that modern machine learning-based tracking systems can reliably detect equine landmarks in 3D without markers.

Methodological Considerations and Outlook

The results of this study definitively show that morphometric measurements in horses, even when standardized, are influenced by behaviour, perception and technique. It is clear that the measurement side is the most significant influencing factor, and ethological explanations support this (Krüger et al., 2011) [25]. The findings further support and emphasis on the integration of learning theory and ethology into equine management and research design (McGreevy and McLean, 2010) [29]. The good reproducibility under consistent environmental and methodological conditions is encouraging, although temporal repetition will always introduce minor deviations.

From a practical standpoint, it is essential to standardise the measurement side consistently and document this in official height assessments. Investigation of individual laterality in horses is vital. Simple eye preference tests must be used to help interpret behavioural and measurement related deviations.

Exploration of alternative anatomical landmarks for morphometric measurements is a promising approach to improve accuracy and reproducibility in equine conformation analysis. The sacral tuberosity, as part of the pelvic skeleton, offers a structurally fixed reference point that, unlike the withers, is not subject to the dynamic variability introduced by the thoracic muscular sling. Preliminary scientific literature suggests that measurements or angular relationships originating from the pelvis may provide a more stable and reproducible foundation for morphometric assessments (Holmström, 2000) [42]. In contrast to the withers, which are influenced by muscular compensations in the shoulder girdle, the sacral tuberosities may serve as a more anatomically reliable landmark for precise measurements. This approach could open promising new avenues for biomechanically informed assessments of equine conformation and functional movement. Another consideration for future research is the implementation of advanced measurement technologies. Digital 3D scanning, motion capture, and other imaging-based techniques could offer greater objectivity and repeatability, especially relevant in clinical or breeding contexts where decisions hinge on millimetric precision.

5. Conclusion

This study provides a valuable contribution to understanding the relationship between morphometric parameters and withers height in horses. The study design was methodologically sound, incorporating standardized measurements across a heterogeneous population. Although the sample size was limited, making it difficult to draw statistically robust conclusions, meaningful tendencies were observed, particularly regarding the influence of specific angular parameters and the limitations of conventional measurement techniques. No significant breed effect was found within this group of horses. However, such differences may become more apparent with larger and more breed-specific sample sizes and should be a focus in future research.

One of the central findings of this study is the potential for measurement error associated with using the traditional measuring stick to determine withers height. Despite its widespread use, this method is susceptible to multiple internal and external influencing factors, such as ground conditions, posture, muscle tone, and handler variability. This issue becomes especially critical in cases where measurement thresholds carry regulatory or classificatory importance, such as the formal distinction between ponies and horses based on a difference of just one centimeter, underscoring the need for objective and highly reproducible measurement techniques.

In summary, this study demonstrates that even seemingly straightforward measurements, such as withers height, are subject to a complex array of influencing factors. The findings emphasize the importance of careful methodological choices, consideration of fixed anatomical landmarks, awareness of training-related functional changes, and adoption of modern measurement technologies. Future research should include expanding sample sizes, exploring alternative morphometric reference points, and integrating biomechanical and technological advancements. This will establish a more reliable framework for equine conformational assessment.

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Agenda 2026 – Nationale und internationale militärmedizinische Veranstaltungen / Kongresse

Veranstaltung	**Ort**	**Datum**
Jahrestagung 2026 der ÖGWMPh	*Wals-Siezenheim (A)*	*10. - 11.09.2026*
Internationale Tagung IT 2026 – SGOS	*Spiez (CH)*	*19.09.2026*
57. Jahreskongress der DGWMP e. V.	*Pappenburg (D)*	*08. - 10.10.2026*
46th ICMM World Congress of Military Medicine	*Abu Dhabi (VAE)*	*09. - 13.11.2026*
Combat Medical Care (CMC) Conference	*Paris (F)*	*19. - 20.11.2026*

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