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A personalized approach to the treatment of traumatic spinal injuries: rationale, basic concept, and potential methods of implementation

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Traumatic spinal injuries (TSIs) are a leading cause of disability and represent a significant socio-economic burden. Despite advancements in diagnostic and surgical techniques, treatment outcomes remain inconsistent. Standardized protocols often fail to account for individual patient characteristics, which can reduce the effectiveness of interventions and increase the risk of complications. This highlights the growing relevance of adopting individualized approaches in the treatment of TSIs.

Objective: To comprehensively analyze the economic, legal, clinical, and deontological aspects of implementing individualized approaches to the treatment of TSIs.

Materials and methods: An analytical literature review was conducted in accordance with the PRISMA protocol. Sources were selected from international scientific databases over the past 10 years using relevant MeSH terms.

Results: The literature review revealed that, despite technological advances, treatment outcomes in TSIs do not always improve proportionally with increased healthcare spending, illustrating the phenomenon of diminishing returns. The use of the QALY metric in several countries enables the evaluation of the cost-effectiveness of medical interventions; however, it has ethical limitations and is not yet implemented in Ukraine. The domestic Health Technology Assessment (HTA) system, introduced in 2020, does not currently include mandatory protocols for managing TSIs due to clinical heterogeneity, resource constraints, and legal risks. Standardized, diagnosis-driven protocols focused on the “average patient” often disregard individual variability, potentially leading to both overtreatment and undertreatment. Simplified injury classification systems enhance standardization but may reduce clinical decision-making accuracy in atypical cases. Furthermore, limited public understanding of evidence-based medicine contributes to ethical and communicative challenges. These findings underscore the importance of individualized approaches in TSI management.

Conclusions: Individualization of TSI treatment represents a logical extension of evidence-based medicine and promotes optimization of outcomes. It allows for flexible, patient-specific therapeutic strategies, improves the efficiency of healthcare resource utilization, and reduces complication rates. The ongoing development of analytical tools offers promising prospects for constructing personalized algorithms for managing highly heterogeneous patient populations.

Keywords: *traumatic spinal injuries; personalized approach; diagnosis-oriented strategy; clinical and economic effectiveness; prospects for healthcare development*

Introduction

Traumatic spinal injuries (TSIs) represent one of the most pressing issues in modern traumatology and neurosurgery. Each year, a significant number of cases involving damage to the osteoligamentous structures of the spine are recorded globally. These injuries are commonly associated with road traffic accidents, falls from heights, industrial and sports injuries, among other causes [1]. The proportion of osteoporotic fractures in elderly patients within the structure of TSIs is increasing, which is attributed to the general aging of the

population, lifestyle changes, dietary preferences, and the growing prevalence of osteoporosis [2]. According to the Global Burden of Disease estimates (Institute for Health Metrics and Evaluation, University of Washington, Seattle, USA), the global incidence of TSIs in 2021 was approximately 7.50 million (95% confidence interval [CI]: 5.83–9.74 million), while the prevalence—defined as the presence of clinically significant consequences of previously sustained TSIs—reached 5.37 million cases (95% CI: 4.70–6.20 million) [3]. TSIs are often accompanied by acute symptoms such as severe



pain, marked limitation of mobility, and may require emergency medical care, including surgical intervention [4]. Their consequences often manifest in the long term. Neurological deficits, frequently observed due to spinal cord or nerve root injury, can result in persistent disability and significantly impaired quality of life [5]. This, in turn, limits daily activity, work capacity, and self-care abilities, and may lead to social isolation. Long-term consequences of spinal injuries impose a substantial socioeconomic burden on healthcare systems due to the need for prolonged treatment, rehabilitation, social reintegration, and continuous support. Additionally, they increase expenditures related to disability and reduce overall population productivity [6]. In 2021, the estimated number of patients suffering from the effects of traumatic cervical spinal cord injury was approximately 7.42 million (95% CI: 6.74–8.35 million), with an annual incidence of around 0.31 million (95% CI: 0.22–0.46 million). Thoracolumbar injuries are even more prevalent, with an estimated 7.98 million (95% CI: 7.15–9.16 million) individuals presenting with persistent symptoms and approximately 0.27 million (95% CI: 0.18–0.39 million) new cases annually [3]. These figures highlight the urgent need for a comprehensive approach to injury prevention, rehabilitation of patients with TSIs, and optimization of surgical treatment strategies aimed at achieving adequate spinal stabilization, restoration of neurological function, and reduction of rehabilitation duration.

In recent decades, significant progress has been made in the diagnostic techniques for TSIs [7]. Modern technologies such as multislice computed tomography [8,9], magnetic resonance imaging [10, 11], and high-resolution ultrasonography [12, 13] provide detailed visualization of damaged structures and allow evaluation of surrounding tissues. These tools enhance diagnostic precision, enabling assessment of spinal segment stability, spinal cord compression, and soft tissue injury severity.

Furthermore, the implementation of advanced anesthesiology practices—such as multimodal anesthesia and regional analgesia techniques—has significantly reduced perioperative complications and improved surgical tolerability, even in patients with severe comorbidities [14, 15]. Advances in surgical methods, particularly minimally invasive techniques, endoscopic approaches, robotic systems, and real-time navigation, have markedly improved surgical accuracy, reduced operative time, and shortened the recovery period [16, 17].

The expanding range of available treatment options and a growing emphasis not only on clinical effectiveness but also on the economic feasibility of each method are key trends shaping contemporary healthcare. Nevertheless, numerous issues accompanying these developments remain debatable and/or insufficiently explored.

The aim of this review is to comprehensively evaluate the prospects of implementing an individualized approach to the treatment of traumatic spinal injuries—

one of the most socially significant categories of musculoskeletal disorders. The review explores economic, legal, medical, and deontological aspects associated with integrating individualization strategies into the existing diagnostically oriented paradigm.

Materials and methods

This analytical review was conducted following the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), which ensured transparency, systematicity, and objectivity throughout the search and selection process. The literature search was carried out using international scientometric databases including PubMed, Scopus, Web of Science, and Google Scholar. The key inclusion criteria were: relevance to individualized approaches in the treatment of spinal trauma, the presence of economic, legal, medical, or deontological aspects, and a publication date within the last 10 years. The main keywords (MeSH terms) used during the search included: "Spinal Injuries", "Spinal Fractures", "Precision Medicine", "Individualized Medicine", "Treatment Outcome", "Cost-Benefit Analysis", "Health Economics", "Clinical Effectiveness", "Ethics, Medical", "Jurisprudence", "Diagnostic Techniques and Procedures", "Evidence-Based Medicine".

A stepwise screening process was applied, initially based on titles and abstracts, followed by full-text evaluation. In addition, reference lists of the selected articles were reviewed to identify further relevant sources. The final analytical review included original research articles, systematic reviews, clinical guidelines, and methodological materials that met the aforementioned criteria.

The results of the analysis were structured according to the thematic sections of the review.

Results

The Economic threshold of excellence

Despite significant advances, the outcomes of TSI remain equivocal [18]. In certain cases, the introduction of novel technologies and treatment methods results in only marginal improvements in long-term clinical outcomes, whereas the associated healthcare costs continue to rise steadily. This leads to the attainment of a certain threshold, beyond which further technological advancements yield diminishing clinical benefits while requiring increasingly substantial financial and resource investments [19]. This phenomenon, known as diminishing returns, indicates that the effectiveness of treatment does not increase indefinitely with the sophistication and expense of technology. On the contrary, additional investments in high-end solutions may offer only minimal clinical advantages, which often do not justify the resources and efforts expended [20–22]. In spinal surgery, this phenomenon is already clearly observable. While modern approaches help reduce intraoperative risks and shorten postoperative recovery periods, their impact on long-term outcomes—such as functional recovery, disability reduction, or improvements in patient quality of life—diminishes with each successive technological enhancement [19]. This

raises not only medical but also economic concerns regarding the rationale for employing highly complex and expensive technologies in cases where more accessible methods may yield comparable results. As such, it is essential to reconsider priorities and emphasize strategies that ensure an optimal balance between cost and clinical benefit. One promising solution is the implementation of a personalized approach, enabling targeted use of advanced technologies where they provide the greatest benefit. Furthermore, developing predictive methodologies to assess in advance the effectiveness of costly interventions for individual patients may help improve decision-making efficiency [23].

A practical manifestation of efforts to regulate the effect of diminishing returns is the application of the Quality-Adjusted Life Year (QALY) metric in several countries. QALY incorporates two primary components: the number of additional years a patient may gain from treatment and the projected quality of those years, expressed on a scale from 0 to 1—where 1 represents perfect health and 0 equates to a health state comparable to death [24]. The core purpose of QALY is to quantitatively evaluate the potential benefit of a given medical intervention or therapy. For example, if a treatment adds one year of life in perfect health, it results in a gain of 1.0 QALY; if it prolongs life by four years in a condition rated at 0.5, the total benefit would amount to 2.0 QALYs.

Utilization of the QALY metric supports evidence-based decision-making under limited healthcare budgets, particularly when assessing the appropriateness of expensive technologies, pharmaceuticals, or surgical procedures [25]. In countries with well-developed healthcare systems, there are established thresholds for the cost per QALY. For instance, in the United Kingdom, the National Institute for Health and Care Excellence (NICE) has set the threshold at £30,000 per 1.0 QALY [26, 27]. If the cost of treatment exceeds a certain threshold, it may be deemed economically unjustifiable, even when it offers clear clinical benefits. The use of QALY is associated with several ethical and methodological challenges. For instance, patients with chronic illnesses or disabilities typically have a lower baseline health status assessment, which inevitably results in lower QALY estimates, effectively introducing a discriminatory factor. This raises concerns about the fairness of applying QALY in resource allocation decisions, especially in cases involving the preservation of life in patients with initially low quality of life. Furthermore, the QALY methodology can lead to situations where expensive interventions with marginal QALY gains are rejected in favor of more cost-effective measures that produce greater impact at the population level [28]. This creates significant challenges in decision-making for the treatment of orphan or severe diseases, where the cost per 1.0 QALY may be extraordinarily high due to the rarity or complexity of the condition [29].

Even in the most developed countries, QALY has limited applicability in the context of injuries in general, and TSI in particular. This is due to inherent conflicts involving both medical and legal considerations, primarily rooted in the need to balance limited healthcare

resources with the patient's right to receive necessary medical care [30, 31].

In Ukraine, the QALY criterion has not yet been adopted. However, in 2020, the country officially introduced the Health Technology Assessment (HTA) mechanism—a systematic process for evaluating the clinical effectiveness, safety, economic feasibility, and social impact of medical interventions. The assessment is conducted by the State Expert Center of the Ministry of Health of Ukraine, as regulated by Resolution No. 1300 of December 23, 2020, "On the Approval of the procedure for the state assessment of health technologies" [32]. Nevertheless, neither in Ukraine nor globally have mandatory algorithms or protocols been developed for providing medical care to patients with TSIs, existing guidelines remain merely recommendatory in nature [33, 34].

Problems of standards and protocols

Mandatory recommendations for the treatment of specific diseases, especially those as resource-intensive as TSI, appear particularly promising for institutions that fund healthcare services—such as insurance companies or governmental health authorities. This approach could promote a more rational allocation of financial and medical resources, facilitate monitoring of their utilization, prevent potential overspending, and ensure effective planning. A commonly cited argument in favor of implementing such guidelines is the improvement of care quality and treatment outcomes through reduced variability in clinical decision-making [4].

However, mandatory treatment protocols for TSI are currently lacking due to several key factors. Firstly, these injuries represent an extremely heterogeneous group of clinical conditions, including varying degrees of spinal instability, neurological deficits, soft tissue injuries, and concomitant trauma. Capturing all such variables within a single, universally applicable protocol is inherently challenging [35]. Secondly, despite the traditional diagnosis-driven approach in modern medicine, there is a gradual shift toward individualized treatment strategies, wherein decisions are tailored to patient-specific factors such as age, bone quality, overall health status, and trauma characteristics. Universal mandatory protocols risk limiting the flexibility required in complex or atypical cases. Moreover, ethical and legal concerns are also relevant [36].

Pronounced and inevitable disparities in resource availability across regions within the same healthcare system complicate the development of standardized protocols. These include significant differences in staff qualifications, access to advanced technologies, and institutional capacity. For instance, high-cost, high-resolution diagnostic equipment that may be available in major referral centers is often inaccessible in peripheral facilities, rendering certain mandatory recommendations unfeasible in practice [37].

Mandatory protocols carry the risk of shifting liability onto individual healthcare providers in situations where strict adherence to such guidelines results in complications or suboptimal outcomes [38]. In practice, the legal implications of this vary. Physicians may be accused of failing to address individual patient needs, even when strictly following the guidelines, particularly

in cases where the intervention proves ineffective or leads to adverse effects, and the harmed party can demonstrate that such outcomes were foreseeable. This places healthcare professionals in a dilemma: whether to adhere rigidly to protocols or to deviate in favor of personalized care—potentially violating regulations [39].

At the level of protocol developers, responsibility may fall on the institutions or experts involved in drafting the guidelines, especially if the recommendations fail to consider rare or atypical clinical scenarios. Outdated or flawed protocols may carry reputational risks.

At the health system level, governmental or regulatory authorities that mandate such protocols may face criticism for insufficient due diligence, particularly if the guidelines fail to reflect local conditions or are inadequately adapted to clinical realities [40]. In such cases, the greatest burden of negative consequences tends to fall on the implementation tier—namely, the individual clinician providing direct care. This asymmetry of liability, as demonstrated by global practice, is often a key reason why the medical community resists over-standardization, especially when decision-makers are not subject to clearly defined legal repercussions for adverse outcomes [41–43].

Diagnosis-oriented and individualized strategy

When considering the concept of individualization in the context of the overall evolution of medicine, and TSI in particular, it is important to note that its gradual implementation reflects a shift from universal, standardized treatment protocols toward more flexible, targeted approaches that account for individual patient characteristics [44]. Historically, medicine has evolved from general empirical methods to evidence-based, diagnosis-oriented strategies, and subsequently to personalized solutions [45]. In the field of vertebrology, especially in the management of TSI, individualization comes to the forefront, as anatomical, physiological, and psychosocial differences between patients can significantly affect the choice of optimal treatment tactics [46].

The traditional diagnosis-oriented strategy in the surgical treatment of TSI is based on unified classification principles derived from widely accepted systems such as the AO Spine classification, and the TLICS (Thoracolumbar Injury Classification and Severity Score) and SLIC (Subaxial Cervical Spine Injury Classification) scales for thoracolumbar and subaxial cervical injuries, respectively. This approach involves standardized protocols for diagnosis, timing, surgical technique, and the extent of intervention [47–49]. Based on the assessment of anatomical localization, injury characteristics, degree of instability, and presence of neurological deficits, the diagnosis-oriented strategy enables surgeons to select optimal implants and fixation methods according to a formally defined injury type. This unification, shaped by years of clinical experience, provides a convenient framework for decision-making in typical cases, facilitates outcome prediction, and promotes adherence to widely accepted standards of care [50]. However, this approach targets the "average" patient and does not always adequately account for anatomical, physiological, and psychosocial

differences that may substantially influence treatment outcomes. Consequently, in some cases, this may lead to insufficient or excessive surgical intervention, thereby reducing the quality of results and increasing the risk of complications [4]. A mechanism that can partially mitigate these negative effects is the pre-defined variability and adaptability of protocols. Nevertheless, both TSI treatment recommendations and most clinical guidelines lack clearly delineated boundaries for acceptable deviations from the recommended strategy. In cases involving pronounced patient-specific characteristics or injuries that deviate significantly from the "average", it becomes difficult to determine precisely where acceptable protocol adaptation ends and protocol violation begins—creating additional uncertainty and risks in clinical decision-making [51].

However, the diagnosis-oriented strategy, which aims to precisely define the nosological form of a disease and relies on systematized clinical and diagnostic criteria, has significantly simplified and standardized the selection of optimal treatment tactics, while simultaneously increasing the predictability of outcomes in typical clinical scenarios. The use of evidence-based medicine principles has made it possible to scientifically substantiate this approach and achieve broad recognition [52]. Through the systematic evaluation of clinical research data and the application of statistical methods, evidence-based medicine has provided the necessary methodological foundation to compare the efficacy and safety of different treatment algorithms, thereby supporting the validity of a diagnosis-oriented approach not only at the level of expert opinion but also through objective and reproducible results. Overall, a diagnosis-oriented strategy supplemented by an evidence base enables physicians to make informed decisions, better understand disease pathogenesis, tailor treatment to individual patient characteristics, and improve the quality of medical care. The accumulation and systematization of numerous research findings, which form the foundation of evidence-based medicine, underscore the relevance of the so-called "average patient" problem [53]. This issue arises from the fact that the results obtained from studying large groups of individuals reflect averaged indicators of treatment efficacy and safety, thus masking individual differences among study participants. Because clinical trials and statistical analyses are primarily focused on the "mean" value within a sample, real patients—with their unique combinations of genetic traits, comorbidities, age, lifestyle, and treatment responses—may fall outside the scope of the "typical" scenario [54]. Such variability may lead to a significant dispersion of treatment outcomes even when the same therapeutic method is applied [55]. Beyond the medical aspect, the "average patient" problem has considerable economic implications. Within a single classification category that prescribes uniform therapy (whether pharmacological or surgical), a subset of patients will inevitably receive overtreatment (including diagnostics, rehabilitation, recommended disability durations, etc.), while for another subset, the same method will be insufficiently aggressive or effective. As a result, the total cost of treatment may increase, the efficiency of healthcare resource utilization may decline, and the socio-economic burden on both

patients and the healthcare system as a whole may rise [56,57].

The described phenomenon can be illustrated using spinal trauma as an example. Let us assume a cohort of patients with AO Spine type A4 thoracolumbar injuries is selected for analysis. These patients have confirmed posterior ligamentous complex injuries without significant neurological deficits or severe spinal canal compression by bone fragments (5 points according to the TLICS scale). For most such cases, the optimal treatment strategy is transpedicular stabilization. However, within this cohort, patients may differ significantly in terms of sex, age, body mass index, lifestyle, anatomical level of the injury, degree of vertebral body fragmentation, bone mineral density, presence of comorbidities, and other factors. All of these parameters are dynamically interrelated and collectively determine an individual's conditional "severity" of disease, which, however, is not considered in the AO Spine classification system. If we plot this conditional severity of disease along the X-axis within a single classification category, and the number of patients along the Y-axis, we obtain a Gaussian curve, representing a normal distribution. This follows from the Central Limit Theorem, which states that if a variable is formed as a sum of many independent or weakly dependent random factors, the resulting distribution tends toward normality [58]. The peak of this curve corresponds to the "average patient" for whom transpedicular stabilization presents the optimal balance of risks and benefits (**Fig. 1A**). Patients within the central range of the distribution receive the most appropriate level of care, offering the best benefit–risk ratio.

However, in real-world clinical practice, individual patient characteristics often diverge significantly from the conditional "average." As we move away from the center of the Gaussian curve in either direction, we encounter scenarios that are not fully accounted for by standard protocols. Patients in the "right tail" of the distribution may find that the universal protocol is insufficiently effective or surgically aggressive, leading to underestimation of disease severity and, consequently, inadequate treatment. An example would be the use of short-segment fixation for TSI at the thoracolumbar junction, which often results in construct failure and pseudarthrosis [59]. Conversely, patients in the "left tail" may receive overtreatment. For instance, successful conservative management of type A4 fractures has been documented in specific patient populations. Clearly, performing surgery when it could be avoided not only increases the risk of complications but is also economically unjustified [60]. It is logical that, further along the abscissa axis to the right, another cohort of A4 fracture patients—those whose disease severity is explicitly accounted for in clinical protocols, such as those with neurological deficits—requires a different therapeutic approach, namely decompression combined with stabilization.

Two strategies can be employed to reduce episodes of overtreatment in patients with TSI. The first involves "shifting" the entire distribution curve toward less aggressive interventions. This approach entails revising standardized protocols to adopt more conservative or minimally invasive procedures as the default. Such a shift reduces surgical complications and the economic

burden of unnecessary operations [61]. However, this carries the risk of undertreatment for patients whose conditions significantly exceed the "average" severity (right "tail" of the curve), resulting in increased likelihood of reoperations, exacerbations, construct failures, and prolonged rehabilitation (**Fig. 1B**). As a result, this group is more likely to experience repeated interventions, exacerbations, inability to stabilise, fragmentation of structures, and a prolonged rehabilitation period. In addition, the existence of a statistically established "average patient" complicates the idea of "shifting" the curve, since the entire logic of standardised protocols is most often built around this averaged model [62]. The "center" of the distribution is not merely an abstract point on a curve but the outcome of large-scale data analysis that underpins existing classifications, clinical guidelines, and treatment algorithms. Any shift would necessitate redefining the criteria that determine what constitutes a "typical" case and "standard" therapy [63].

The second approach involves "narrowing" the curve by applying stricter inclusion criteria and additional patient stratification. In this case, individuals whose specific characteristics (e.g., risk factors or presence of multifactorial comorbidities) do not align with the "typical" representative of the target category are excluded from the general cohort. This results in a more homogeneous group for which a standardized protocol is genuinely effective. At the same time, this approach reduces the risk of unjustifiably aggressive therapy in "mild" cases, since patients with extremely unfavorable or highly favorable clinical profiles are excluded from the standard protocol and either referred to specialized centers or offered alternative treatment regimens. However, such stringent filtering narrows the scope of the protocol, complicates patient routing, and may lead to the exclusion of individuals who formally meet the criteria but in reality require a different level of care. Furthermore, reliable verification of clinical status demands more comprehensive diagnostics, which increases both time and resource expenditures [64].

Thus, "shifting" the curve toward less invasive methods reduces the number of cases in which patients are exposed to unnecessarily aggressive interventions, but increases the risk of insufficient consideration of individual factors in severely ill patients. Conversely, "narrowing" the curve enhances the precision and effectiveness of standard protocols for a narrowly defined subgroup, but significantly increases the risk of excluding patients who could have benefited from the protocol, while also complicating diagnostic and stratification processes.

Therefore, a standard protocol designed for the "average patient" indeed delivers the most effective outcomes for the majority of the population. Nevertheless, as the diversity of clinical conditions increases, the efficacy of such a protocol predictably diminishes—especially at the "margins" of the distribution. The very methodology underlying the development of clinical practice guidelines implies that achieving 100% treatment effectiveness for all patients is fundamentally impossible, regardless of the expertise of healthcare professionals, the quality of medical infrastructure, or the resources invested in the diagnostic and therapeutic process. Such a "universal" approach inevitably leaves a

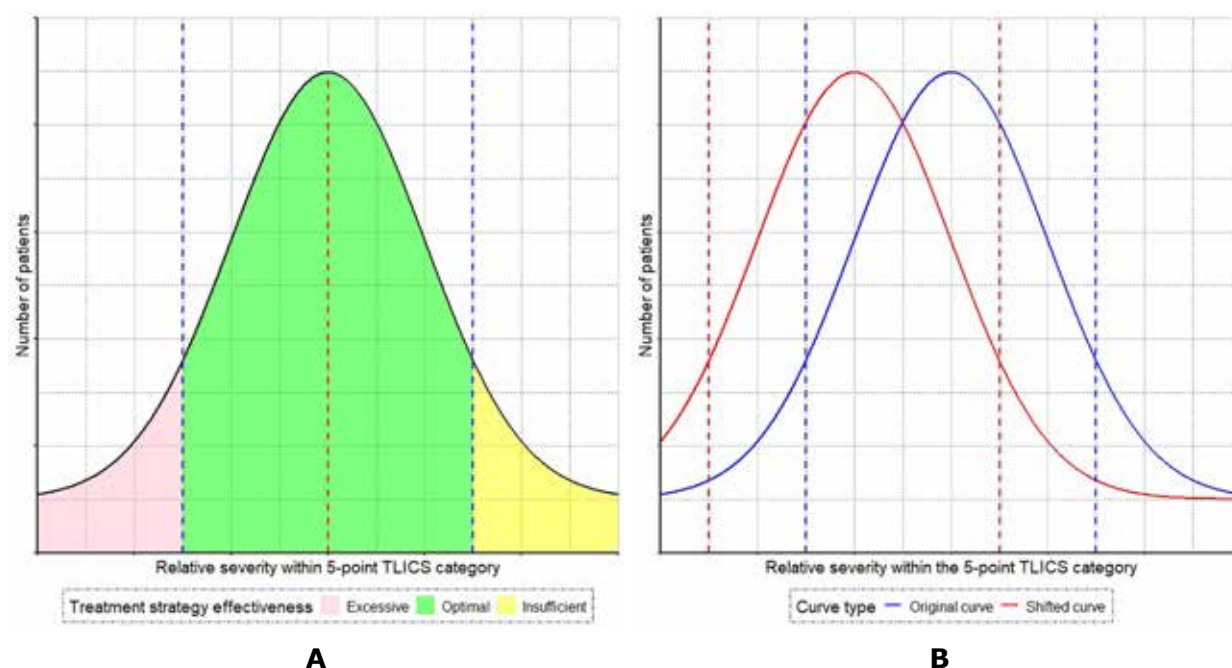


Fig. 1. Visual representation of the "average patient" problem

subset of patients with suboptimal treatment outcomes, as their individual characteristics fall outside the capabilities of an averaged clinical algorithm [65].

The Problem of classifications

Despite advances in diagnostic methods that provide ample opportunities for detailed characterization and assessment of injury severity, recent decades have seen a trend toward simplification of spinal trauma classification systems in vertebrology. This tendency contradicts the logic of the aforementioned arguments. The accumulation of data on the biomechanics and morphology of traumatic injuries through imaging technologies throughout the 20th century led to the evolution of TSI grading schemes. Most researchers aimed to enhance detail and precision in describing the anatomical and biomechanical features of injuries to facilitate optimal treatment strategies. Examples of such classification systems include those proposed by F. Magerl et al. for the thoracolumbar spine (1994) and by B. L. Allen et al. for the subaxial cervical spine (1982) [66,67]. Some authors developed classification categories not based on empirically documented and described injury types, but rather on hypothetical ones predicted by presumed mechanisms of trauma [68]. A pivotal historical shift in the conceptualization of TSI classification occurred with the attempt to unify all existing systems of musculoskeletal injury classification, initiated by the Association for the Study of Internal Fixation/Orthopaedic Trauma Association (AO/OTA). This initiative culminated in the development and global implementation of the AO/OTA Fracture and Dislocation Classification, a system based on a unified structural principle [69]. Within this framework, each anatomical region is assigned a code—"51" for the cervical spine, "52" for the thoracic spine, "53" for the lumbar spine, and "54" for the sacrum. Each region encompasses three primary injury types: Type A (injuries involving only bony structures), Type B

(combined injuries of bone and ligamentous structures), and Type C (predominantly ligamentous injuries, possibly with bony involvement and displacement). Each type is further subdivided into subtypes (usually numbered from 1 to 3, or more), reflecting increasing severity. In addition, TSI classifications incorporate modifiers assessing neurological deficits, involvement of facet joints, and other pathological processes, allowing for more precise injury characterization [70]. The widely adopted AO Spine Subaxial Cervical Spine Classification System and the AO Spine Thoracolumbar Spine Classification System are in fact segments of this global classification framework [47, 71].

One of the primary reasons for modifying the concept of classifying traumatic injuries was the pursuit of greater reproducibility and standardization. It is well established that complex, multi-level schemes often led to low inter-rater agreement—different specialists, using the same classification system, could arrive at different diagnoses and propose divergent treatment strategies. In contrast, simplified systems based on a few key factors (such as stability, neurological status, and the condition of the ligamentous and bony structures) offer improved reproducibility and predictability of outcomes [72, 73].

In the context of evidence-based medicine, simplified classifications are also more appropriate. Firstly, they allow for the formation of large homogeneous patient samples and facilitate the objective evaluation of the effectiveness of specific treatment approaches. Secondly, the results of multicenter studies and meta-analyses that rely on such standardized classifications are easier to compare across various institutions and regions, thereby ensuring a higher level of evidentiary strength. The simplicity and standardization of criteria enable the development of clinical guidelines that can subsequently serve as the foundation for protocols and manuals aligned with evidence-based principles [74].

It is assumed that excessive detail complicates rapid decision-making and often fails to offer significant advantages in treatment selection, particularly when a swift and standardized approach is required [75]. Therefore, the current trend in TSI grading is oriented toward a tactics-driven approach, with a notable shift in emphasis toward practicality over precision [76].

Nonetheless, in the broader context of evidence-based medicine and scientific research, simplified assessment systems have limitations, as they may obscure critical parameters that influence treatment outcomes [77]. For example, in a previously analyzed cohort of patients with B2 spinal trauma (type A4 vertebral body injuries) and a TLICS score of 5, one can evaluate the efficacy of a specific treatment modality, such as transpedicular fixation, using a set of defined criteria. However, comparing the effectiveness of different approaches based solely on these parameters is challenging, and selecting the optimal treatment for an individual patient becomes even more difficult [54]. Thus, while a simplified scoring system or classification (albeit convenient for rapid diagnostics and statistical analysis) does not provide a comprehensive answer to the question of which treatment method would be most effective for a given patient [78].

Optimizing treatment within the framework of evidence-based medicine requires that standardized protocols—although useful in generalized form—be complemented by personalized criteria. This would establish a more reliable foundation for comparing various methods (e.g., transpedicular fixation, combined surgical intervention, or conservative management) and facilitate the selection of an approach most beneficial to the patient [79].

Deontological challenges

The issue of the "average patient" remains a key factor influencing the unconditional acceptance of results from high-evidence-level studies [80]. Although this issue has accompanied evidence-based medicine throughout its historical development, it remains insufficiently recognized both among medical professionals and the general public, leading to not only medical but also deontological challenges [81, 82]. Modern patients often possess broad yet superficial knowledge about available treatment options. With the advancement of the internet and digital technologies, information on medical procedures has become readily accessible to a wide audience. Patients can quickly find details about various diseases, diagnostic methods, and treatments, thereby expanding their general awareness [83]. However, not all available information is of high quality or scientifically validated [83]. Many sources provide incomplete, outdated, erroneous, or deliberately distorted data, which results in a superficial understanding of complex medical concepts [84]. Furthermore, even when high-quality information is available, patients often face difficulties interpreting it due to a lack of specialized knowledge. This almost invariably leads to misinterpretation of medical recommendations or suboptimal treatment choices when such a choice is permitted. A further challenge in today's society is the active promotion of certain

medical methods and pharmaceutical products through marketing campaigns and social media, which distorts public perceptions of their effectiveness and safety. Patients may be influenced by misleading reviews and promotional promises, further complicating informed decision-making about their care [85,86]. Moreover, the popularity of evidence-based medicine as a trend, and the perception of its standards as absolute dogma, often leads to situations where deviations from established protocols are viewed by patients or their relatives as signs of professional incompetence, rather than as attempts to adapt treatment to individual patient characteristics and the capabilities of the healthcare facility [87]. Similar situations arise during expert evaluations of medical staff actions, where certain flexibility in clinical approaches may be perceived as a lack of professionalism or an absence of a clear treatment strategy for a given nosological unit, despite the clinical rationale behind such decisions [88].

Discussion

The concept of individualization is embedded within the very foundation of evidence-based medicine. One of its pioneers, Archie Cochrane, emphasized that evidence is only useful insofar as it can guide the treatment of individual patients [89,90]. His work highlighted the need to differentiate between approaches aimed at populations as a whole and those designed for individual medical care. The former, according to Cochrane, should serve primarily as the basis for developing general recommendations or clinical protocols [91]. As a potential solution, he proposed the use of subgroup analysis in clinical research to determine how treatments affect different patient categories [92].

The exponential growth in computational power over recent decades, the development of new statistical analysis techniques, and the adoption of previously known but computationally intensive methods—such as Bayesian approaches—have enabled a fundamentally new level of patient-specific treatment adaptation. This transition marks a shift from the physician's subjective judgment in a given clinical situation to mathematically and statistically grounded decision-making [93, 94].

A review of the literature has identified several methodologies most commonly applied in the context of personalized treatment strategies:

- regression analysis methods – used for modeling and predicting relationships between variables. This category includes linear regression, logistic regression, multilevel (hierarchical) regression, and Poisson regression [95, 96];
- survival analysis methods – focused on time-to-event data, including Kaplan–Meier curves, Cox proportional hazards models, and competing risks models [97, 98];
- machine learning and artificial intelligence methods – employed to process large datasets and uncover complex nonlinear patterns. Key techniques include decision trees, random forests, gradient boosting, neural networks, and deep learning algorithms [99, 100];
- bayesian methods – based on Bayes' theorem for updating probabilities as new data becomes available.

Examples include Bayesian networks, naïve Bayes classifiers, and Markov chain Monte Carlo (MCMC) simulations [101, 102];

- cluster analysis methods – used to group patients based on similar characteristics without prior labeling. Common approaches include K-means clustering, hierarchical clustering, and DBSCAN (Density-Based Spatial Clustering of Applications with Noise) [103, 104];

- feature selection methods – assist in identifying the most informative variables for model building, thereby reducing data dimensionality and preventing overfitting. These include stepwise regression, LASSO and Ridge regression, and feature importance-based techniques [105].

While this list is by no means exhaustive, it demonstrates the wide and diverse range of data analysis methods available for identifying the most informative predictors and their interactions. The appropriate selection and application of such methods allow for the development of effective, individualized treatment plans.

The findings presented in this review highlight specific aspects of the rationale for developing individualized approaches to treating a heterogeneous condition such as TSI. It is emphasized that protocols and standards based on the principles of evidence-based medicine should not be seen as rigid doctrines but rather as frameworks that define the general direction of therapy, within which individualized treatment plans are to be developed. The relevance of such an approach is underscored by the growing body of research demonstrating the effectiveness of advanced models—particularly those using neural networks—not only for diagnostic purposes but also for optimizing therapeutic decision-making. Individualization provides clear advantages not only in medical terms but also in economic contexts, by contributing to reduced treatment costs and more efficient use of healthcare resources—thus addressing one of the pressing challenges of modern healthcare systems.

Conclusions

An individualized approach to the treatment of TSI represents a significant advancement in contemporary medical practice. The preconditions discussed highlight the necessity of shifting from standardized therapeutic methods toward more flexible and tailored strategies that account for the unique characteristics of each patient. Personalizing TSI treatment not only enhances the efficacy and safety of both surgical and conservative interventions but also contributes to the development of a more resilient and cost-effective healthcare system. Ongoing advancements in technology and data analysis methods support the refinement of these approaches, enabling more precise and patient-centered care. The relevance of research in this field is driven by the growing societal demand for effective and economically sound individualized medical solutions.

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Conflict of interest

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References

1. Diseases GBD, Injuries C. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet* (London, England). 2020;396(10258):1204–1222. doi: 10.1016/S0140-6736(20)30925-9
2. Williams AL, Al-Busaidi A, Sparrow PJ, Adams JE, Whitehouse RW. Under-reporting of osteoporotic vertebral fractures on computed tomography. *Eur J Radiol*. 2009;69(1):179–183. doi: 10.1016/j.ejrad.2007.08.028
3. Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2021 (GBD 2021) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME); 2022. <https://vizhub.healthdata.org/gbd-results/>
4. Sandean D. Management of acute spinal cord injury: A summary of the evidence pertaining to the acute management, operative and non-operative management. *World J Orthop*. 2020;11(12):573–583. doi: 10.5312/wjo.v11.i12.573
5. Peterson MD, Meade MA, Lin P, Kamdar N, Rodriguez G, Krause JS, et al. Psychological morbidity following spinal cord injury and among those without spinal cord injury: the impact of chronic centralized and neuropathic pain. *Spinal Cord*. 2022;60(2):163–169. doi: 10.1038/s41393-021-00731-4
6. Limthongkul W, Singhatanadgige W, Vaccaro AR, Albert TJ, Radcliff K. Health-related quality of life and cost after cervical spine trauma. *Seminars in Spine Surgery*. 2014;26(1):30–37. doi: 10.1053/j.semss.2013.07.008
7. Fiani B, Noblett C, Nanney J, Doan T, Pennington E, Jarrah R, et al. Diffusion tensor imaging of the spinal cord status post trauma. *Surg Neurol Int*. 2020;11:276. doi: 10.25259/SNI_495_2020
8. Fatehi D, Dayani MA, Rostamzadeh A. Role of CT scan in theranostic and management of traumatic spinal cord injury. *Saudi J Biol Sci*. 2018;25(4):739–746. doi: 10.1016/j.sjbs.2016.08.004
9. Ordonez CA, Parra MW, Holguin A, Garcia C, Guzman-Rodriguez M, Padilla N, et al. Whole-body computed tomography is safe, effective and efficient in the severely injured hemodynamically unstable trauma patient. *Colomb Med (Cali)*. 2020;51(4):e4054362. doi: 10.25100/cm.v51i4.4362
10. Seif M, Curt A, Thompson AJ, Grabher P, Weiskopf N, Freund P. Quantitative MRI of rostral spinal cord and brain regions is predictive of functional recovery in acute spinal cord injury. *Neuroimage Clin*. 2018;20:556–563. doi: 10.1016/j.nicl.2018.08.026
11. Aly MM, Al-Shoaibi AM, Aljuzair AH, Issa TZ, Vaccaro AR. A Proposal for a Standardized Imaging Algorithm to Improve the Accuracy and Reliability for the Diagnosis of Thoracolumbar Posterior Ligamentous Complex Injury in Computed Tomography and Magnetic Resonance Imaging. *Global Spine J*. 2023;13(3):873–896. doi: 10.1177/21925682221129220
12. Chuang CH, Huang CY, Ho SW, Chen CC. Rapid Detecting Brachial Plexus Injury by Point-of-Care Ultrasonography. *J Med Ultrasound*. 2022;30(4):303–305. doi: 10.4103/jmu.jmu_185_21
13. VV, Bhoi S, Aggarwal P, Murmu LR, Agrawal D, Kumar A, et al. Diagnostic utility of point of care ultrasound in identifying cervical spine injury in emergency settings. *Australas J Ultrasound Med*. 2021;24(4):208–216. doi: 10.1002/ajum.12274
14. Taylor C, Metcalf A, Morales A, Lam J, Wilson R, Baribeault T. Multimodal Analgesia and Opioid-Free Anesthesia in Spinal Surgery: A Literature Review. *J Perianesth Nurs*. 2023;38(6):938–942. doi: 10.1016/j.jopan.2023.04.003
15. Yang S, Xiao W, Wu H, Liu Y, Feng S, Lu J, et al. Management Based on Multimodal Brain Monitoring May Improve Functional Connectivity and Post-operative Neurocognition in Elderly Patients Undergoing Spinal Surgery. *Front Aging Neurosci*. 2021;13:705287. doi: 10.3389/fnagi.2021.705287
16. Avrumova F, Lebl DR. Augmented reality for minimally invasive spinal surgery. *Front Surg*. 2022;9:1086988. doi: 10.3389/fsurg.2022.1086988
17. Walker CT, Xu DS, Godzik J, Turner JD, Uribe JS, Smith

- WD. Minimally invasive surgery for thoracolumbar spinal trauma. *Ann Transl Med*. 2018;6(6):102. doi: 10.21037/atm.2018.02.10
18. Ding W, Hu S, Wang P, Kang H, Peng R, Dong Y, et al. Spinal Cord Injury: The Global Incidence, Prevalence, and Disability From the Global Burden of Disease Study 2019. *Spine (Phila Pa 1976)*. 2022;47(21):1532-1540. doi: 10.1097/BRS.0000000000004417
 19. Morone G, Pirrera A, Iannone A, Giansanti D. Development and Use of Assistive Technologies in Spinal Cord Injury: A Narrative Review of Reviews on the Evolution, Opportunities, and Bottlenecks of Their Integration in the Health Domain. *Healthcare (Basel)*. 2023 Jun 4;11(11):1646. doi: 10.3390/healthcare11111646
 20. Sammon JD, Abdollah F, Klett DE, Pucheril D, Sood A, Trinh QD, et al. The diminishing returns of robotic diffusion: complications after robot-assisted radical prostatectomy. *BJU Int*. 2016;117(2):211-212. doi: 10.1111/bju.13111
 21. Passias PG, Bortz C, Horn SR, Segreto FA, Stekas N, Ge DH, et al. Diminishing Clinical Returns of Multilevel Minimally Invasive Lumbar Interbody Fusion. *Spine (Phila Pa 1976)*. 2019;44(20):E1181-E1187. doi: 10.1097/BRS.0000000000003110
 22. Gold MR, Siegel JE, Russell LB, Weinstein MC, editors. *Cost-Effectiveness in Health and Medicine*. New York: Oxford Academic; 1996. doi: 10.1093/oso/9780195108248.001.0001
 23. Dietz N, Sharma M, Alhourani A, Ugiliweneza B, Wang D, Nuno MA, et al. Variability in the utility of predictive models in predicting patient-reported outcomes following spine surgery for degenerative conditions: a systematic review. *Neurosurg Focus*. 2018;45(5):E10. doi: 10.3171/2018.8.FOCUS18331
 24. Toure M, Kouakou CRC, Poder TG. Dimensions Used in Instruments for QALY Calculation: A Systematic Review. *Int J Environ Res Public Health*. 2021;18(9). doi: 10.3390/ijerph18094428
 25. Lotfi R, Haqiqat E, Sadra Rajabi M, Hematyar A. Robust and resilience budget allocation for projects with a risk-averse approach: A case study in healthcare projects. *Computers and Industrial Engineering*. 2023 Feb;176:108948. doi: 10.1016/j.cie.2022.108948
 26. Siverskog J, Henriksson M. On the role of cost-effectiveness thresholds in healthcare priority setting. *Int J Technol Assess Health Care*. 2021;37:e23. doi: 10.1017/S0266462321000015
 27. Iino H, Hashiguchi M, Hori S. Estimating the range of incremental cost-effectiveness thresholds for healthcare based on willingness to pay and GDP per capita: A systematic review. *PLoS One*. 2022;17(4):e0266934. doi: 10.1371/journal.pone.0266934
 28. Petrou S. Methodological challenges surrounding QALY estimation for paediatric economic evaluation. *Cost Eff Resour Alloc*. 2022;20(1):10. doi: 10.1186/s12962-022-00345-4
 29. Towse A, Garau M. Appraising ultra-orphan drugs: is cost-per-QALY appropriate? A review of the evidence. *Consulting Report*. 2018 Mar 1(001978). <https://www.ohe.org/wp-content/uploads/2018/03/468-Appraising-ultra-orphan-drugs.pdf>
 30. Use of QALYs: advantages and concerns. *PharmacoEconomics & Outcomes News*. 2018;806(1):2-2. doi: 10.1007/s40274-018-5045-5.
 31. Pollard D, Fuller G, Goodacre S, van Rein EAJ, Waalwijk JF, van Heijl M. An economic evaluation of triage tools for patients with suspected severe injuries in England. *BMC Emerg Med*. 2022;22(1):4. doi: 10.1186/s12873-021-00557-6
 32. Кабінет Міністрів України. Постанова від 23 грудня 2020 р. № 1300 "Про затвердження Порядку проведення державної оцінки медичних технологій". Київ: Кабінет Міністрів України; 2020. <https://zakon.rada.gov.ua/laws/show/1300-2020-%D0%BF#Text>
 33. Greenberg JK, Burks SS, Dibble CF, Javeed S, Gupta VP, Yahanda AT, et al. An updated management algorithm for incorporating minimally invasive techniques to treat thoracolumbar trauma. *J Neurosurg Spine*. 2022;36(4):558-567. doi: 10.3171/2021.7.SPINE21790
 34. Portelli Tremont JN, Cook N, Murray LH, Udekwu PO, Motameni AT. Acute Traumatic Spinal Cord Injury: Implementation of a Multidisciplinary Care Pathway. *J Trauma Nurs*. 2022;29(4):218-224. doi: 10.1097/JTN.0000000000000664
 35. O'Toole JE, Kaiser MG, Anderson PA, Arnold PM, Chi JH, Dailey AT, et al. Congress of Neurological Surgeons Systematic Review and Evidence-Based Guidelines on the Evaluation and Treatment of Patients with Thoracolumbar Spine Trauma: Executive Summary. *Neurosurgery*. 2019;84(1):2-6. doi: 10.1093/neuros/nyy394
 36. Bolcato M, Fassina G, Rodriguez D, Russo M, Aprile A. The contribution of legal medicine in clinical risk management. *BMC Health Serv Res*. 2019;19(1):85. doi: 10.1186/s12913-018-3846-7
 37. Agha L, Frandsen B, Rebitzer JB. Fragmented division of labor and healthcare costs: Evidence from moves across regions. *Journal of Public Economics*. 2019;169:144-159. doi: 10.1016/j.jpubeco.2018.11.001.
 38. Kellner DB, Urman RD, Greenberg P, Brovman EY. Analysis of adverse outcomes in the post-anesthesia care unit based on anesthesia liability data. *J Clin Anesth*. 2018;50:48-56. doi: 10.1016/j.jclinane.2018.06.038
 39. Corte-Real A, Caetano C, Alves S, Pereira AD, Rocha S, Nuno Vieira D. Patient Safety in Dental Practice: Lessons to Learn About the Risks and Limits of Professional Liability. *Int Dent J*. 2021;71(5):378-383. doi: 10.1016/j.identj.2020.12.014
 40. Akmal A, Podgorodnichenko N, Foote J, Greatbanks R, Stokes T, Gauld R. Why is Quality Improvement so Challenging? A Viable Systems Model Perspective to Understand the Frustrations of Healthcare Quality Improvement Managers. *Health Policy*. 2021;125(5):658-664. doi: 10.1016/j.healthpol.2021.03.015
 41. Arntsen B, Torjesen DO, Karlsen TI. Asymmetry in inter-municipal cooperation in health services - How does it affect service quality and autonomy? *Soc Sci Med*. 2021;273:113744. doi: 10.1016/j.socscimed.2021.113744
 42. Sittig DF, Belmont E, Singh H. Improving the safety of health information technology requires shared responsibility: It is time we all step up. *Healthc (Amst)*. 2018;6(1):7-12. doi: 10.1016/j.hjdsi.2017.06.004
 43. Vilchik TB, Krainyk HS, Shandula OO. Legal enforcement and development directions of health law in Ukraine. *Wiad Lek*. 2019;72(4):692-696. doi: 10.36740/wlek201904136
 44. Guest JD, Kelly-Hedrick M, Williamson T, Park C, Ali DM, Sivaganesan A, et al. Development of a Systems Medicine Approach to Spinal Cord Injury. *J Neurotrauma*. 2023;40(17-18):1849-1877. doi: 10.1089/neu.2023.0024
 45. Gameiro GR, Sinkunas V, Liguori GR, Auler-Junior JOC. Precision Medicine: Changing the way we think about healthcare. *Clinics (Sao Paulo, Brazil)*. 2018;73:e723. doi: 10.6061/clinics/2017/e723
 46. Tian C, Lv Y, Li S, Wang DD, Bai Y, Zhou F, et al. Factors related to improved American Spinal Injury Association grade of acute traumatic spinal cord injury. *World J Clin Cases*. 2020;8(20):4807-4815. doi: 10.12998/wjcc.v8.i20.4807
 47. Vaccaro AR, Oner C, Kepler CK, Dvorak M, Schnake K, Bellabarba C, et al. AOSpine thoracolumbar spine injury classification system: fracture description, neurological status, and key modifiers. *Spine (Phila Pa 1976)*. 2013;38(23):2028-2037. doi: 10.1097/BRS.0b013e3182a8a381
 48. Vaccaro AR, Lehman RA, Jr., Hurlbert RJ, Anderson PA, Harris M, Hedlund R, et al. A new classification of thoracolumbar injuries: the importance of injury morphology, the integrity of the posterior ligamentous complex, and neurologic status. *Spine (Phila Pa 1976)*. 2005;30(20):2325-2333. doi: 10.1097/01.brs.0000182986.43345.cb
 49. Canseco JA, Schroeder GD, Paziuk TM, Karamian BA, Kandziora F, Vialle EN, et al. The Subaxial Cervical AO Spine Injury Score. *Global Spine J*. 2022;12(6):1066-1073. doi:

- 10.1177/2192568220974339
50. Verheyden AP, Spiegl UJ, Ekkerlein H, Gercek E, Hauck S, Josten C, et al. Treatment of Fractures of the Thoracolumbar Spine: Recommendations of the Spine Section of the German Society for Orthopaedics and Trauma (DGOU). *Global Spine J*. 2018;8(2 Suppl):34S-45S. doi: 10.1177/2192568218771668
 51. Nilsbakken IMW, Sollid S, Wisborg T, Jeppesen E. Assessing Trauma Management in Urban and Rural Populations in Norway: A National Register-Based Research Protocol. *JMIR Res Protoc*. 2022;11(6):e30656. doi: 10.2196/30656
 52. Wuthisuthimethawee P, Sookmee W, Damnoi S. Non-randomized comparative study on the efficacy of a trauma protocol in the emergency department. *Chinese journal of traumatology = Zhonghua chuang shang za zhi*. 2019;22(4):207-211. doi: 10.1016/j.cjtee.2019.04.003
 53. Jureidini J, McHenry LB. The illusion of evidence based medicine. *BMJ (Clinical research ed)*. 2022;376:o702. doi: 10.1136/bmj.o702
 54. Sadeghi-Bazargani H, Tabrizi JS, Azami-Aghdash S. Barriers to evidence-based medicine: a systematic review. *J Eval Clin Pract*. 2014;20(6):793-802. doi: 10.1111/jep.12222
 55. Every-Palmer S, Howick J. How evidence-based medicine is failing due to biased trials and selective publication. *J Eval Clin Pract*. 2014;20(6):908-914. doi: 10.1111/jep.12147
 56. Ioannidis JP. Why Most Clinical Research Is Not Useful. *PLoS Med*. 2016;13(6):e1002049. doi: 10.1371/journal.pmed.1002049
 57. Greenhalgh T, Howick J, Maskrey N, Evidence Based Medicine Renaissance G. Evidence based medicine: a movement in crisis? *BMJ (Clinical research ed)*. 2014;348:g3725. doi: 10.1136/bmj.g3725
 58. Kwak SG, Kim JH. Central limit theorem: the cornerstone of modern statistics. *Korean J Anesthesiol*. 2017;70(2):144-156. doi: 10.4097/kjae.2017.70.2.144
 59. Alimohammadi E, Bagheri SR, Joseph B, Sharifi H, Shokri B, Khodadadi L. Analysis of factors associated with the failure of treatment in thoracolumbar burst fractures treated with short-segment posterior spinal fixation. *Journal of orthopaedic surgery and research*. 2023;18(1):690. doi: 10.1186/s13018-023-04190-w
 60. Soultanis K, Thanos A, Soucacos PN. "Outcome of thoracolumbar compression fractures following non-operative treatment". *Injury*. 2021;52(12):3685-3690. doi: 10.1016/j.injury.2021.05.019
 61. Bruckner J, Hashmi S, Williams SK, Ludwig S. Minimally invasive surgery for the management of thoracolumbar burst fractures. *Seminars in Spine Surgery*. 2021;33(1):100848. doi: 10.1016/j.semss.2021.100848
 62. Cowley A, Nelson M, Hall C, Goodwin S, Kumar DS, Moore F. Recommendation for changes to the guidelines of trauma patients with potential spinal injury within a regional UK ambulance trust. *Br Paramed J*. 2022;7(3):59-67. doi: 10.29045/14784726.2022.12.7.3.59
 63. Alfaro-Mico J, Ramirez-Villaescusa J, Martinez-Lozano MD, Sanchez-Honrubia RM, Ruiz-Picazo D. Emergency stabilisation by single-stage posterior transpedicular approach for treatment of unstable lumbar spine fracture with neurological injury. *Trauma case reports*. 2020;27:100300. doi: 10.1016/j.tcr.2020.100300
 64. Rogers JR, Pavisic J, Ta CN, Liu C, Soroush A, Kuen Cheung Y, et al. Leveraging electronic health record data for clinical trial planning by assessing eligibility criteria's impact on patient count and safety. *J Biomed Inform*. 2022;127:104032. doi: 10.1016/j.jbi.2022.104032
 65. Nouhi M, Hadian M, Olyaeemanesh A. The clinical and economic consequences of practice style variations in common surgical interventions: A protocol for systematic review. *Medicine (Baltimore)*. 2018;97(42):e12439. doi: 10.1097/MD.00000000000012439
 66. Allen BL, Jr., Ferguson RL, Lehmann TR, O'Brien RP. A mechanistic classification of closed, indirect fractures and dislocations of the lower cervical spine. *Spine (Phila Pa 1976)*. 1982;7(1):1-27. doi: 10.1097/00007632-198200710-00001
 67. Magerl F, Aebi M, Gertzbein SD, Harms J, Nazarian S. A comprehensive classification of thoracic and lumbar injuries. *Eur Spine J*. 1994;3(4):184-201. doi: 10.1007/BF02221591
 68. Nekhlopochny OS, Cheshuk YV. Traumatic injuries of the thoracolumbar junction. Classification by Friedrich P. Magerl et al. *Trauma*. 2022;23(3):4-22. doi: 10.22141/1608-1706.3.23.2022.895.
 69. Marsh JL, Slongo TF, Agel J, Broderick JS, Creevey W, DeCoster TA, et al. Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. *J Orthop Trauma*. 2007;21(10 Suppl):S1-133. doi: 10.1097/00005131-200711101-00001
 70. Divi SN, Schroeder GD, Oner FC, Kandziora F, Schnake KJ, Dvorak MF, et al. AOSpine-Spine Trauma Classification System: The Value of Modifiers: A Narrative Review With Commentary on Evolving Descriptive Principles. *Global Spine J*. 2019;9(1 Suppl):77S-88S. doi: 10.1177/2192568219827260
 71. Vaccaro AR, Koerner JD, Radcliff KE, Oner FC, Reinhold M, Schnake KJ, et al. AOSpine subaxial cervical spine injury classification system. *Eur Spine J*. 2016;25(7):2173-2184. doi: 10.1007/s00586-015-3831-3
 72. Azimi P, Mohammadi HR, Azhari S, Alizadeh P, Montazeri A. The AOSpine thoracolumbar spine injury classification system: A reliability and agreement study. *Asian journal of neurosurgery*. 2015;10(4):282-285. doi: 10.4103/1793-5482.162703
 73. Lopes FAR, Ferreira A, Santos R, Macaneiro CH. Intraobserver and interobserver reproducibility of the old and new classifications of toracolumbar fractures. *Rev Bras Ortop*. 2018;53(5):521-526. doi: 10.1016/j.rboe.2018.07.015
 74. Sriganesh K, Shanthanna H, Busse JW. A brief overview of systematic reviews and meta-analyses. *Indian journal of anaesthesia*. 2016;60(9):689-694. doi: 10.4103/0019-5049.190628
 75. Vaccaro AR, Schroeder GD, Kepler CK, Cumhur Oner F, Vialle LR, Kandziora F, et al. The surgical algorithm for the AOSpine thoracolumbar spine injury classification system. *Eur Spine J*. 2016;25(4):1087-1094. doi: 10.1007/s00586-015-3982-2
 76. Pishnamaz M, Balosu S, Curfs I, Uhing D, Laubach M, Herren C, et al. Reliability and Agreement of Different Spine Fracture Classification Systems: An Independent Intraobserver and Interobserver Study. *World Neurosurg*. 2018;115:e695-e702. doi: 10.1016/j.wneu.2018.04.138
 77. Berkman ND, Lohr KN, Ansari MT, Balk EM, Kane R, McDonagh M, et al. Grading the strength of a body of evidence when assessing health care interventions: an EPC update. *J Clin Epidemiol*. 2015;68(11):1312-1324. doi: 10.1016/j.jclinepi.2014.11.023
 78. Kent DM, Steyerberg E, van Klaveren D. Personalized evidence based medicine: predictive approaches to heterogeneous treatment effects. *BMJ (Clinical research ed)*. 2018;363:k4245. doi: 10.1136/bmj.k4245
 79. Gugiu PC. Hierarchy of evidence and appraisal of limitations (HEAL) grading system. *Eval Program Plann*. 2015;48:149-159. doi: 10.1016/j.evalprogplan.2014.08.003
 80. Ioannidis JPA. Hijacked evidence-based medicine: stay the course and throw the pirates overboard. *J Clin Epidemiol*. 2017;84:11-13. doi: 10.1016/j.jclinepi.2017.02.001
 81. Keane M, Berg C. Evidence-based medicine: A predictably flawed paradigm. *Trends in Anaesthesia and Critical Care*. 2016;9:49-52. doi: 10.1016/j.tacc.2016.07.002
 82. Tebala GD. The Emperor's New Clothes: a Critical Appraisal of Evidence-based Medicine. *Int J Med Sci*. 2018;15(12):1397-1405. doi: 10.7150/ijms.25869
 83. Roland D. Social Media, Health Policy, and Knowledge Translation. *J Am Coll Radiol*. 2018;15(1 Pt B):149-152. doi: 10.1016/j.jacr.2017.09.009
 84. Jeyaraman M, Ramasubramanian S, Kumar S, Jeyaraman N, Selvaraj P, Nallakumarasamy A, et al. Multifaceted Role of Social Media in Healthcare: Opportunities, Challenges, and the Need for Quality Control. *Cureus*. 2023;15(5):e39111. doi: 10.7759/cureus.39111
 85. Dijkstra S, Kok G, Ledford JG, Sandalova E, Stevelink R. Possibilities and Pitfalls of Social Media for Translational Medicine. *Front Med (Lausanne)*. 2018;5:345. doi: 10.3389/fmed.2018.00345

86. Jacobs R, Prabhu AV, Monaco EA, Tonetti D, Agarwal N. Patient perception of gamma knife stereotactic radiosurgery through twitter and instagram. *Interdisciplinary Neurosurgery*. 2018;13:138-140. doi: 10.1016/j.inat.2018.05.005
87. Forgie EME, Lai H, Cao B, Stroulia E, Greenshaw AJ, Goetz H. Social Media and the Transformation of the Physician-Patient Relationship: Viewpoint. *J Med Internet Res*. 2021;23(12):e25230. doi: 10.2196/25230
88. Boushehri E, Soltani Arabshahi K, Monajemi A. Clinical reasoning assessment through medical expertise theories: past, present and future directions. *Med J Islam Repub Iran*. 2015;29:222
89. Shah HM, Chung KC. Archie Cochrane and his vision for evidence-based medicine. *Plast Reconstr Surg*. 2009;124(3):982-988. doi: 10.1097/PRS.0b013e3181b03928
90. Cochrane A. Effectiveness and Efficiency: Random Reflections on Health Services. London: Nuffield Provincial Hospitals Trust; 1972. <https://www.nuffieldtrust.org.uk/research/effectiveness-and-efficiency-random-reflections-on-health-services>
91. Gerris J. The legacy of Archibald Cochrane: from authority based towards evidence based medicine. *Facts Views Vis Obgyn*. 2011;3(4):233-237
92. Askheim C, Sandset T, Engebretsen E. Who cares? The lost legacy of Archie Cochrane. *Med Humanit*. 2017;43(1):41-46. doi: 10.1136/medhum-2016-011037
93. Arjas E, Gasbarra D. Adaptive treatment allocation and selection in multi-arm clinical trials: a Bayesian perspective. *BMC Med Res Methodol*. 2022;22(1):50. doi: 10.1186/s12874-022-01526-8
94. Williamson SF, Jacko P, Villar SS, Jaki T. A Bayesian adaptive design for clinical trials in rare diseases. *Comput Stat Data Anal*. 2017;113:136-153. doi: 10.1016/j.csda.2016.09.006
95. Edlitz Y, Segal E. Prediction of type 2 diabetes mellitus onset using logistic regression-based scorecards. *Elife*. 2022;11. doi: 10.7554/eLife.71862
96. Fukunishi H, Nishiyama M, Luo Y, Kubo M, Kobayashi Y. Alzheimer-type dementia prediction by sparse logistic regression using claim data. *Comput Methods Programs Biomed*. 2020;196:105582. doi: 10.1016/j.cmpb.2020.105582
97. van Walraven C, McAlister FA. Competing risk bias was common in Kaplan-Meier risk estimates published in prominent medical journals. *J Clin Epidemiol*. 2016;69:170-173 e178. doi: 10.1016/j.jclinepi.2015.07.006
98. Hu C, Cao J, Zeng L, Luo Y, Fan H. Prognostic factors for squamous cervical carcinoma identified by competing-risks analysis: A study based on the SEER database. *Medicine (Baltimore)*. 2022;101(39):e30901. doi: 10.1097/MD.00000000000030901
99. Khan O, Badhiwala JH, Grasso G, Fehlings MG. Use of Machine Learning and Artificial Intelligence to Drive Personalized Medicine Approaches for Spine Care. *World Neurosurg*. 2020;140:512-518. doi: 10.1016/j.wneu.2020.04.022
100. Inoue T, Ichikawa D, Ueno T, Cheong M, Inoue T, Whetstone WD, et al. XGBoost, a Machine Learning Method, Predicts Neurological Recovery in Patients with Cervical Spinal Cord Injury. *Neurotrauma Rep*. 2020;1(1):8-16. doi: 10.1089/neur.2020.0009
101. Langarizadeh M, Moghbeli F. Applying Naive Bayesian Networks to Disease Prediction: a Systematic Review. *Acta informatica medica : AIM : journal of the Society for Medical Informatics of Bosnia & Herzegovina : casopis Drustva za medicinsku informatiku BiH*. 2016;24(5):364-369. doi: 10.5455/aim.2016.24.364-369
102. Vemulapalli V, Qu J, Garren JM, Rodrigues LO, Kiebish MA, Sarangarajan R, et al. Non-obvious correlations to disease management unraveled by Bayesian artificial intelligence analyses of CMS data. *Artif Intell Med*. 2016;74:1-8. doi: 10.1016/j.artmed.2016.11.001
103. Khanmohammadi S, Adibeig N, Shanehbandy S. An improved overlapping k-means clustering method for medical applications. *Expert Systems with Applications*. 2017;67:12-18. doi: 10.1016/j.eswa.2016.09.025
104. Zhu H, He H, Xu J, Fang Q, Wang W. Medical Image Segmentation Using Fruit Fly Optimization and Density Peaks Clustering. *Comput Math Methods Med*. 2018;2018:3052852. doi: 10.1155/2018/3052852
105. Kocbek P, Fijacko N, Soguero-Ruiz C, Mikalsen KO, Maver U, Povalej Brzan P, et al. Maximizing Interpretability and Cost-Effectiveness of Surgical Site Infection (SSI) Predictive Models Using Feature-Specific Regularized Logistic Regression on Preoperative Temporal Data. *Comput Math Methods Med*. 2019;2019:2059851. doi: 10.1155/2019/2059851