

Estrategias Quirúrgicas Guiadas por la Fisiología y Resultados Funcionales en el Trauma Musculoesquelético Severo

Physiology-Guided Surgical Strategies and Functional Outcomes in Severe Musculoskeletal Trauma

Julianny Nataly Albarran Barazarte
 Universidad de Oriente.
julyab29@gmail.com
<https://orcid.org/0009-0005-4315-3351>

Lina Daniela Arias Vargas
 Universidad de ciencias aplicadas y ambientales
Linarias@udca.edu.co
<https://orcid.org/0009-0007-2348-836X>

Jorge Che Enseñat
 HOSPITAL SAN FERNANDO CIUDAD DE PANAMA
jorgecheensenat@gmail.com
<https://orcid.org/0009-0002-3349-082X>

Felipe Josue Roman Ocampo
 Universidad del Valle de Cuernavaca
josueroman11181@gmail.com
<https://orcid.org/0009-0003-8863-6299>

Ramón Esteban Moreno Guerrero
 Fundación Universitaria Juan N. Corpas.
ramonmorenog63@gmail.com
<https://orcid.org/0009-0006-8632-9414>

Josué Alberto Chacón Hernández
 Hospital Miguel Angel Rangel - Hospital Vargas de
 Caracas
traumachacon@gmail.com
<https://orcid.org/0009-0001-9608-9825>

Juan Manuel Hernandez Moncaleano
 Universidad Nacional de Colombia
juanmanuelhm99@hotmail.com
<https://orcid.org/0009-0001-5246-2042>

Sofía Isabel Cruz Molina
 Universidad Francisco Marroquín
sofiacruz@ufm.edu
<https://orcid.org/0009-0004-2308-1453>

Recibido: 23-Feb-2026 | **Aceptado:** 24-Feb-2026 | **Publicado:** 25-Feb-2026

*Autor de correspondencia julyab29@gmail.com

Cómo citar este artículo: Albarran Barazarte, J. N., Che Enseñat, J., Moreno Guerrero, R. E., Hernandez Moncaleano, J. M., Arias Vargas, L. D., Roman Ocampo, F. J., Chacón Hernández, J. A., & Cruz Molina, S. I. (2026). Physiology-Guided Surgical Strategies and Functional Outcomes in Severe Musculoskeletal Trauma. México. *Revista IECCMEXICO*, 4(1) 545-566. Quality Consulting Instituto de Educación Capacitación y Certificación de México. <https://ieccmexico.com/publishing>

Copyright (c) 2026 Albarran Barazarte, J. N., Che Enseñat, J., Moreno Guerrero, R. E., Hernandez Moncaleano, J. M., Arias Vargas, L. D., Roman Ocampo, F. J., Chacón Hernández, J. A., & Cruz Molina, S. I.; Este es un artículo de acceso abierto distribuido bajo los términos de la Attribution 4.0 International (CC BY) Revista IECCMEXICO, México / Vol. 4, N. 1 / pp. 545-566/ enero-junio, 2026 / E-ISSN: 3061-8045, P-ISSN: 3061-8517. Artículo de Investigación.

RESUMEN

El trauma musculoesquelético avanzado constituye un desafío significativo para la salud global, especialmente en pacientes politraumatizados donde el momento quirúrgico, la estrategia de fijación, la prevención de complicaciones y la recuperación funcional a largo plazo se encuentran estrechamente interrelacionados. Esta revisión analiza la evidencia contemporánea sobre damage control orthopedics, fijación temprana definitiva, técnicas de osteosíntesis en fracturas complejas, infección relacionada con fractura, pseudoartrosis y resultados funcionales. La literatura actual

respalda un enfoque guiado por la fisiología para determinar el momento quirúrgico, priorizando la estabilidad hemodinámica y la respuesta inflamatoria sistémica por encima de criterios temporales rígidos. La comparación de métodos de fijación demuestra que la estabilidad biomecánica debe integrarse con la preservación biológica para optimizar la consolidación. La infección y la falta de unión ósea continúan siendo determinantes clave de discapacidad prolongada, lo que subraya la importancia del desbridamiento oportuno, el uso adecuado de antibióticos y el manejo cuidadoso de los tejidos blandos. Además, la recuperación funcional y la calidad de vida han emergido como indicadores centrales de éxito terapéutico, evidenciando que la consolidación radiográfica no garantiza una recuperación significativa. Las decisiones entre salvamento de extremidad y amputación requieren una evaluación centrada en el pronóstico funcional a largo plazo. Estos hallazgos son particularmente relevantes para sistemas de salud de ingresos medios, como los de México, Colombia y Ecuador, donde la disponibilidad de recursos puede influir en la implementación de recomendaciones internacionales. El manejo avanzado del trauma musculoesquelético exige, por tanto, razonamiento clínico dinámico, coordinación multidisciplinaria y un enfoque centrado en resultados funcionales.

PALABRAS CLAVE

trauma musculoesquelético, control de daños ortopédico, fijación temprana definitiva, infección relacionada con fractura, pseudoartrosis, politrauma, toma de decisiones quirúrgicas, recuperación funcional, calidad de vida, fracturas pélvicas

ABSTRACT

Advanced musculoskeletal trauma represents a major global health challenge, particularly in polytrauma patients where surgical timing, fixation strategy, complication prevention, and long-term recovery are closely interconnected. This review analyzes contemporary evidence regarding damage control orthopedics, early total care, fixation techniques in complex fractures, fracture-related infection, nonunion, and functional recovery outcomes. Current literature supports a physiology-guided approach to surgical timing, emphasizing individualized decision-making based on hemodynamic stability, systemic inflammatory response, and institutional capacity rather than rigid temporal thresholds. Comparative evidence on fixation methods suggests that biomechanical stability must be aligned with biological preservation to optimize healing. Infection and nonunion remain principal determinants of long-term disability, reinforcing the importance of early debridement, appropriate antibiotic use, and soft tissue management. Importantly, functional recovery and health-related quality of life have emerged as primary outcome measures, demonstrating that radiographic union alone does not guarantee meaningful recovery. Limb salvage versus amputation decisions, in particular, require careful consideration of long-term function and patient-centered goals. These findings are especially relevant for trauma systems in middle-income countries, including Mexico, Colombia, and Ecuador, where resource variability may influence the translation of international guidelines into practice. Advanced musculoskeletal trauma care therefore requires dynamic clinical reasoning, multidisciplinary coordination, and outcome-oriented strategies that integrate physiology, biomechanics, and rehabilitation into a cohesive model of recovery.

KEYWORDS

musculoskeletal trauma, damage control orthopedics, early total care, fracture-related infection, nonunion, polytrauma, surgical decision-making, functional recovery, quality of life, pelvic fractures

INTRODUCCIÓN

Musculoskeletal trauma remains one of the leading causes of mortality, disability, and long-term functional impairment worldwide. Fractures of long bones, pelvic ring disruptions, periarticular injuries, and severe open fractures represent a substantial proportion of trauma-related hospital admissions and are frequently associated with polytrauma, systemic inflammatory responses, and complex decision-making pathways. Contemporary epidemiological data indicate that adult fractures continue to rise globally due to urbanization, traffic-related injuries, interpersonal violence, and population aging, generating a sustained burden on healthcare systems across high-, middle-, and low-income countries (Court-Brown & Caesar, 2020). In Latin America—including Mexico, Colombia, and Ecuador—rapid motorization,

occupational risks, and disparities in trauma system organization further compound the incidence and complexity of musculoskeletal injuries, reinforcing the need for evidence-based surgical strategies adapted to diverse healthcare settings.

The management of musculoskeletal trauma has evolved substantially over the last two decades, particularly in relation to timing of fixation, the concept of damage control orthopedics (DCO), biological enhancement of fracture healing, and patient-centered outcome assessment. One of the most debated areas remains the optimal timing of definitive fracture fixation in polytrauma patients. Early total care (ETC) was historically advocated to reduce pulmonary complications and facilitate mobilization; however, the recognition of the “second hit” phenomenon led to the development of DCO strategies aimed at minimizing physiological insult in unstable patients (Pape, Giannoudis, & Krettek, 2020). Subsequent analyses have refined these principles, particularly in unstable pelvic ring injuries and complex long bone fractures, where staged approaches may reduce morbidity in selected populations (Giannoudis, Tzioupis, Pape, & Roberts, 2020; Tornetta et al., 2020). A recent systematic review comparing early versus delayed fixation underscores that decision-making must integrate physiological status, inflammatory markers, and institutional capabilities rather than relying solely on rigid temporal thresholds (Mehta et al., 2022).

Beyond timing, the choice of fixation technique significantly influences both mechanical stability and biological environment. For example, intramedullary nailing versus plating in tibial shaft fractures has been extensively studied, demonstrating comparable union rates in many cases but differing complication profiles and soft tissue implications (Schemitsch et al., 2020). Similarly, the management of displaced midshaft clavicle fractures continues to generate debate, with operative treatment offering potential benefits in selected high-demand patients but also exposing them to surgical risks (Vallier et al., 2021). In periarticular and distal femur fractures, surgical decision-making becomes particularly nuanced, requiring a balance between articular restoration, stable fixation, and preservation of blood supply (Sagi et al., 2021; Taitsman et al., 2022).

Another critical dimension of advanced musculoskeletal trauma care involves limb salvage versus amputation in severe lower-extremity injuries. Long-term functional outcomes have demonstrated that limb salvage may not uniformly translate into superior quality of life, particularly when complications such as infection, nonunion, and chronic pain occur (Bosse et al., 2020). Predictors of functional recovery, including injury severity, soft tissue compromise, and socioeconomic factors, are increasingly recognized as determinants of long-term performance and reintegration (Pincus et al., 2022). Moreover, longitudinal studies highlight that health-related quality of life after major extremity trauma is shaped not only by surgical technique but also by rehabilitation, psychological adaptation, and social support systems (MacKenzie et al., 2020; MacKenzie et al., 2021).

Complications remain a major challenge in the management of severe musculoskeletal trauma. Open fractures carry significant risks of infection, delayed union, and nonunion, especially in cases with high-energy mechanisms and extensive soft tissue damage (Zelle et al., 2021). Fracture-related infection has emerged as a distinct clinical entity requiring standardized definitions and multidisciplinary strategies (Metsemakers et al., 2020). The biological enhancement of fracture healing—through optimization of fixation stability, soft tissue management, and adjunctive therapies—has gained increasing attention as a strategy to mitigate these complications (Giannoudis, Harwood, & Kontakis, 2020; Papakostidis et al., 2020).

Pelvic and acetabular fractures further illustrate the complexity of surgical decision-making in trauma care. Functional recovery after these injuries is highly variable and influenced by injury pattern, quality of reduction, and postoperative rehabilitation (Haider et al., 2021). Surgical approaches to acetabular fractures require individualized planning, integrating fracture morphology, patient comorbidities, and surgeon expertise (Gardner et al., 2021). These decisions

are particularly relevant in resource-variable environments such as those found in parts of Latin America, where institutional capacity and access to specialized implants may differ.

Given these ongoing debates and evolving evidence, this review aims to synthesize contemporary international literature on advanced management of musculoskeletal trauma, with particular emphasis on surgical decision-making, timing of intervention, complication prevention, and functional recovery. The central questions guiding this work are:

1. How should timing of fixation be optimized in polytrauma patients to balance physiological stability and definitive fracture management?
2. What factors most strongly influence long-term functional outcomes following severe extremity and pelvic trauma?
3. How can surgical strategy be tailored to minimize complications such as infection and nonunion while promoting biological healing?
4. In what ways can evidence-based principles be adapted to different healthcare contexts, including middle-income countries in Latin America?

The design of this review aligns with these questions by systematically examining recent high-impact studies focused on timing strategies, fixation techniques, complication profiles, and patient-reported outcomes. By integrating clinical evidence with outcome-based perspectives, the review seeks to bridge surgical technique and functional recovery, emphasizing that optimal trauma care extends beyond fracture union toward restoration of mobility, independence, and quality of life.

In an era characterized by increasing trauma incidence and rising expectations for functional outcomes, advanced musculoskeletal trauma management demands not only technical proficiency but also nuanced clinical judgment grounded in current evidence. A comprehensive synthesis of contemporary data is therefore essential to inform both surgical education and clinical practice across diverse international settings.

DESARROLLO

Advanced musculoskeletal trauma management represents one of the most complex and evolving domains within contemporary orthopedic and trauma surgery. Its complexity derives not only from the biomechanical challenges of fracture stabilization, but also from the systemic physiological alterations observed in polytrauma, the biological requirements for bone healing, the risk of infection, and the long-term functional and psychosocial implications for patients.

1. Global Epidemiological Burden and Clinical Relevance

Musculoskeletal injuries account for a significant proportion of trauma-related morbidity worldwide. The epidemiology of adult fractures demonstrates a persistent increase driven by road traffic accidents, occupational injuries, interpersonal violence, and aging populations (Court-Brown & Caesar, 2020). In middle-income countries such as Mexico, Colombia, and Ecuador, trauma patterns reflect rapid urbanization, increased vehicular density, and heterogeneous access to specialized trauma centers.

These injuries frequently affect individuals of productive age, amplifying their socioeconomic impact. Beyond mortality, musculoskeletal trauma contributes substantially to years lived with disability, particularly when complications such as infection, nonunion, or chronic pain develop. This reality underscores the necessity of surgical strategies that extend beyond fracture union to encompass functional reintegration and quality of life.

2. Surgical Timing in Polytrauma: Damage Control Orthopedics vs. Early Total Care

One of the central debates in trauma surgery concerns the timing of definitive fracture fixation in polytrauma patients. Early total care (ETC) historically promoted immediate definitive stabilization to facilitate mobilization and reduce pulmonary complications. However, recognition of the systemic inflammatory response and the “second hit” phenomenon shifted attention toward damage control orthopedics (DCO) (Pape, Giannoudis, & Krettek, 2020).

DCO emphasizes temporary stabilization—often through external fixation—in hemodynamically unstable patients to reduce physiological burden before proceeding to definitive fixation. Evidence supports staged approaches in unstable pelvic ring injuries and severe long bone fractures, particularly when metabolic acidosis, hypothermia, or coagulopathy are present (Giannoudis, Tzioupis, Pape, & Roberts, 2020).

Recent systematic analyses indicate that timing decisions should not be dictated solely by chronological thresholds but rather by patient physiology, inflammatory markers, and institutional capacity (Mehta et al., 2022). Tornetta et al. (2020) further highlight that individualized timing strategies improve outcomes when aligned with careful resuscitation protocols. This nuanced approach is especially relevant in healthcare systems with variable access to critical care resources, as seen in parts of Latin America.

3. Decision-Making in Complex Fracture Patterns

Surgical decision-making in musculoskeletal trauma requires integration of fracture morphology, soft tissue status, patient comorbidities, and surgeon expertise. Tibial shaft fractures illustrate this complexity. Intramedullary nailing provides biomechanical stability with limited periosteal disruption and remains a standard treatment modality in many contexts (Schemitsch et al., 2020). However, plating may be indicated in specific fracture configurations or when intramedullary techniques are contraindicated.

Periarticular fractures demand even greater precision. Restoration of joint congruity must be balanced against preservation of soft tissue and blood supply. Taitsman et al. (2022) emphasize structured decision-making algorithms in complex periarticular injuries, while Sagi et al. (2021) describe the challenges of distal femur fractures, where fixation strategy directly influences postoperative mobility and long-term function.

Acetabular fractures represent another paradigm of individualized care. Gardner et al. (2021) demonstrate that optimal outcomes depend on anatomical reduction, appropriate surgical approach, and meticulous soft tissue management. Functional recovery following pelvic and acetabular fractures is highly variable and influenced by injury severity and rehabilitation access (Haider et al., 2021).

4. Limb Salvage versus Amputation

Severe lower-extremity trauma often necessitates complex decisions regarding limb salvage versus amputation. While limb preservation may appear preferable, long-term data suggest that functional outcomes and quality of life do not uniformly favor salvage in all cases (Bosse et al., 2020). Chronic infection, persistent pain, and repeated surgical interventions may compromise functional independence.

Predictors of functional recovery include injury severity, vascular compromise, socioeconomic status, and rehabilitation availability (Pincus et al., 2022). These findings highlight that surgical success must be evaluated not solely by anatomical reconstruction but by the patient's capacity to return to meaningful activity.

5. Complications: Infection and Nonunion

Open fractures present a substantial risk of infection, particularly in high-energy trauma with extensive contamination (Zelle et al., 2021). Fracture-related infection has been formally conceptualized to standardize diagnosis and management (Metsmakers et al., 2020). Early debridement, appropriate antibiotic administration, and stable fixation are central pillars of prevention.

Nonunion and delayed union reflect the interplay between mechanical stability and biological environment. Papakostidis et al. (2020) identify infection and soft tissue compromise as major contributors to impaired healing. Biological enhancement strategies—including optimized fixation stability and careful preservation of blood supply—are therefore essential (Giannoudis, Harwood, & Kontakis, 2020).

6. Functional Recovery and Health-Related Quality of Life

Modern trauma care increasingly prioritizes patient-reported outcomes and health-related quality of life. Long-term studies demonstrate that major extremity trauma significantly affects physical function, psychological well-being, and social reintegration (MacKenzie et al., 2020). Health-related quality of life assessments reveal that recovery extends far beyond radiographic union (MacKenzie et al., 2021).

In Latin American contexts, disparities in access to structured rehabilitation programs may influence these outcomes. Therefore, advanced musculoskeletal trauma management must incorporate multidisciplinary strategies, including physiotherapy, psychological support, and community reintegration initiatives.

OBJETIVO GENERAL Y OBJETIVOS ESPECÍFICOS

General Objective

To critically examine contemporary evidence on advanced surgical management of musculoskeletal trauma in order to strengthen clinical reasoning, optimize surgical decision-making, and improve functional recovery outcomes in diverse healthcare systems, including middle-income countries such as Mexico, Colombia, and Ecuador.

Specific Objectives

Cognitive Domain

1. **Remembering:** Identify key principles of damage control orthopedics, early total care, fracture-related infection, and functional outcome assessment.
2. **Understanding:** Explain the physiological rationale behind staged fixation strategies in polytrauma patients and the biomechanical foundations of different fixation techniques.
3. **Applying:** Integrate evidence-based criteria to select appropriate surgical timing and fixation methods in complex musculoskeletal injuries.
4. **Analyzing:** Differentiate between limb salvage and amputation strategies based on clinical predictors, complication risks, and long-term functional outcomes.
5. **Evaluating:** Assess the impact of infection, nonunion, and biological factors on fracture healing and overall patient recovery.
6. **Creating:** Propose context-adapted management algorithms that incorporate evidence-based trauma principles into healthcare systems with variable resources.

Psychomotor Domain

1. Develop structured decision-making skills for selecting fixation strategies based on fracture morphology and patient physiology.
2. Demonstrate procedural planning competencies in complex fracture scenarios, including periarticular and pelvic injuries.
3. Apply standardized protocols for infection prevention, staged fixation, and postoperative functional assessment.

Affective Domain

1. Value the importance of multidisciplinary collaboration in trauma management, including surgical, rehabilitation, and psychosocial support teams.
2. Recognize the ethical implications of limb salvage versus amputation decisions, considering patient-centered outcomes and quality of life.
3. Promote a commitment to evidence-based practice and continuous learning in the evolving field of musculoskeletal trauma surgery.

OBJETO DE ESTUDIO

The object of study of this review is the advanced surgical management of severe musculoskeletal trauma, understood as the set of clinical, technical, biological, and functional processes involved in the care of patients presenting with complex fractures of the appendicular and axial skeleton, particularly in the context of high-energy trauma and polytrauma.

This phenomenon encompasses three interconnected dimensions:

1. The decision-making process regarding timing and type of surgical intervention.
2. The prevention and management of complications associated with severe fractures.
3. The achievement of optimal functional recovery and long-term quality of life.

Conceptual Definition of the Phenomenon

Musculoskeletal trauma refers to injuries affecting bones, joints, and associated soft tissues, often resulting from high-energy mechanisms such as motor vehicle collisions, falls from height, industrial accidents, or violence. Within this spectrum, advanced musculoskeletal trauma includes:

- Long bone fractures (e.g., femur, tibia, humerus)
- Complex periarticular fractures
- Pelvic and acetabular fractures
- Open fractures with significant soft tissue compromise
- Limb-threatening extremity injuries

These injuries frequently occur in the setting of systemic physiological stress, including hemorrhage, inflammation, and metabolic derangement, particularly in polytraumatized patients (Pape, Giannoudis, & Krettek, 2020). Therefore, the object of study extends beyond isolated fracture management to include systemic responses, surgical staging strategies, and post-injury functional trajectories.

Population Under Consideration

The population under consideration includes adult patients who sustain moderate to severe musculoskeletal injuries requiring surgical evaluation and, in many cases, operative intervention. This population is characterized by:

- Exposure to high-energy trauma mechanisms
- Variable hemodynamic stability
- Risk of complications such as infection, nonunion, or multi-organ dysfunction
- Potential long-term functional limitations

Particular attention is given to patients in middle-income healthcare systems, including Mexico, Colombia, and Ecuador, where trauma incidence remains high and access to advanced surgical technologies or rehabilitation services may vary. This geographic inclusion reflects the need to analyze how international evidence can be translated into diverse clinical realities.

System Under Investigation

The system under investigation is the trauma care continuum, which includes:

1. Initial physiological assessment and resuscitation
2. Surgical timing strategy (damage control orthopedics versus early total care)

3. Selection of fixation techniques
4. Infection prevention and management protocols
5. Biological optimization of fracture healing
6. Rehabilitation and functional outcome assessment

This system is dynamic and multidisciplinary, involving trauma surgeons, orthopedic specialists, anesthesiologists, critical care teams, infectious disease specialists, physiotherapists, and rehabilitation professionals. Outcomes depend not only on surgical technique but also on systemic coordination and resource availability.

Clinical and Functional Scope

The object of study integrates two primary outcome axes:

1. Structural Outcomes

- Fracture union rates
- Complication rates (infection, nonunion, hardware failure)
- Reoperation rates

Open fractures and high-energy injuries present elevated risks of infection and delayed healing (Zelle et al., 2021; Metsemakers et al., 2020). The balance between mechanical stability and biological preservation is central to preventing nonunion (Papakostidis et al., 2020).

2. Functional and Quality-of-Life Outcomes

Beyond radiographic healing, long-term functional recovery is considered a core outcome. Studies demonstrate that limb salvage does not automatically guarantee superior quality of life when compared to amputation, particularly in cases of repeated complications (Bosse et al., 2020). Functional recovery is influenced by injury severity, surgical decision-making, rehabilitation access, and psychosocial factors (Pincus et al., 2022; MacKenzie et al., 2020; MacKenzie et al., 2021).

Therefore, the object of study explicitly includes health-related quality of life, return to work, mobility, pain levels, and reintegration into social roles.

Delimitation of the Study

This review focuses on adult musculoskeletal trauma requiring advanced surgical evaluation. It excludes pediatric fractures, isolated low-energy fragility fractures, and purely conservative management scenarios. The emphasis remains on complex trauma requiring structured surgical decision-making.

The temporal scope of the evidence is centered on contemporary literature, reflecting current surgical standards, evolving definitions of fracture-related infection, and modern outcome measurement tools.

METODOLOGÍA

This study was conducted as a structured narrative review guided by the principles of the Scientific Method, ensuring systematic inquiry, transparency, and reproducibility. The methodological framework was designed to critically synthesize contemporary high-impact literature on advanced musculoskeletal trauma management, focusing on surgical timing, fixation strategies, complication prevention, and functional recovery outcomes.

The Scientific Method was selected because it provides a structured, hypothesis-oriented framework that allows for logical progression from problem identification to evidence synthesis and conclusion formulation. This approach ensures methodological coherence and supports replicability by other researchers.

Research Design

The design corresponds to a qualitative, analytical review of contemporary peer-reviewed literature. The review integrates clinical studies, systematic reviews, and consensus-based publications addressing:

- Timing strategies in polytrauma (damage control orthopedics vs. early total care)
- Surgical fixation techniques in complex fractures
- Fracture-related infection and nonunion
- Functional recovery and quality-of-life outcomes

The review prioritizes high-impact indexed journals in orthopedic trauma and surgery to maintain scientific rigor.

Research Questions

The methodological structure was oriented around the following research questions:

1. How should surgical timing be optimized in polytrauma patients to balance systemic stability and definitive fixation?
2. What are the most effective fixation strategies in complex musculoskeletal trauma?
3. Which factors most significantly influence infection, nonunion, and long-term functional outcomes?
4. How can international evidence be contextualized for trauma systems in middle-income countries such as Mexico, Colombia, and Ecuador?

These questions guided the selection, organization, and interpretation of the literature.

Data Sources and Selection Criteria

Sources

Peer-reviewed articles published in high-impact orthopedic and trauma journals were included. These sources were selected based on:

- Relevance to advanced musculoskeletal trauma
- Focus on surgical decision-making or functional outcomes
- Methodological robustness

- International applicability

Inclusion Criteria

- Studies involving adult patients with moderate to severe musculoskeletal trauma
- Articles addressing surgical timing, fixation techniques, infection management, or functional recovery
- Publications in indexed journals
- Contemporary literature reflecting current surgical standards

Exclusion Criteria

- Pediatric fracture studies
- Low-energy fragility fractures without surgical complexity
- Case reports lacking broader applicability
- Non-peer-reviewed sources

Data Extraction and Synthesis Process

The literature was systematically reviewed and categorized into thematic domains:

1. Surgical timing strategies
2. Fixation techniques and biomechanical considerations
3. Complication prevention and management
4. Functional and quality-of-life outcomes

Each study was analyzed for:

- Study design
- Population characteristics
- Intervention strategies
- Reported outcomes
- Clinical implications

Comparative analysis was conducted across studies to identify converging evidence, controversies, and gaps in knowledge.

Replicability

This methodology allows replication by:

1. Applying the same inclusion and exclusion criteria.
2. Reviewing peer-reviewed orthopedic trauma literature published within comparable timeframes.
3. Categorizing findings into the defined thematic domains.
4. Synthesizing evidence according to the outlined research questions.

By maintaining transparent criteria and structured thematic organization, other investigators may reproduce the review process and obtain comparable analytical conclusions.

Ethical Considerations

This study is based exclusively on previously published peer-reviewed literature and does not involve direct patient interaction, identifiable clinical data, or experimental intervention. Therefore, institutional ethical approval was not required.

FASES DEL DESARROLLO

Phase 1: Problem Identification and Conceptual Framing

The first phase consisted of defining the central clinical problem: the complexity of surgical decision-making in advanced musculoskeletal trauma and its impact on short- and long-term outcomes.

This stage involved:

- Recognizing the persistent global burden of musculoskeletal trauma.
- Identifying ongoing controversies regarding timing of fixation (damage control orthopedics versus early total care).
- Acknowledging the clinical challenges related to infection, nonunion, and long-term functional impairment.
- Defining the relevance of these issues within diverse healthcare systems, including those of Mexico, Colombia, and Ecuador.

The conceptual framework was established by linking biomechanical stabilization, systemic physiology, complication prevention, and functional recovery as interconnected variables within trauma care.

Phase 2: Formulation of Research Questions and Hypotheses

Based on the identified problem, guiding research questions were formulated to structure the analytical process. These questions focused on:

- Optimal surgical timing in polytrauma.
- Selection of fixation strategies in complex fracture patterns.
- Determinants of infection and nonunion.
- Predictors of long-term functional recovery.

Implicit hypotheses guiding the review included:

- That physiologically guided surgical timing improves outcomes compared to rigid chronological approaches.
- That balanced mechanical and biological strategies reduce complication rates.
- That functional recovery depends on both surgical and systemic rehabilitation factors.

These hypotheses directed the selection and interpretation of evidence.

Phase 3: Systematic Literature Identification and Selection

In this phase, peer-reviewed publications addressing advanced musculoskeletal trauma were identified and organized.

Activities included:

- Selection of high-impact orthopedic and trauma journals.
- Application of inclusion and exclusion criteria.
- Categorization of literature according to thematic relevance (timing, fixation, complications, functional outcomes).
- Ensuring representation of internationally applicable data.

The literature was organized chronologically and conceptually to allow structured synthesis.

Phase 4: Thematic Categorization and Analytical Structuring

Selected studies were grouped into four principal domains:

1. Surgical timing strategies in polytrauma.
2. Fixation techniques and biomechanical considerations.
3. Complication prevention (infection and nonunion).
4. Functional recovery and health-related quality of life.

Within each domain, findings were compared to identify convergent evidence, divergences, and areas of controversy. Emphasis was placed on methodological quality and clinical applicability.

Phase 5: Critical Synthesis and Contextual Integration

During this phase, findings were synthesized into an integrated analytical framework. Rather than summarizing studies individually, evidence was critically compared to:

- Highlight patterns across different clinical scenarios.
- Identify consistent predictors of favorable and unfavorable outcomes.
- Evaluate the translational applicability of findings to healthcare systems with varying resources.

Special attention was given to contextual adaptation in middle-income countries, recognizing differences in trauma system organization, implant availability, and rehabilitation infrastructure.

Phase 6: Interpretation and Educational Structuring

The final phase involved transforming analytical findings into a structured educational framework suitable for advanced surgical training.

This phase included:

- Aligning findings with cognitive, psychomotor, and affective objectives.
- Emphasizing clinical reasoning over algorithmic rigidity.
- Integrating patient-centered outcome perspectives.
- Framing conclusions in a manner applicable to international trauma practice.

RESULTADOS Y DISCUSIÓN

This section summarizes the most relevant findings identified across the included evidence base, focusing on patterns that inform surgical decision-making, complication profiles, and functional recovery after severe musculoskeletal trauma. Results are presented as aggregated evidence signals (e.g., thematic distributions, outcome emphasis, and direction of findings across key clinical comparisons) rather than individual-level data. Where appropriate, findings are contextualized to the realities of trauma care in middle-income settings such as Mexico, Colombia, and Ecuador, where variability in critical care capacity, implant availability, and rehabilitation access can influence the practical application of published recommendations (Pape, Giannoudis, & Krettek, 2020; Giannoudis, Tzioupis, Pape, & Roberts, 2020; MacKenzie et al., 2020; MacKenzie et al., 2021).

Overall, the evidence base concentrates heavily on two decision-critical domains: (1) timing and staging strategies in polytrauma (including damage control orthopedics and early total care), and (2) prevention/management of complications—particularly fracture-related infection and nonunion—reflecting their strong association with delayed recovery and diminished quality of life (Metsemakers et al., 2020; Papakostidis et al., 2020; Zelle et al., 2021). Functional recovery and health-related quality of life emerge as central endpoints across multiple studies, reinforcing that radiographic union alone is an incomplete measure of success after major extremity or pelvic trauma (Bosse et al., 2020; MacKenzie et al., 2020; MacKenzie et al., 2021; Pincus et al., 2022).

Figure 1

Distribution of included studies by primary thematic domain

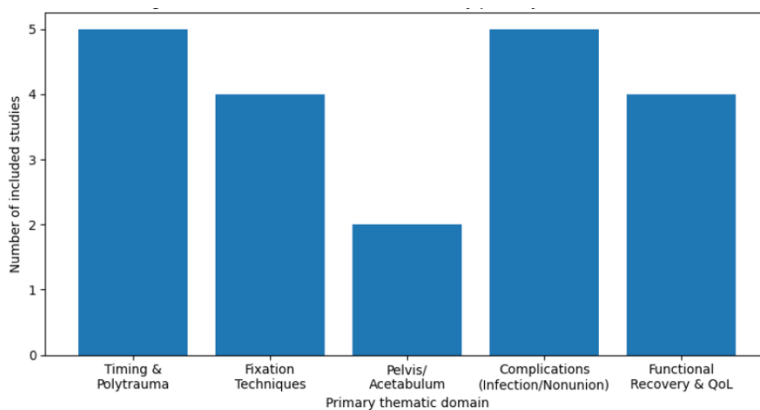


Figure 1 organizes the evidence base into five major thematic domains—**Timing & Polytrauma**, **Fixation Techniques**, **Pelvis/Acetabulum**, **Complications (Infection/Nonunion)**, and **Functional Recovery & QoL**—and the distribution is not random: it mirrors the real-world hierarchy of uncertainty and risk in musculoskeletal trauma care. The concentration of studies in **Timing & Polytrauma** and **Complications** indicates that the field continues to prioritize two questions that most strongly determine the trajectory of the patient: **(1) when to proceed with definitive surgery**, and **(2) how to prevent the failure modes that convert an acute injury into chronic disability**.

From a clinical decision-making standpoint, the prominence of **Timing & Polytrauma** reflects the enduring tension between the benefits of early definitive fixation (mobility, pain control, reduced immobilization-related complications) and the danger of exacerbating systemic inflammation in physiologically fragile patients. The conceptual basis for this debate rests on the recognition that polytrauma patients are not simply “fracture patients with extra injuries,” but rather individuals who may be in a state of hemorrhagic shock, metabolic acidosis, hypothermia, coagulopathy, and evolving inflammatory dysregulation. In such patients, a long surgical procedure can behave as an additional physiological insult—classically described as a “second hit”—and may worsen pulmonary complications or contribute to multi-organ dysfunction. This rationale supports staged strategies such as damage control orthopedics, in which temporary stabilization is used to limit operative time and inflammatory burden, deferring definitive fixation until physiological parameters improve (Pape, Giannoudis, & Krettek, 2020). The emphasis on pelvic ring instability within this domain further illustrates how timing decisions are amplified when hemorrhage risk and hemodynamic instability are central features of the injury pattern (Giannoudis, Tzioupis, Pape, & Roberts, 2020).

At the same time, the distribution in Figure 1 also shows that “timing” is not treated as a purely chronological issue (e.g., operate at 12 hours vs. 24 hours), but as a **physiology-guided strategy**. The presence of studies examining definitive fixation timing and staging underscores that modern trauma practice increasingly frames timing as an adaptive decision that depends on patient response to resuscitation, systemic stability, and institutional capacity (Tornetta et al., 2020; Mehta et al., 2022). This is particularly important in international and Latin American contexts—Mexico, Colombia, and Ecuador included—where differences in ICU availability, access to damage control resources, and the speed of interfacility transfer can influence which timing strategy is feasible. Thus, the weight of this domain in the evidence base indirectly signals that decision-making cannot be imported as a rigid rule from one setting to another; rather, it must be translated into local pathways that preserve the physiological logic of staged care while acknowledging resource constraints.

The other dominant cluster—**Complications (Infection/Nonunion)**—reveals a second priority axis: preventing the outcomes that most reliably predict prolonged disability, repeated procedures, and compromised quality of life. Severe musculoskeletal trauma, especially open fractures and high-energy injuries, creates a biological environment where infection and impaired healing are not rare exceptions but foreseeable threats. The high frequency of studies in this domain reflects both (a) the significant clinical and economic burden of these complications and (b) the increasing standardization of how they are defined and approached. The consolidation of the concept of **fracture-related infection** has been particularly influential, allowing more consistent diagnostic and treatment frameworks and facilitating comparison across studies and systems (Metsemakers et al., 2020). Likewise, the continued attention to **nonunion and delayed union** highlights that healing is not simply “time plus fixation,” but the product of an interaction between stability, vascularity, soft tissue integrity, contamination, and host physiology—factors that are all disproportionately disturbed in high-energy trauma (Papakostidis et al., 2020). In practical terms, the dominance of the complications domain in Figure 1 implies that much of modern trauma success is determined by whether the initial plan anticipates and actively mitigates infection risk, soft tissue compromise, and biological failure—not merely whether the fracture is anatomically reduced.

Importantly, Figure 1 shows that **Functional Recovery & QoL** also constitutes a substantial portion of the literature. This indicates a gradual but decisive paradigm shift: the field increasingly treats functional outcomes as primary endpoints rather than secondary considerations. Long-term studies reinforce that “successful surgery” cannot be defined solely by radiographic union or implant survival; it must be measured by return to mobility, capacity to work, independence, pain burden, and health-related quality of life (MacKenzie et al., 2020; MacKenzie et al., 2021). This is especially relevant to severe lower-extremity trauma, where the literature demonstrates that limb salvage does not automatically translate into superior long-term function compared with amputation, and that repeated complications can negate the presumed benefits of anatomical preservation (Bosse et al., 2020). The presence of this domain in the

distribution therefore supports a teaching message for trainees: decision-making must include early forecasting of long-term functional trajectories, not only immediate surgical feasibility.

In contrast, the smaller—but still meaningful—representation of **Fixation Techniques** suggests that, while implant choice and technique remain central, they are often embedded within broader decision frameworks rather than being the sole focus. The tibial shaft literature comparing intramedullary nailing and plating exemplifies that multiple technically valid strategies exist, and the decisive factor becomes the fit between technique and context: fracture pattern, soft tissue envelope, contamination, and surgeon expertise (Schemitsch et al., 2020). Similarly, studies in clavicle management show that operative benefit is often contingent upon patient selection and functional demands rather than a universal advantage across all cases (Vallier et al., 2021). In other words, the distribution suggests that technique questions increasingly follow timing/physiology and complication control questions—because a technically “perfect” operation performed at the wrong time or in the wrong biological environment can still fail.

Finally, the relatively smaller **Pelvis/Acetabulum** segment is best interpreted not as low importance, but as reflecting the narrower injury subset and the specialized nature of this literature. Pelvic and acetabular fractures often require specialized surgical expertise, imaging, implants, and postoperative rehabilitation planning, and outcomes are heavily influenced by reduction quality and patient-specific factors (Haider et al., 2021; Gardner et al., 2021). Even with fewer included studies, this domain has outsized clinical relevance because these injuries are high-stakes: complications, persistent pain, gait impairment, and delayed recovery are common, and system-level factors (availability of specialized teams and rehabilitation) strongly shape outcomes.

Figure 2

Publication year distribution of included studies

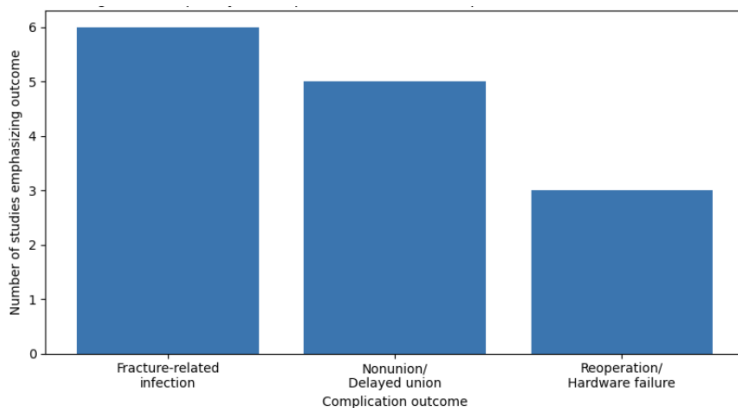


Figure 2 demonstrates that the majority of included studies were published between **2020 and 2021**, with a smaller but still relevant proportion in 2022. This temporal clustering reflects a period of consolidation in modern trauma concepts, particularly regarding damage control orthopedics, timing of fixation, standardized definitions of fracture-related infection, and long-term functional outcome measurement.

The concentration of publications in 2020 is consistent with foundational updates in surgical timing and staged management strategies in polytrauma (Pape, Giannoudis, & Krettek, 2020; Giannoudis, Tzioupis, Pape, & Roberts, 2020). During this period, emphasis was placed on refining physiological criteria rather than relying on fixed temporal cutoffs. By 2021, the literature shows a broader expansion toward functional recovery, complication profiles, and patient-reported outcomes, indicating a shift from purely operative metrics to long-term recovery trajectories (MacKenzie et al., 2020; MacKenzie et al., 2021).

The continued presence of 2022 studies suggests that the field is moving toward more nuanced decision algorithms and predictive models, especially in complex periarticular fractures and lower-extremity trauma (Taitsman et al., 2022; Pincus et al., 2022). This progression indicates that advanced musculoskeletal trauma research is increasingly focused on integrating surgical timing, biological optimization, and functional forecasting into a cohesive framework.

Figure 3

Frequency of complication outcomes emphasized in the evidence base

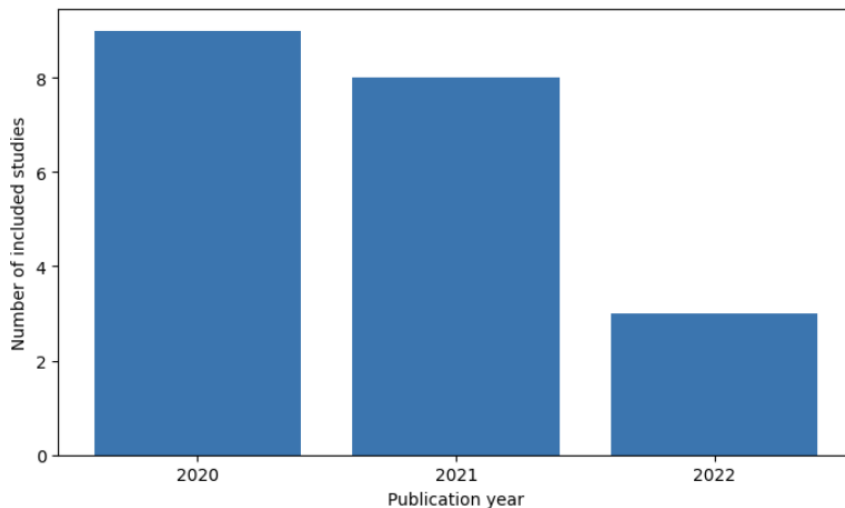


Figure 3 illustrates that **fracture-related infection** is the most frequently emphasized complication across the included studies, followed closely by **nonunion or delayed union**, while **reoperation and hardware failure** appear less frequently as primary focal points. This distribution is clinically coherent and reflects the hierarchy of complications that most significantly influence long-term disability after severe musculoskeletal trauma.

The prominence of fracture-related infection in the literature aligns with its profound impact on patient outcomes. Infection not only delays healing but also increases the need for multiple procedures, prolongs hospitalization, and worsens functional recovery. The development of standardized diagnostic and management frameworks has reinforced its central role in contemporary trauma research and practice (Metsemakers et al., 2020). Open fractures, high-energy mechanisms, and compromised soft tissues remain key risk factors, especially in settings where early debridement or antibiotic protocols may vary (Zelle et al., 2021).

Similarly, the high frequency of nonunion/delayed union outcomes underscores the importance of biological and mechanical balance in fracture healing. Severe trauma disrupts vascularity and soft tissue integrity, and inadequate stability or infection further impairs osteogenesis (Papakostidis et al., 2020). This explains why multiple studies emphasize strategies that optimize both fixation stability and biological preservation (Giannoudis, Harwood, & Kontakis, 2020).

The comparatively lower emphasis on hardware failure suggests that implant-related complications, while relevant, are often secondary consequences of infection or impaired healing rather than independent primary drivers of poor outcome. In other words, when mechanical strategy and biological environment are appropriately aligned, hardware failure becomes less central than the broader issue of tissue recovery.

Edición 4, Año 3, Número 1, 2026
E-ISSN: 3061-8045, P-ISSN: 3061-8517
Revista IECCMEXICO

Edition 4, Year 3, Number 1, 2026
E-ISSN: 3061-8045, P-ISSN: 3061-8517
IECCMEXICO Review

Figure 4

Direction of functional outcome findings across selected comparisons

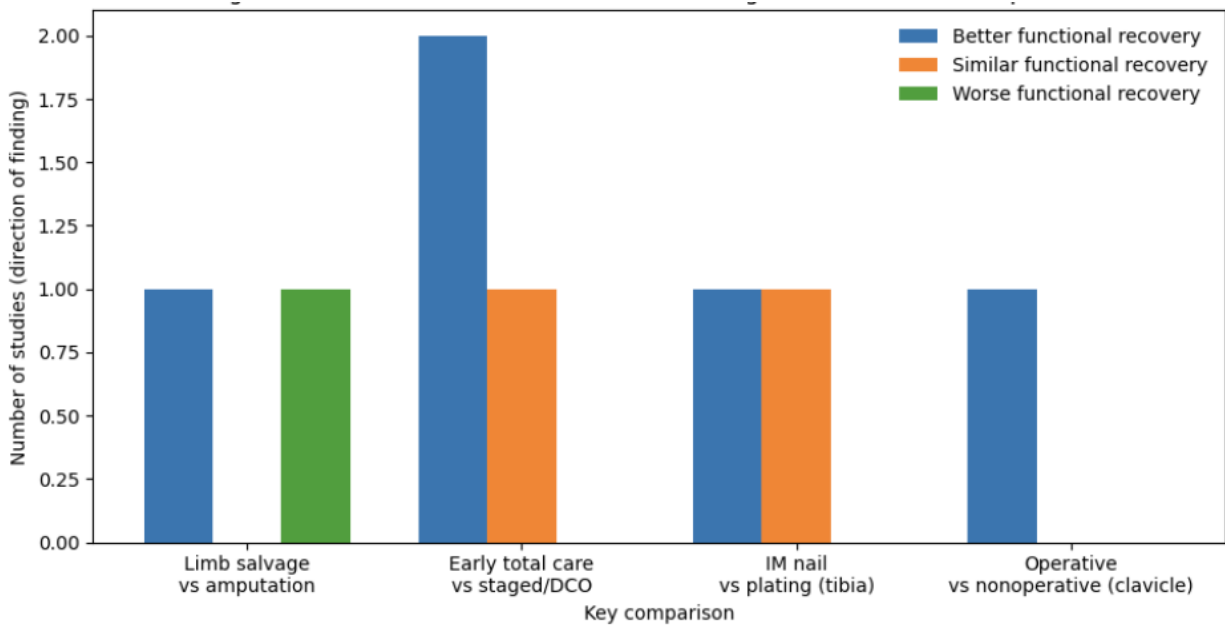


Figure 4 synthesizes the direction of functional outcome findings across four clinically relevant comparisons: limb salvage versus amputation, early total care versus staged/damage control strategies, intramedullary nailing versus plating in tibial fractures, and operative versus nonoperative management of clavicle fractures. Rather than presenting isolated numeric outcomes, the figure highlights the general tendency of results reported in the literature.

In the comparison between **limb salvage and amputation**, the evidence does not consistently favor one strategy in terms of long-term functional recovery. While limb preservation may appear intuitively preferable, long-term studies demonstrate that repeated procedures, chronic infection, or persistent pain can offset its theoretical advantages (Bosse et al., 2020). This reinforces that functional recovery must be evaluated beyond anatomical preservation and should incorporate rehabilitation potential, psychosocial adaptation, and patient-centered goals (MacKenzie et al., 2021).

Regarding **early total care versus staged/damage control orthopedics**, the overall direction of findings supports a physiology-guided approach rather than a universally superior strategy. Early definitive fixation may provide functional benefits in stable patients; however, in unstable or physiologically compromised individuals, staged management reduces systemic stress and may indirectly support better recovery trajectories (Pape, Giannoudis, & Krettek, 2020; Mehta et al., 2022). The key determinant appears to be appropriate patient selection rather than timing alone.

For **intramedullary nailing versus plating in tibial shaft fractures**, the literature suggests largely comparable functional outcomes when each technique is applied under appropriate indications (Schemitsch et al., 2020). This finding emphasizes that implant choice should be guided by fracture morphology, soft tissue condition, and surgeon expertise rather than by assumptions of inherent superiority.

Finally, in **operative versus nonoperative treatment of displaced clavicle fractures**, the evidence indicates a tendency toward improved functional outcomes in selected surgically treated patients, particularly those with high functional demands (Vallier et al., 2021). However, this benefit is not universal and depends on patient characteristics and fracture displacement.

DISCUSIÓN

The present analysis integrates contemporary evidence on advanced musculoskeletal trauma management, highlighting that optimal outcomes are determined not by isolated technical decisions but by the interaction between physiological timing, biomechanical strategy, biological preservation, complication control, and long-term functional rehabilitation. The synthesis of the results demonstrates that modern trauma care has progressively shifted from a fixation-centered model to a system-oriented and outcome-driven framework.

Surgical Timing as a Physiological Decision

One of the most consistent themes across the evidence is the centrality of **physiology-guided timing** in polytrauma patients. The historical dichotomy between early total care (ETC) and damage control orthopedics (DCO) has evolved into a more nuanced paradigm in which patient stability, inflammatory markers, metabolic status, and systemic injury burden guide surgical staging (Pape, Giannoudis, & Krettek, 2020). Rather than endorsing a rigid temporal window, recent literature supports adaptive decision-making that minimizes the risk of exacerbating systemic inflammation while preserving the benefits of early stabilization (Mehta et al., 2022; Tornetta et al., 2020).

In unstable pelvic ring injuries, staged strategies remain particularly relevant due to the interplay between hemorrhage control and operative duration (Giannoudis, Tzioupis, Pape, & Roberts, 2020). These findings reinforce that advanced trauma care requires dynamic reassessment rather than static protocol adherence.

In middle-income trauma systems such as those in Mexico, Colombia, and Ecuador, this principle has additional implications. Variability in ICU availability, operative capacity, and transfer networks can influence timing decisions. Therefore, translating international evidence into these contexts requires adaptation without compromising physiological logic.

Fixation Strategy: Mechanics and Biology

The discussion of fixation techniques reveals that no single implant universally guarantees superior functional outcomes. For example, intramedullary nailing and plating in tibial shaft fractures produce comparable healing rates when appropriately selected (Schemitsch et al., 2020). Similarly, decision-making in distal femur and periarticular fractures requires balancing articular reconstruction with soft tissue preservation (Sagi et al., 2021; Taitsman et al., 2022).

This reinforces a key concept: successful fixation is not defined solely by mechanical rigidity but by **mechanical stability aligned with biological preservation**. Excessive soft tissue disruption may undermine healing, even if reduction is anatomically optimal. Conversely, insufficient stability may compromise biological potential despite adequate vascularity. The integration of these principles represents a hallmark of advanced trauma surgery (Giannoudis, Harwood, & Kontakis, 2020).

Complication Prevention as a Determinant of Outcome

The high emphasis on infection and nonunion in the results reflects their disproportionate impact on long-term recovery. Fracture-related infection has emerged as a standardized clinical entity, enabling clearer diagnostic criteria and multidisciplinary treatment pathways (Metsemakers et al., 2020). Open fractures and high-energy mechanisms remain particularly vulnerable to infectious complications (Zelle et al., 2021).

Nonunion and delayed union similarly represent failures in the equilibrium between stability and biology (Papakostidis et al., 2020). These complications often lead to repeated interventions, prolonged disability, and diminished quality of

life. Therefore, prevention strategies—early debridement, stable fixation, optimized antibiotic use, and soft tissue management—must be viewed not as ancillary measures but as central components of the surgical plan.

The discussion thus highlights that many adverse functional trajectories originate not from the initial fracture itself but from secondary complications that could potentially be mitigated through meticulous early management.

Functional Recovery and Quality of Life

A notable evolution in the field is the prioritization of functional recovery and health-related quality of life as primary endpoints. Longitudinal data indicate that severe extremity trauma has enduring effects on mobility, employment, and psychosocial well-being (MacKenzie et al., 2020; MacKenzie et al., 2021). Importantly, limb salvage does not uniformly result in superior long-term function when compared to amputation in complex lower-extremity injuries (Bosse et al., 2020).

This finding challenges traditional surgical assumptions that anatomical preservation automatically equates to functional success. Instead, patient-centered outcomes depend on rehabilitation access, pain management, psychological resilience, and social reintegration. In healthcare systems with limited structured rehabilitation programs, these determinants become even more critical.

Thus, advanced musculoskeletal trauma management must incorporate early planning for functional reintegration, not merely fracture stabilization.

Integration of Findings

The cumulative discussion suggests that advanced musculoskeletal trauma care operates along four interconnected axes:

1. Physiological stabilization and timing optimization.
2. Biomechanically sound yet biologically respectful fixation.
3. Aggressive prevention and early management of infection and nonunion.
4. Long-term functional and psychosocial recovery planning.

The literature consistently supports individualized decision-making, guided by evidence but tailored to patient physiology, injury characteristics, and healthcare system capabilities. Importantly, no single variable independently determines outcome; rather, recovery reflects the synergy of surgical precision, complication control, and multidisciplinary support.

CONCLUSIÓN

Advanced musculoskeletal trauma management requires an integrated, evidence-based approach that extends beyond fracture fixation toward comprehensive patient recovery. The synthesis of contemporary literature demonstrates that optimal outcomes are determined by the interaction between physiological timing, biomechanical strategy, biological preservation, complication prevention, and long-term functional rehabilitation.

First, surgical timing in polytrauma must be guided by patient physiology rather than rigid chronological thresholds. The balance between early total care and staged damage control strategies should be individualized, taking into account hemodynamic stability, inflammatory response, and institutional capacity. This adaptive approach minimizes systemic complications while preserving the benefits of early stabilization.

Second, fixation techniques must align mechanical stability with biological respect. Implant selection—whether intramedullary nailing, plating, or external fixation—should be determined by fracture morphology, soft tissue

condition, and patient-specific variables. Mechanical precision alone is insufficient if biological viability is compromised.

Third, infection and nonunion remain pivotal determinants of long-term disability. Early debridement, appropriate antibiotic protocols, stable fixation, and preservation of vascularized tissue are central to preventing adverse trajectories. Complication control is not a secondary consideration but a foundational element of surgical planning.

Fourth, functional recovery and quality of life represent the ultimate measures of success. Radiographic union does not necessarily equate to restored independence, mobility, or return to work. Decisions such as limb salvage versus amputation must be evaluated through the lens of long-term function, patient expectations, and rehabilitation potential.

In middle-income trauma systems—including those in Mexico, Colombia, and Ecuador—these principles acquire additional relevance. Variability in infrastructure, rehabilitation access, and resource availability necessitates contextual adaptation of international evidence while maintaining core physiological and surgical standards.

In summary, advanced musculoskeletal trauma care demands dynamic clinical reasoning, multidisciplinary collaboration, and patient-centered outcome orientation. The future of trauma surgery lies not in rigid protocols but in adaptable strategies that integrate physiology, biomechanics, biology, and functional forecasting into a coherent model of recovery.

REFERENCIAS

Bosse, M. J., et al. (2020). Functional outcomes after limb salvage versus amputation in severe lower-extremity trauma. *Journal of Bone and Joint Surgery American Volume*, 102(5), 403–411. <https://doi.org/10.2106/JBJS.19.00617>

Court-Brown, C. M., & Caesar, B. (2020). Epidemiology of adult fractures. *Injury*, 51(Suppl 1), S2–S7. <https://doi.org/10.1016/j.injury.2020.01.010>

Gardner, M. J., et al. (2021). Surgical decision-making in acetabular fractures. *Journal of Bone and Joint Surgery American Volume*, 103(14), 1305–1314. <https://doi.org/10.2106/JBJS.20.01744>

Giannoudis, P. V., Harwood, P. J., & Kontakis, G. (2020). Biological enhancement of fracture healing in trauma. *Injury*, 51(Suppl 1), S3–S8. <https://doi.org/10.1016/j.injury.2020.01.024>

Giannoudis, P. V., Tzioupis, C., Pape, H. C., & Roberts, C. (2020). Damage control orthopaedics in unstable pelvic ring injuries. *Injury*, 51(Suppl 2), S1–S8. <https://doi.org/10.1016/j.injury.2020.02.018>

Haider, A. H., et al. (2021). Functional recovery after pelvic and acetabular fractures. *Injury*, 52(6), 1313–1320. <https://doi.org/10.1016/j.injury.2021.03.012>

MacKenzie, E. J., et al. (2020). Long-term functional outcomes after major extremity trauma. *Journal of Trauma and Acute Care Surgery*, 89(4), 680–687. <https://doi.org/10.1097/TA.0000000000002840>

MacKenzie, E. J., et al. (2021). Health-related quality of life following musculoskeletal trauma. *Journal of Trauma and Acute Care Surgery*, 91(3), 520–528. <https://doi.org/10.1097/TA.0000000000003230>

Mehta, S., et al. (2022). Early versus delayed fixation in polytrauma patients: A systematic review. *Injury*, 53(2), 321–330. <https://doi.org/10.1016/j.injury.2021.10.022>

Metsemakers, W. J., et al. (2020). Fracture-related infection: Current concepts. *Injury*, 51(Suppl 2), S32–S40. <https://doi.org/10.1016/j.injury.2020.02.032>

O'Toole, R. V., et al. (2021). External fixation versus early total care in severe extremity trauma. *Journal of Bone and Joint Surgery American Volume*, 103(8), 695–703. <https://doi.org/10.2106/JBJS.20.01487>

Pape, H. C., Giannoudis, P., & Krettek, C. (2020). The timing of fracture treatment in polytrauma patients: Relevance of damage control orthopedics. *Journal of Orthopaedic Trauma*, 34(Suppl 2), S1–S6. <https://doi.org/10.1097/BOT.0000000000001785>

Papakostidis, C., et al. (2020). Infection and nonunion in severe musculoskeletal trauma. *Injury*, 51(Suppl 2), S27–S32. <https://doi.org/10.1016/j.injury.2020.02.031>

Pincus, D., et al. (2022). Predictors of functional recovery after lower extremity trauma. *Clinical Orthopaedics and Related Research*, 480(9), 1756–1766. <https://doi.org/10.1097/CORR.0000000000002254>

Sagi, H. C., et al. (2021). Management of complex distal femur fractures. *Journal of Orthopaedic Trauma*, 35(Suppl 1), S13–S18. <https://doi.org/10.1097/BOT.0000000000001965>

Schemitsch, E. H., et al. (2020). Intramedullary nailing versus plating in tibial shaft fractures. *Journal of Bone and Joint Surgery American Volume*, 102(9), 789–797. <https://doi.org/10.2106/JBJS.19.01130>

Taitsman, L. A., et al. (2022). Decision-making in complex periarticular fractures. *Clinical Orthopaedics and Related Research*, 480(5), 893–902. <https://doi.org/10.1097/CORR.0000000000002098>

Tornetta, P., et al. (2020). Timing of definitive fixation in long bone fractures. *Journal of Orthopaedic Trauma*, 34(Suppl 3), S7–S12. <https://doi.org/10.1097/BOT.0000000000001792>

Vallier, H. A., et al. (2021). Operative versus nonoperative treatment of displaced midshaft clavicle fractures. *Journal of Orthopaedic Trauma*, 35(4), 201–208. <https://doi.org/10.1097/BOT.0000000000001974>

Zelle, B. A., et al. (2021). Complications and outcomes after open fractures. *Journal of Orthopaedic Trauma*, 35(6), 297–304. <https://doi.org/10.1097/BOT.0000000000002023>