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Update on Non-surgical Treatments for Lumbar Pain
Instability Prevention and Treatment inTotal Hip Replacement
Sarcopenia in Senior Subjects with Hip Fracture: Study of Prevalence, Correlation with Obesity, and Ultrasonography of the Rectus Femoris Muscle
Reverse Posterior Interosseous Artery Flap: Indications, Technique, and Complications in 18 Consecutive Cases
Arthroplasty in Thumb (CMC Joint) Osteoarthritis: Avoiding Trapeziectomy
Fat Harvesting for Micro-Fragmented Adipose Tissue Injections: A Pilot Study Comparing Safety in Procedures Performed by Orthopedic and Plastic Surgeons
Value of Clinical Tests in Diagnosing Anterior Cruciate Ligament Tears: What Is New?
Does Arterial Blood Gas Analysis Predict an Adverse Course in Patients Admitted with Isolated Diaphyseal Femur Fractures?
Mobile-Bearing versus Fixed-Bearing Total Knee Arthroplasty: A Comparative Analysis of Long- Term Clinical and Implant Survival Outcomes
Lesser Metatarsals Load after Minimally-Invasive Surgery for Hallux Valgus Correction: A Finite Element Model
Underweight Patients with Low Bone Density are at Greater Risk of Intraoperative Fracture during Hemiarthroplasty
The Pencil Fulcrum Technique: A Simple Method for Closed Reduction of Extra-Octave Fractures in Children

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André Wan Wen Tsai, Márcio Fin, Ibrahim Afrânio Willi Liu, Rosana Fontana, Sérgio Mendonça Melo Junior, Jose Eduardo Nogueira Forni

Hip

Instability Prevention and Treatment inTotal Hip Replacement
Bruno Alves Rudelli, Fabio Seiji Mazzi Yamaguchi, Marco Rudelli, Lucas Torres Oliveira, Helder de Souza Miyahara, Henrique Melo de Campos Gurgel

Original Articles

Hip

Sarcopenia in Senior Subjects with Hip Fracture: Study of Prevalence, Correlation with Obesity, and Ultrasonography of the Rectus Femoris Muscle
Maurício Rodrigues Miyasaki, Juliano Casonatto, Carolina Morgato de Mello Miyasaki, Bruno Leguizamón Baruki, Yano Altomar de Sá, Rodrigo Antonio Carvalho Andraus

Hand

Reverse Posterior Interosseous Artery Flap: Indications, Technique, and Complications in 18 Consecutive Cases
Alvaro Baik Cho, Antonio Isidoro de Sousa Neto, Kríssia Caroline Soares Franco, Marcelo Rosa de Rezende, Teng Hsiang Wei, Rames Mattar Junior

Arthroplasty in Thumb (CMC Joint) Osteoarthritis: Avoiding Trapeziectomy
Marcio Aurelio Aita, Giulia Cordeiro Aita, Cleyton Rocha, Sullivan Savaris, Mauricio Leite, Samuel Pajares Cabanilla

Knee

Fat Harvesting for Micro-Fragmented Adipose Tissue Injections: A Pilot Study Comparing Safety in Procedures Performed by Orthopedic and Plastic Surgeons
Bruno Butturi Varone, Rodrigo Bernstein Conde, Chilan B. G. Leite, Pedro Nogueira Giglio, Riccardo Gomes Gobbi, Marco Kawamura Demange

Value of Clinical Tests in Diagnosing Anterior Cruciate Ligament Tears: What Is New?
Long Thanh Nguyen, Son Van Truong, Uyen Thi Phuong Nguyen

Trauma

Does Arterial Blood Gas Analysis Predict an Adverse Course in Patients Admitted with Isolated Diaphyseal Femur Fractures?
D. Sidharth, Thatchinamoorthy Santhamoorthy, Anish Anto Xavier, Lalithambigai Chellamuthu, S. Ahilan

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Knee

Mobile-Bearing versus Fixed-Bearing Total Knee Arthroplasty: A Comparative Analysis of Long-Term Clinical and Implant Survival Outcomes

Pablo Agustín Ramos Guarderas, Pablo David Ramos Murillo, Carlos Patricio Peñaherrera Carrillo, Francisco Endara Urresta, Daniel Alejandro Ramos Murillo, Alejandro Xavier Barros Castro

Foot and Ankle

Lesser Metatarsals Load after Minimally-Invasive Surgery for Hallux Valgus Correction: A Finite Element Model

Henrique Mansur, Bruno Abdo, Gabriel Ferraz Ferreira, Miguel Viana Pereira Filho, Roberto Zambelli, Gustavo Araújo Nunes

Trauma

Underweight Patients with Low Bone Density are at Greater Risk of Intraoperative Fracture during Hemiarthroplasty

Jun Takeuchi

Technical Note

Pediatric Orthopedics

The Pencil Fulcrum Technique: A Simple Method for Closed Reduction of Extra-Octave Fractures in Children

Vivek M. Sodhai, Darshan Munot, Rahul Jaiswal, Sandeep Patwardhan

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Update on Non-surgical Treatments for Lumbar Pain

Atualização sobre os tratamentos não cirúrgicos para a dor lombar

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Abstract

Low back pain (LBP) is a very prevalent clinical condition worldwide. Approximately 90% of the cases are of nonspecific LBP, due to the lack of anatomopathological changes as potential causes of pain. A more assertive therapeutic approach requires identifying red or yellow flags and diagnosing the pain pattern (nociceptive, neuropathic, nociplastic, or mixed pain). Acute LBP prognosis is favorable in most cases, and the therapeutic objective is to prevent chronicity. For chronic LBP, the goals include pain reduction and improvements in functionality and quality of life. In acute and chronic cases, the principle of multimodal analgesia guides the treatment, which combines pharmacological, non-pharmacological, and interventional methods. The most common medications for LBP are simple analgesics, such as paracetamol, muscle relaxants, nonsteroidal antiinflammatory drugs (NSAIDs), and opioid analgesics. Opioids and NSAIDs should be prescribed at the lowest dose and for the shortest possible time. Patients with neuropathic components may receive adjuvant drugs. Phytocannabinoids may play a role when the previous pharmacological treatment fails. Physical methods, including heat, laser, and extracorporeal shock wave therapy, improve local circulation, produce muscle relaxation, and treat the myofascial component. Interventions such as acupuncture and radiofrequency promote peripheral and/or central neuromodulation. Aligning the patient's expectations to the outcomes of the proposed treatments is essential; to do so, we must consider the educational measures, behavioral therapies, and physical rehabilitation.

Keywords
- analgesia
- conservative treatment
- low back pain
- multimodal treatment
- musculoskeletal pain

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Resumo

A dor lombar (DL) é condição clínica muito prevalente no mundo. Cerca de 90% dos casos são classificados como lombalgias inespecíficas, pois não há alterações anatomopatológicas que justifiquem sua dor. Para uma abordagem terapêutica mais assertiva, é preciso identificar as bandeiras vermelhas ou amarelas, bem como diagnosticar o padrão de dor (nociceptiva, neuropática, nociplástica ou mista) desses pacientes. Nas lombalgias agudas, a evolução natural é favorável na maioria das vezes, e o objetivo do tratamento é evitar a sua cronificação. Nos casos das lombalgias crônicas, visamos a diminuição da dor, e a melhora da funcionalidade e da qualidade de vida. Tanto nos casos agudos quanto crônicos, guiamos nossas condutas pelo princípio da analgesia multimodal, que combina medidas farmacológicas, não farmacológicas e intervencionistas contra a dor. Entre os medicamentos mais utilizados estão analgésicos simples, como o paracetamol, relaxantes musculares, anti-inflamatórios não esteroidais (AINEs) e os analgésicos opioides. Os AINEs e os opioides, quando indicados, devem ser prescritos na menor dose e pelo menor tempo possível. As medicações adjuvantes estão indicadas na presença do componente neuropático. Os fitocanabinoides são possibilidade quando as drogas anteriores falham. Medidas físicas, como calor, laser e terapia de ondas de choque extracorpórea, melhoram a circulação local, produzem relaxamento muscular e tratam o componente miofascial. Intervenções como acupuntura e radiofrequência promovem neuromodulação periférica e/ou central. Alinhar a expectativa do paciente aos resultados dos tratamentos propostos é fundamental; para isso, devemos considerar as medidas educacionais, terapias comportamentais e a reabilitação física.

Palavras-chave

- analgesia
- dor lombar
- dor musculoesquelética
- tratamento conservador
- tratamento multimodal

Introduction

Low back pain (LBP) is one of the most common reasons for patients to seek medical care worldwide, and it affects a significant portion of the working-age population. In addition, it is the most common cause of limited physical activity and absenteeism from work.[1] The prevalence of LBP in the American population ranges from 10 to 30%, and 65 to 80% of the population has LBP at some point in their lifetime.[1] In Brazil, the 1-year incidence of LBP in the adult population exceeds 50%. Meanwhile, the incidence of its chronic form ranges from 4.2 to 14.7%, depending on factors such as level of schooling, regional socioeconomic index, obesity, and sedentary lifestyle.[2]

The identification of the precise etiology of LBP is rare; most cases are nonspecific, presenting no anatomopathological abnormalities, such as root compression or systemic disease.[3] Patients with signs and symptoms suggestive of infection, malignancy, fractures, and spinal cord or radicular compression meet the criteria for the so-called *red flags* for LBP, requiring a proper approach with laboratory and imaging tests.[4] In addition to the red flags, it is crucial to evaluate psychological and emotional factors, such as anxiety, depression, catastrophism, kinesiophobia, and professional and personal dissatisfaction, which are predictive factors for chronic LBP (yellow flags).[5]

Moreover, it is essential to identify the different pathophysiological components involving pain (that is, nociceptive, neuropathic, and nociplastic elements), which often present as a mixed LBP picture.[6,7]

Most LBP cases respond to simple measures and do not require additional tests. Patients should be encouraged to resume their activities as soon as the pain allows it. The principle of multimodal analgesia guides the therapeutic approach, including pharmacological, non-pharmacological (physical methods, education, and rehabilitation), and interventional treatments.[8]

Pharmacological Treatment

The LBP pharmacological treatment guidelines derive from studies[9] with severe limitations, including short-term trials and those involving heterogeneous populations. The most commonly-prescribed oral medications for LBP are paracetamol and nonsteroidal antiinflammatory drugs (NSAIDs), muscle relaxants, antidepressants, anticonvulsants, and opioids.[9] These medications have similar efficacy in reducing pain, but they cause different side effects. Regardless of the drug class, evidence[9] indicates good short-term analgesic efficacy and safety, but an unclear long-term efficacy.

Drug selection relies on LBP duration, from acute (< 6 weeks) to subacute (6–12 weeks) and chronic (> 12 weeks), and NSAIDs are prescribed in all stages. With the development of LBP chronicity, we observe a decrease in opioid use and increases in the use of antidepressant and antiepileptic medications[10] (►**Table 1**).

NSAIDs and Simple Analgesic Agents

Evidence suggests a short course of paracetamol or NSAIDs for LBP treatment, avoiding prolonged treatment.[9] A

Table 1 Prevalence of pharmacological class indication based on the progression time of low back pain[10]

N: 22	NSAIDs	Muscle relaxants	Opioids	Paracetamol	Antidepressants	Anticonvulsants
Acute	54.5%	27.2%	36.3%	22.7%	9.1%	4.5%
Subacute	50%	22.7%	18.2%	18.2%	9.1%	4.5%
Chronic	59.1%	22.7%	27.2%	18.2%	27.2%	13.6%
Unclassified	18.2%	NAS	13.6%	9.1%	4.5%	NAS

Abbreviations: N, number of guidelines; NAS, not assessed; NSAIDs, nonsteroidal anti-inflammatory drugs.

systematic review[9] found no significant differences between paracetamol and NSAIDs in LBP relief. However, unlike NSAIDs, paracetamol does not increase the risk of myocardial infarction or gastrointestinal bleeding, and it is a safer option for patients predisposed to these conditions.[9]

Although the literature supporting dipyrone (metamizole) for LBP treatment is scarce, this drug remains widely used in Brazil. However, Sociedade Brasileira de Reumatologia[11] (the Brazilian Society of Rheumatology) recommends dipyrone for LBP treatment.

In a systematic review and meta-analysis, Wewege et al.[12] reported that confidence in the evidence regarding pain intensity reduction with several NSAIDs and analgesics was low or very low. Drugs such as tolperisone, aceclofenac with tizanidine, and pregabalin have shown some efficacy, but with significant uncertainties. Additionally, the analysis[12] indicated that some medications, such as tramadol and its combinations with paracetamol, had an association with a moderately-increased risk of events.

Muscle Relaxants

Muscle relaxants can belong to two groups:[9]

- Antispastics: baclofen, tizanidine, dantrolene, and diazepam. There is no recommendation for their use in nonspecific LBP, and these drugs are often indicated to treat spasticity associated with central nervous system diseases, such as multiple sclerosis. It is better to avoid benzodiazepines due to their potential for addiction.[8,9]
- Antispasmodics: cyclobenzaprine and carisoprodol. Although playing a role in the short-term treatment (2 weeks) for acute conditions, their prolonged use is not recommended.[8,9]

Antidepressants

Tricyclic antidepressants (amitriptyline and nortriptyline) have demonstrated a slight pain reduction in patients with chronic LBP. Selective serotonin reuptake inhibitors have not shown any efficacy superior to placebo for chronic pain. In contrast, serotonin-norepinephrine reuptake inhibitors (venlafaxine and duloxetine) have shown analgesic potential in selected conditions.[9] Tricyclic antidepressants, duloxetine, and venlafaxine are first-line treatments for neuropathic pain.[13]

Anticonvulsants

Gabapentin may be indicated for chronic LBP in selected patients, such as those with spinal stenosis, neurogenic claudication, and radicular pain, especially if the response to the initial treatments was unsatisfactory. Other anticonvulsants, such as carbamazepine, pregabalin, and lamotrigine, have no formal recommendations due to limited evidence. However, for neuropathic pain, gabapentin is the first-line treatment, while pregabalin is the second-line therapy.[13]

Although a systematic review[12] indicated that anticonvulsants may cause moderate pain reduction compared to placebo, the evidence level is considered very low. Even so, they were superior to other therapeutic classes[12] (►**Fig. 1**).

Opioids

Short-term opioid therapy may be indicated for the management of severe acute LBP, as supported by the literature. However, prolonged use requires care and strict supervision with the goals of patient rehabilitation and the achievement of well-defined therapeutic objectives. Treatment discontinuation should be considered in cases of therapeutic failure or repeated risk behavior, such as substance use disorder.[9] There is a trend towards a reduction in opioid prescriptions as LBP becomes chronic.[10]

Cannabis

Phytocannabinoids modulate pain pathways by activating cannabinoid receptors. Although the pharmacological mechanisms responsible for analgesic effects have not yet been fully understood, recent research has highlighted the anti-inflammatory properties of phytocannabinoids and their impact on pain relief. The literature on the effectiveness of cannabis as an analgesic is p wide.[14] A placebo-controlled review[15] concluded that there is moderate-quality evidence supporting the use of cannabinoids for chronic pain treatment.

Cannabinoid receptors are widely distributed in pain-modulating pathways, including peripheral and central sensory neurons, and they also influence the regulation of emotional responses to noxious and painful stimuli. At the supraspinal level, these receptors modulate the cognitive and emotional components of pain perception in the sensorimotor cortex and amygdala, reducing unpleasant pain-associated sensations. In the periphery, activation of type-1 cannabinoid receptors (CB1) inhibits the transmission of nociceptive stimuli, while activation of type-2 cannabinoid receptors (CB2) located in cutaneous immune cells hinders the release of inflammatory cytokines.[16]

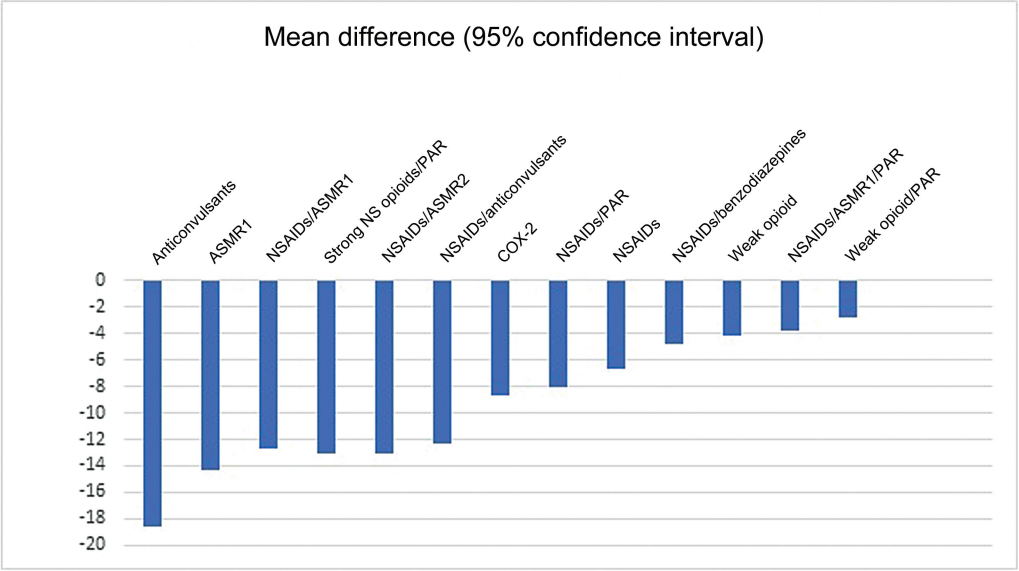


Fig. 1 Comparison of analgesic effects of drug classes with placebo. Lines more to the right are more favorable to placebo interventions. **Abbreviations:** ASMR1, antispasmodic muscle relaxants; ASMR2, antispastic muscle relaxants; COX-2, cyclooxygenase-2 inhibitors; NS, non-selective; NSAIDs, nonsteroidal anti-inflammatory drugs; PAR, paracetamol.[12]

Biological Agents

Animal model studies support the involvement of tumor necrosis factor alpha (TNF-α) in disc herniation, nerve sensitization, and ingrowth, demonstrating the preventive effects of blocking this inflammatory factor. Local TNF-α production is higher in herniated and degenerated discs, motivating clinical studies[17] to evaluate the efficacy of its inhibition in the treatment of discogenic pain in humans. Biological agents block or inhibit crucial steps in inflammation triggering and propagation, with a potential complementary role in LBP and sciatica management, especially when traditional interventions fail. However, despite promising results in preclinical studies, clinical evidence remains inconsistent. A study[17] tested two biological agent classes: anti-TNFs for patients with chronic LBP with radiculopathy and anti-nerve growth factor (NGF) for chronic non-radicular LBP. The quality of systematic reviews is low due to the heterogeneity of the studies. Furthermore, few studies have focused on the direct test of these therapies with other pharmacological options, and further research is required. Tanezumab may have greater effectiveness in pain control and functional improvements in chronic, nonspecific LBP. However, anti-NGF's inconsistent results do not support a recommendation for its use in LBP with no radiculopathy, as the evidence is weak.[17]

Physical Interventions

Heat and superficial cryotherapy increase blood circulation, followed by local cooling, potentially relieving muscle tension and improving joint movement restriction. These techniques demonstrate moderate short-term efficacy in reducing pain and disability in acute and subacute LBP, particularly when associated with physical exercise. However, most studies have limited evidence. For chronic LBP, the evidence on the efficacy of adjunctive thermotherapy (heat) and cryotherapy is insufficient and conflicting regarding the assessment of differences between them.[6,18]

Therapeutic ultrasound (TUS) has not shown efficacy in LBP treatment. Low-quality evidence[19] failed to demonstrate differences between actual and sham ultrasound in reducing pain after treatment at a 4-week follow-up and compared with a control group. Furthermore, there were no significant effects on functional improvement. Evidence remains insufficient in the medium and long terms.[19]

Evidence on transcutaneous electrical nerve stimulation (TENS) is also insufficient to prove efficacy in chronic LBP treatment. Studies with a low level of evidence[20,21] have not identified differences between actual and sham TENS in short-term pain intensity reduction or functional gain.

Low-level laser therapy (LLLT), or photobiomodulation, is the cutaneous application of different light wavelengths to promote biochemical reactions, decreasing local inflammation and pain. For LBP, low-quality evidence[22,23] suggests a small to moderate short-term improvement in pain and a small benefit in function.

In a meta-analysis,[22] high-level laser therapy (HILT) demonstrated a significantly better reduction in pain compared to the control group, in addition to improvements in the Oswestry and Roland-Morris' disability indices. A prospective clinical trial[23] comparing HILT and TUS revealed that HILT led to a statistically significant reduction in pain and disability after treatment and at a 3-month follow-up.

Extracorporeal shock wave therapy (ESWT) uses high-pressure, short-duration mechanical waves followed by a negative pressure stage. This process triggers a mechanotransduction phenomenon, resulting in biological effects on the affected tissue. These effects lead to pain reduction and increase local vascularization, tissue regeneration, and osteogenesis. Studies have indicated ESWT yields benefits for myofascial syndrome, contributing to extracellular matrix

regulation. In a prospective randomized study,[24] ESWT and an exercise program decreased chronic LBP compared to exercise alone within 3 months; however, there was no significant impact on function.

The available evidence[19] was insufficient to prove the efficacy of other physical methods, such as electrical muscle stimulation and short-wave diathermy, in acute and subacute LBP and chronic pain, with or without radiculopathy.

Interventional Methods

Interventional methods are medical procedures used for pain relief and/or diagnostic aid (block test), usually performed under imaging guidance.[25]

In addition to the clinical treatments mentioned herein, specific interventions may be considered based on the structure involved in nonspecific LBP:[25]

a) Discogenic component – more common in younger patients, often under 40 years of age, with exacerbated pain in trunk flexion;
b) Facet component – more frequent in elderly patients over the age of 60 presenting with pain in lumbar hyperextension;
c) Sacroiliac joint components – more prevalent in patients undergoing lumbar spine arthrodesis and presenting with worse pain when remaining seated;
d) Myofascial component – highly-prevalent in musculoskeletal pain, responding well to treatments such as acupuncture.

Acupuncture

Acupuncture is a medical treatment widely used worldwide due to its proven clinical efficacy in several conditions, especially acute and chronic pain, including LBP.[19,26,27] Some mechanisms involved in acupuncture analgesia are well established, including reduced proinflammatory cytokine concentrations at the intervention point, modulation at the level of the posterior horn of the spinal cord, and activation of a descending inhibitory system affecting the serotonergic and the noradrenergic pathways.[27] In addition, the activation of the hypothalamic-pituitary-adrenal axis and the involvement of the endogenous opioid system are also well established. Other mechanisms remain under study,[27] including trigger point inactivation, the endocannabinoid system, mast cell degranulation, and transduction through A1, transient receptor potential cation channel subfamily V member 1 (TRPV1), and transient receptor potential cation channel subfamily V member 2 (TRPV2) adenosine receptors. Several studies[28–30] have demonstrated that acupuncture improves pain and function in LBP compared to the placebo group. Pain relief and improved function are observed, on average, after five sessions, and the best outcomes occur when acupuncture is associated with conventional treatment, whether pharmacological or not.[31]

Radiofrequency and Miscellaneous Blocks

Radiofrequency denervation is an invasive method for chronic nonspecific LBP treatment. Its indications include pain originating from a disc, a facet, or the sacroiliac joint. Although the outcomes are controversial, it is another tool for pain control. Despite the lack of robust scientific evidence on the duration of pain relief, leading experts[32] recommend it as an additional alternative in chronic LBP management.

The main interventions for LBP treatment include facet blocks, discogenic blocks, sacroiliac joint blocks, pulsed and ablative radiofrequency application in facets, and middle branch blocks.

For LBP with a discogenic origin, after diagnosis confirmation by physical examination, imaging tests, and provocative discography, the international literature[33] reports that treatment with intradiscal pulsed radiofrequency has led to good outcomes.

For LBP originating from facet joints, after clinical diagnosis, imaging tests, and confirmation by block test (in which an injection of 0.5 mL of 2% xylocaine into the facet leads to more than 70% of pain improvement), treatment can use joint ablative radiofrequency and pulsed radiofrequency in the medial branch of the spinal nerve.[34–36] Ablative radiofrequencies present better long-term results in pain control.[34–36]

For pain originating from the sacroiliac joint, diagnostic confirmation includes clinical examination, imaging tests, and a block test with 0.5 mL 2% xylocaine injection. With a marked improvement in pain, treatment can use injectable dexamethasone with ropivacaine.[36] However, this procedure leads to short-term pain control. Alternatively, ablative radiofrequency or cryotherapy blockade of the sacroiliac joint may improve pain for a longer period.[37]

Education and Physical and Mental Rehabilitation

Education on musculoskeletal pain aims to provide relevant information about pain and the clinical condition, especially for patients with a higher degree of anxiety, worry, passive behavior, or fear.[38] Guiding patients to change their lifestyle for weight loss and smoking cessation and raising awareness of their role in the treatment increase the rate of good outcomes.[38]

Cognitive-behavioral therapy (CBT) is an approach to chronic musculoskeletal pain with a small to moderate effect on chronic LBP improvement. The goal of CBT is to modify one of the three response systems (behavioral, cognitive, and physiological reactivity). The most promising interventions for physical treatment and rehabilitation in patients with chronic LBP are multidisciplinary treatment or behavioral treatment. All types of behavioral therapy were more effective in reducing pain intensity when compared with the control group. Furthermore, there is some evidence that the addition of behavioral components may decrease time off work and sick leave costs.[20,39]

Another approach, mindfulness, seeks to reduce stress by encouraging the mind to focus on the present moment. Mindfulness may have a small to moderate short-term effect, but a lower medium-term effect over LBP. One study demonstrated that 60% of the patients undergoing this technique presented a 30% improvement compared to baseline values, with clinical significance after 6 months. When compared with the CBT group, 58% of the patients in the mindfulness group improved, as did 44% in the regular care group.[19,39]

Both CBT and mindfulness aim to adjust thoughts and behaviors perpetuating pain. They have a moderate contribution to functional gain, which persisted for up to 2 years.[19,39]

Exercise therapy also significantly reduced pain intensity and disability compared with regular care; the literature reports[20,40] strong evidence for strengthening exercises for the muscles stabilizing the spine and pelvis (the core muscles).

Final Considerations

Low back pain is a highly-prevalent clinical condition in Brazil and worldwide. Specific causes, including fractures, herniated discs, canal stenosis, and systemic diseases, account for less than 10% of all cases.[10,19] Pharmacological treatment is part of the multimodal LBP management regardless of the clinical stage, with a preference for short-term use, especially of NSAIDs and opioids. Some drugs, such as gabapentinoids, tricyclic antidepressants, and dual serotonin and norepinephrine reuptake inhibitors, are the first option in cases of neuropathic pain with LBP.[13]

Cannabis emerges as a treatment option when conventional medications fail. In addition, interventional methods for non-specific LBP treatment represent an additional resource and an adjunct to other pharmacological modalities, aiming at faster and more effective rehabilitation.

Lastly, physical methods, education, and physical and mental rehabilitation for acute and chronic LBP patients play a crucial role.

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Conflict of Interests

The authors have no conflict of interests to declare.

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Instability Prevention and Treatment in Total Hip Replacement

Prevenção e tratamento da instabilidade na artroplastia total do quadril

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Abstract

Instability is a challenging complication and a significant revision cause in hip replacement surgery. The incidence of dislocation ranges from 0.5 to 10% in primary prostheses and can reach up to 30% in revision surgeries. The literature describes several risk factors, including surgeon-, patient-, and implant-related factors. Knowledge of these factors is essential to preventing and managing instability cases. Preventive treatment involves preoperative planning, adequate component positioning, normal hip biomechanics reestablishment, risk factor identification, and proper implant selection. Approximately two thirds of dislocation episodes are treatable with non-surgical treatment with closed reduction, education, and muscle strengthening. One third of the cases develop recurrent dislocations and require surgical intervention. Revision surgery should target the cause of instability. When necessary, consider special implants, such as dual-mobility acetabular components, polyethylene-based lipped acetabular liners, constrained acetabular inserts, or large-diameter prosthetic heads. Technological advances in robotic surgery and the understanding of the biomechanics of spinopelvic swing-related dislocation are promising current topics that may improve the prevention and treatment of instability.

Keywords
- arthroplasty, replacement, hip
- joint dislocations/ prevention & control
- joint instability
- postoperative complications

Resumo

A instabilidade é uma complicação desafiadora e uma das principais causas de revisão na cirurgia de prótese de quadril. A incidência da luxação varia de 0,5 a 10% nas próteses primárias e pode chegar a 30% nas cirurgias de revisão. Existem diversos fatores de risco

Work carried out at Institute of Orthopedics and Traumatology of the Hospital das Clínicas of the Faculty of Medicine of São Paulo (IOT-HCFMUSP) and at the Department of Orthopedics and Traumatology of the Santa Casa de Misericórdia de São Paulo, São Paulo, SP, Brazil.

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descritos na literatura, sendo que podemos dividi-los em dependentes do cirurgião, dependentes do paciente e dependentes do implante. O conhecimento pleno desses fatores é fundamental para a prevenção e manejo da instabilidade. O tratamento preventivo envolve planejamento pré-operatório, posicionamento adequado dos componentes, restabelecimento da biomecânica normal do quadril, identificação de fatores de risco e escolha adequada do implante. Aproximadamente dois terços dos episódios de luxação podem ser tratados não cirurgicamente com redução fechada, orientações e fortalecimento muscular. Um terço evoluiu para luxações recorrentes e necessita de intervenção cirúrgica. A cirurgia de revisão deve ser direcionada diretamente para a causa da instabilidade. Quando necessário, considerar a utilização de implantes especiais como acetábulos de dupla mobilidade, insertos de polietileno com rebordo elevado, acetábulos constritos ou cabeças de grande diâmetro. Avanços tecnológicos na área da cirurgia robótica e na compreensão da biomecânica da luxação relacionada ao balanço espino-pélvico são temas atuais promissores que devem impactar em melhorias na prevenção e no tratamento da instabilidade.

Palavras-chave
- artroplastia de quadril
- complicações pós-operatórias
- instabilidade articular
- luxações articulares/ prevenção & controle

Introduction

Instability in total hip arthroplasty is a significant and stressful complication and one of the main current causes of surgical revision.[1] Although there is no Brazilian national data registry, information from countries with such databases shows that instability is a critical revision cause. In the Australian registry, instability is the third most common cause for revision, accounting for 14.6% of cases;[2] in the Danish registry, it is the second cause, with a 17% rate;[3] and in the United States, instability is the main indication for revision, with a 17.3% rate.[4]

The incidence of dislocation after primary hip arthroplasty varies considerably in the literature, depending on the population studied, ranging from 0.5 to 10%.[5] In revision arthroplasty, this incidence can reach up to 30%.[6] Historically, in the 1st case series, Charnley reported a dislocation incidence of 4.8%.[7] However, this number has been decreasing over time. In a meta-analysis by van Erp et al.[8] on the incidence of dislocation from 1960 to 2020, the average dislocation rate after total hip arthroplasty was 3.7% from 1960 to 1970 and decreased to 0.7% from 2010 to 2020. This reduction likely reflects technical and conceptual advances in the management and prevention of instability.

In most case series, 60 to 70% of dislocations occur within the 1st 6 weeks after surgery.[9] After this period, the estimated cumulative risk of dislocation is 1% every 5 years from the initial surgery.[7] Late dislocations may occur due to predisposing factors with delayed manifestation, such as improper component positioning, or to new risk factors, including polyethylene wear and neurological conditions.[7]

Risk Factors

The literature describes several risk factors for instability, some with more robust statistical support and others with a certain degree of questioning regarding their actual association with dislocation episodes. In practical terms, there are three risk factor categories for instability: patient-related factors, surgeon-related factors, and implant-related factors.

Patient-Related Factors

Gender

Although the risk of instability in female patients was always deemed higher,[10] more recent systematic reviews and data from national registries have shown no direct association between dislocation and gender.[1] These discrepancies in the literature probably result from confounding biases, including the increased association of females with conditions such as developmental hip dysplasia, femoral neck fractures, and their smaller acetabular sizes, which preclude the placement of larger heads.

Age

Several studies reported a higher risk of dislocation in older patients, although there is no consensus on the specific age range associated with this risk.[11] Miscellaneous aging-related conditions, including loss of lumbosacral spine mobility, sarcopenia, increased fall risk, and neurological diseases, may explain these findings. Interestingly, some recent studies suggested a potential increased risk of dislocation in younger patients, especially those under 50.[12] The greater functional demand and the potential presence of more complex joint conditions in this population may justify this phenomenon.

Neuromuscular Diseases and Abductor Muscle Failure

A myriad of conditions, due to different mechanisms, can increase the likelihood of dislocation resulting from abductor muscle failure, muscle contractures, loss of lumbosacral spine mobility, and lack of cooperation with movements posing a risk for dislocation. These illnesses include Parkinson's disease, cerebral palsy, multiple sclerosis, poliomyelitis sequelae,

stroke sequelae, and spinal cord injuries, and can increase the dislocation risk to 7.5 to 10.6% of cases in some series.[13] Abductor muscle failure may occur in other situations unrelated to neuromuscular diseases that increase the instability risk, such as revision surgeries with pseudoarthrosis or massive greater trochanter osteolysis, disarthrodesis, and extensive tendon attachment loss to the gluteus medius.[14]

Obesity

Obesity, defined as a body mass index (BMI) above 30 kg/m^2, has been associated with an increased risk of dislocation and may present a 2.5-fold risk ratio compared with the non-obese population.[15] However, some more recent studies have cast doubt on this issue as they found no association between BMI and dislocation episodes.[5,11] A potential reason for the higher dislocation risk in obese patients is inadequate component positioning due to surgical approach-related technical difficulties resulting from the copious amount of subcutaneous tissue. However, to date, this correlation remains statistically insignificant.[1] Interestingly, a retrospective cohort of more than 150 thousand patients presented data suggesting a higher dislocation risk in patients with a BMI lower than 20 kg/m^2.[10] Dislocation studies rarely evaluate patients with low BMIs separately, and this may be an underestimated factor in the literature.

Spinopelvic Swing

A little over a decade ago, the concept of spinopelvic swing, including the relationship between lumbosacral spine mobility and the spatial positioning of the acetabulum, emerged as another determining factor in postarthroplasty hip stability.[16] Patients with a rigid system resulting from lumbosacral spine arthrodesis or ankylosis, such as in ankylosing spondylitis, can present a considerable risk increase.[17] An interesting study by Buckland et al.[18] comparing patients who underwent total hip replacement without lumbar spine conditions and those who underwent arthrodesis analyzed the number of instrumented levels and revealed that the greater the number of levels, the greater the risk of dislocation. The relative risk can be 2.7 times for 3 or more fixed levels. Although it remains uncertain how and to what extent this rigidity of the spinopelvic swing influences the usual positioning of the total hip prosthesis,[19] this topic represents a promising field for future scientific advances.

Specific Conditions

Some conditions may increase the risk of dislocation, including femoral head osteonecrosis and rheumatological diseases.[15] According to Yang et al.,[20] the risk of an episode of dislocation occurring 1 year after total hip replacement surgery performed for osteonecrosis is 1.48 times higher than in patients with primary osteoarthritis. This data is consistent with another more recent systematic review and meta-analysis reporting a 1.5 times higher relative risk for osteonecrosis cases.[21] Although developmental hip dysplasia is a complex subject due to its diverse clinical presentations, technical challenges, and different bone reconstruction approaches, most recent evidence showed no association with a higher risk of instability.[22] Nevertheless, Komiyama et al.[23] documented a higher risk of dislocation when acetabular reconstruction occurs 2.39 cm or more above its physiological center.

Another important risk factor is arthroplasties for femoral neck fracture treatment, which can present a 10-fold higher risk of dislocation when compared to elective surgeries.[11,13] Patients with femoral neck fractures often are frail elderly subjects with many of the risk factors mentioned previously, including advanced age, neurological/cognitive abnormalities, abductor muscle weakness, and lumbosacral spine rigidity. For these cases, surgeons commonly select implants with a lower risk of dislocation, such as constrained or dual-mobility prostheses, or proceed to hemiarthroplasties.

Surgeon-Related Factors

Surgical Approach

Historically, the posterolateral approach has been associated with an increased risk of dislocation, probably because it is the only classic approach that exposes the joint through a posterior capsule opening. However, more recent studies evaluating the risk of dislocation in the posterior approach with capsular repair showed a similar incidence of instability.[24] A systematic review by Kwon et al.[25] reported that the relative risk of dislocation in the posterolateral approach with no repair could be up to 8.2 times higher depending on the case series evaluated. However, a comparison of the posterolateral approach with repair to the direct anterior approach and the lateral approach revealed no statistically significant difference. Recent meta-analyses evaluating different surgical approaches corroborated this conclusion.[26] The current trend is to implement and develop approaches that increase the sparing of muscles and tendons, such as the direct anterior approach and, more recently, the Supercapsular Percutaneously-Assisted Total Hip (SuperPATH) and Save the Piriformis And obturator Internus, Repair Externus (SPAIRE) approaches.[27] Nevertheless, no relevant evidence demonstrated superior stability after these approaches.[28]

Component Positioning

The most widely used parameter for component positioning is the classic safety zone described by Lewinnek, with respective acetabular inclination and anteversion values of $40 \pm 10°$ and $15 \pm 10°$.[29] However, these parameters received many criticisms because the original work had several biases, and many subsequent studies were unable to reproduce Lewinnek's findings with statistical significance.[30] Another famous concept is the combined anteversion presented at the Ranawat test, described in 1994[31] and consisting of the

sum of femoral and acetabular versions. In a broad study using navigation, Dorr et al.[32] defined a safety zone of combined anteversion ranging from 25 to 50°. As dislocations still occur even when respecting all these parameters, some authors stated that it is not possible to define a safety zone for component positioning.[5] Instability is multifactorial, and it is often difficult to effectively isolate the various risk factors that can lead to dislocation, including individual anatomical variations. In the future, technological advances, including three-dimensional tomography and biomechanical analyses considering sagittal balance and individual variations, may define the ideal positioning for each patient.

Anatomy Reestablishment

Reconstructing the physiological and anatomical parameters of hip offset, length, and center of rotation is fundamental for proper biomechanical prosthetic function, as it prevents impingements between the prosthetic components and bone structures that cause dislocation from happening. This reconstruction requires meticulous surgical planning and selection of implants that allow the restoration of the patient's physiological anatomy. The current transition from printed radiograph-based planning to digital planning has been causing several adaptation difficulties. However, as technology improves, digital planning accuracy increases.[33]

Implant-Related Factors

Femoral Head Size

The femoral head size is a subject widely discussed in the literature since the head diameter influences the range of motion and jumping distance.[34] Most studies showed that femoral heads smaller than or equal to 28 mm are risk factors for dislocation, while heads greater than or equal to 32 mm are protective factors.[35] However, it is controversial whether a real benefit would derive from using heads larger than 36 mm due to polyethylene volumetric wear, risk of acetabular insert fracture, head impingement on soft tissues causing inguinal pain, trunnionosis, and local adverse tissue reaction

Lipped Acetabular Liners

Polyethylene-based lipped acetabular liners may protect against dislocation by increasing the distance that the femoral head needs to travel to disengage from the acetabular component.[6] Although there is some concern about the possibility of the femoral component impinging on the lipped liner, resulting in a paradoxical increase in the risk of dislocation and early loosening, systematic reviews and cohort studies have not shown complications associated with these implants.[36]

Tribology

Polyethylene acetabular component wear may result in late dislocation, especially after 5 years of the initial surgery,[7] due to ligament laxity caused by the rise of the head in the worn liner and local microinstability.[13] Therefore, some authors have suggested the use of the ceramic/ceramic tribological pair as an alternative to avoid late dislocation. However, the advancement of crosslinked polyethylene reduced long-term wear, which no longer influences the cumulative risk according to national data records.[37]

Constrained Acetabular Inserts

Constricted acetabular components are implants presenting a locking femoral head mechanism to the polyethylene insert. The literature presents considerable controversy regarding their use. Some series report excellent outcomes, with failure rates ranging from 1.8 to 2.4% in a mean follow-up time of 4 to 5 years, especially in patients at high risk of instability.[38,39] In contrast, other investigations suggested that these implants should be used as salvage procedures, presenting failure rates from 10 to 23%.[40,41]

The main concern is the limited range of motion within physiological values, which may generate excessive stress at the implant/bone interface or between the femoral component and the locking mechanism. This phenomenon may result in premature loosening, accelerated polyethylene wear, or failure of the constriction mechanism leading to implant failure.[40] It is worth emphasizing the availability of implant designs with different locking mechanisms, each with different outcomes.[42] Implants with a lower range of motion restriction often present more positive outcomes, including tripolar implants[43] and those with recesses in the most common impingement areas to reduce motion restriction.[44]

Dual-Mobility Acetabular Components

Dual-mobility prostheses are not new, as their development by Bousquet et al.[45] happened in France in 1973. However, due to complications from early polyethylene wear and the high incidence of intra-prosthetic dislocation using the first devices,[46] the literature on dual-mobility acetabular components gained widespread prominence only in 2009, after their approval by the United States Food and Drug Administration.[47] Technological advances in implant design, currently in its third generation, and the advent of crosslinked polyethylene reduced these complications substantially. A more recent meta-analysis evaluating elective primary prostheses demonstrates a survival rate for any cause of revision of 99.7% in 5 years and 96.1% in 15 years.[48] When compared with constrained acetabular components, the literature often favors dual-mobility components, as reported by another systematic review with meta-analysis by Donovan et al.[49] These authors showed a failure rate for dislocation of 3% for dual-mobility components versus 9% for constrained components, a revision rate for instability of 2% versus 9%, and a revision rate for any cause of 8% versus 19%. However, there is still concern about long-term survival and failure in special cases, such as severe abductor mechanism failure.[50]

Navigation and Robotics

The introduction of surgical navigation in hip replacement arthroplasty occurred in 1998 by Jaramaz et al.[51] Surgical navigation consists of a system in which the patient's spatial position (based on intraoperative anatomical references provided by the surgeon) undergoes digital capture and processing by specialized software to provide real-time visual, graphical, or numerical information about the steps of the procedure, increasing component positioning control and precision.[52] Although the studies were promising regarding the precision of acetabular positioning, the literature has failed to demonstrate clinical outcome improvements.[53] Even though studies have shown greater precision in positioning components in the safety zone with robotic-assisted surgery (97%) when compared with navigation (84%) and manual methods (74%),[54] questions regarding the cost-benefit of this technique, considering the robot and operational cost, cast doubt on the advantage of systematically adopting this technique.[55] However, recent studies increasingly demonstrated that robotic assistance decreases the incidence of dislocation, especially in complex cases with spinopelvic swing dysfunction.[56] Robotic techniques have a promising future, particularly in the current scenario of artificial intelligence technology development.

Prevention

Preventive treatment of instability requires technical optimization of all modifiable, that is, surgeon-related risk factors. The elements for consideration include:

- Detailed preoperative planning to accurately reconstruct the physiological positioning of the acetabular rotation center, global offset, and limb equalization.
- Surgical access respecting tissue integrity (regardless of the chosen approach), which requires special care in tendon and muscle manipulation, reattachment, and adequate capsular repair.
- Proper component positioning within the safety zones and combined anteversion.
- Identification of all patient-related risk factors to guide the selection of the implants potentially minimizing the risk of dislocation. Although these factors are not modifiable, options include implants with large-diameter heads, lipped acetabular liners, and dual-mobility or constrained components. Each implant has advantages and disadvantages requiring individual consideration.

Non-Surgical Treatment

Approximately two thirds of dislocations may undergo non-surgical treatment with good outcomes, especially in those occurring within 3 months and presenting proper component positioning and anatomical reestablishment.[13] After closed reduction, patient guidance regarding movements that pose an instability risk and motor physical therapy for strengthening hip stabilizer muscles are essential. When there is no patient cooperation or significant muscle failure, hip abduction orthoses can be used for 8 to 12 weeks. Nevertheless, the literature shows scarce evidence to support the routine use of these devices.[57]

Table 1 Etiological classification of instability[58]

Type I	Inadequate acetabular component positioning
Type II	Inadequate femoral component positioning
Type III	Abductor muscle failure
Type IV	Bone or soft-tissue impingement
Type V	Asymmetrical polyethylene wear
Type VI	No identifiable cause

Surgical Treatment

Recurrent dislocations may require replacement revision. Although no defined number of dislocation episodes indicates surgical intervention, late dislocations or cases with poor component positioning have a higher association with recurrence and require a lower threshold for revision indication.

In these cases, the surgical approach targets instability cause; as a result, a careful analysis of all patient-related risk factors is essential, understanding that etiology is often multifactorial. To help with practical decision-making, Wera et al.[58] classified instabilities into six types (►**Table 1**) and Sheth et al.[59] presented guidelines for managing these instabilities.

Type-I (acetabular component malpositioning) and II (femoral component malpositioning) instabilities must undergo revision of the compromised component to optimize anatomical parameter reestablishment. The evaluation of component positioning may use conventional radiographs in several views, but computed tomography leads to a more accurate understanding of positioning errors.[53]

For type-III instability (abductor muscle failure), the indication is revision with constricted acetabular components.[59] The use of dual-mobility acetabular components in significant abductor mechanism failure has proven inconsistent.[50] If possible, abductor complex failure should be minimized by, for instance, repairing tendon lack of attachments to the gluteus medius and minimus and stabilizing greater trochanter pseudoarthrosis. Although the literature reports that muscle transfer techniques, allograft reconstructions, and distal trochanteric osteotomies improve functional patterns, it is unclear whether they have any impact on instability treatment.[14]

In type-IV instability, dislocation occurs due to impingement resulting in a range of motion limitation potentially related to bone structures or the contracture of inadequate periarticular soft-tissue balance.[59] It is essential to identify

the impingement etiology and remove it. Implants increasing the range of motion, such as large-diameter heads or dual-mobility acetabular components, are desirable in these cases.

Type-V instability results from asymmetric polyethylene insert wear, and it requires revision. If possible, use larger heads with highly cross-linked polyethylene to minimize instability recurrence. In fixed components not allowing a modular exchange of the polyethylene insert due to implant availability, cementation within a fixed metal cup has promising outcomes.[60]

Type-VI instability features no apparent modifiable cause to justify the episodes of dislocation, and the suggested treatment is revision using constrained acetabular liners.

General Considerations

Instability in total hip replacement is one of the main current complications, with a complex and multifactorial etiology. Understanding the risk factors, knowing the several implants available, and performing precise and individualized planning are essential for the prevention and treatment of this challenging complication.

Authors' Contribution
Each author contributed individually and significantly to the development of this article: BAR: coordination and manuscript preparation. FSMY: bibliographic review and manuscript preparation. MRI, LTO, HSM, and HMCG: manuscript preparation.

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Sarcopenia in Senior Subjects with Hip Fracture: Study of Prevalence, Correlation with Obesity, and Ultrasonography of the Rectus Femoris Muscle

Sarcopenia em idosos com fratura do quadril: Estudo da prevalência, correlação com obesidade e ultrassonografia do reto femoral

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Abstract

Objective To determine the prevalence of probable sarcopenia in senior patients with hip fractures and to evaluate the correlation between ultrasound measurements of the rectus femoris (RF) muscle, obesity, and the diagnosis of sarcopenia.

Methods The present study included 60 participants aged $\geq$ 65 years old admitted due to hip fractures. We administered the Strength, Assistance with Walking, Rising from a Chair, Climbing Stairs, and Falls (SARC-F) questionnaire, and measured the calf circumference and handgrip strength. We also assessed the thickness and cross-sectional area of the bilateral RF muscle using ultrasound.

Results We identified probable sarcopenia in 13 participants (20.6%). The mean RF thickness was 1.03 cm (standard deviation [SD] = 0.22) for the right thigh and 1.03 cm (SD = 0.23) for the left thigh. The mean cross-sectional area was 2.61 cm^2 (SD = 0.71) in the right thigh and 2.97 cm^2 (SD = 0.69) in the left thigh. The average calf circumference was 31 cm (SD = 4.29) for the right leg and 31 cm (SD = 4.31) for the left leg. We did not find correlations between ultrasound measurements of the RF muscle and potential sarcopenia. The diagnosis of probable sarcopenia was four times more likely in subjects who were overweight and had hip fractures.

Keywords
- hip fractures
- obesity
- sarcopenia
- ultrasonography

Study developed at Irmandade da Santa Casa de Londrina, Londrina, PR, Brazil.

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Conclusion The prevalence of probable sarcopenia was 20.6%. There was no correlation between ultrasound measurements of the RF and the presence of sarcopenia. Overweight significantly increased fourfold the likelihood of probable sarcopenia in this population.

Resumo

Objetivos Determinar a prevalência de provável sarcopenia em pacientes idosos com fraturas de quadril e avaliar a correlação entre as medidas ultrassonográficas do reto femoral (RF), obesidade e diagnóstico de sarcopenia.

Métodos Sessenta e cinco participantes com idade $\geq$ 60 anos hospitalizados com fraturas de quadril foram incluídos. O questionário SARC-F foi aplicado e a circunferência da panturrilha e a força de preensão manual foram medidas. A espessura bilateral do RF e a área de secção transversal foram avaliadas por ultrassonografia.

Resultados Provável sarcopenia foi identificada em 13 participantes (20,6%). A espessura média do RF foi de 1,03 cm (desvio padrão [DP] = 0,22) para a coxa direita e 1,03 cm (DP = 0,23) para a coxa esquerda. A área de secção transversal média foi de 2,61 cm^2 (DP = 0,71) na coxa direita e 2,97 cm^2 (DP = 0,69) na coxa esquerda. A circunferência média da panturrilha foi de 31 cm (DP = 4,29) para a perna direita e 31 cm (DP = 4,31) para a esquerda. Não foram encontradas correlações entre as medidas ultrassonográficas do RF e a sarcopenia provável. Indivíduos com sobrepeso e fratura de quadril apresentaram quatro vezes mais chances de apresentar o diagnóstico de sarcopenia provável.

Conclusão A prevalência de sarcopenia provável foi de 20,6%. Não foi observada correlação entre as medidas ultrassonográficas do RF e sarcopenia. O sobrepeso esteve significativamente associado a um aumento de quatro vezes na probabilidade de sarcopenia provável nessa população.

Palavras-chave
- fraturas do quadril
- obesidade
- sarcopenia
- ultrassonografia

Introduction

Sarcopenia in senior patients is a severe public health issue due to its relationship with an increased risk of falls and fractures,[1] to the limitation of the ability to perform daily living activities,[2] and to the association with heart and respiratory diseases and cognitive impairment.[3] Sarcopenia limits mobility by decreasing gait speed,[4] contributing to a reduced quality of life, loss of independence, and potential institutionalization requirement.[3]

Sarcopenia is a significant risk factor in patients with hip fractures due to its association with the two etiological factors contributing to their occurrence, that is, osteoporosis and falls,[5,6] and its subsequent complications. Senior adults who suffer hip fractures typically face prolonged hospital stays,[7] high 1-year mortality rates,[7] and greater rehabilitation challenges, often resulting in more pronounced functional limitations.

Several publications compared surgical techniques and implant types for treating hip fractures in senior subjects,[8] with highly reliable protocols for planning surgical treatment. Clinical care and the adoption of orthogeriatric care[9] by multidisciplinary teams also ensure better surgical outcomes. However, sarcopenia, a factor significantly influencing the rehabilitation and prognosis of these senior patients, has not yet received the same attention in the management of these subjects.

The present study aimed to determine the prevalence of sarcopenia in senior patients hospitalized with hip fractures, to evaluate the correlation between ultrasound measurements of the rectus femoris muscle and the diagnosis of sarcopenia, and to verify the correlation between obesity and the diagnosis of sarcopenia.

The present study hypothesizes that the senior population with femur fractures has a high prevalence of sarcopenia, and that the ultrasonographic thickness of the rectus femoris muscle and obesity correlate with the diagnosis of sarcopenia.

Methods

The present cross-sectional study received approval by the institution's ethics committee (opinion number 6.594.376; CAAE 7365123.0.0000.0099).

The study evaluated 65 patients aged $\geq$ 60 years old admitted from March 29, 2023, to March 28, 2024, with a diagnosis of proximal femur fracture. We included subjects with the cognitive capacity to answer the questionnaires and who, along with a responsible family member, agreed to participate in the study. We excluded patients with neoplastic disease, those admitted to the intensive care unit (ICU) before surgery, and those who demonstrated cognitive impairment rendering them unable to complete the self-administered SARC-F questionnaire.

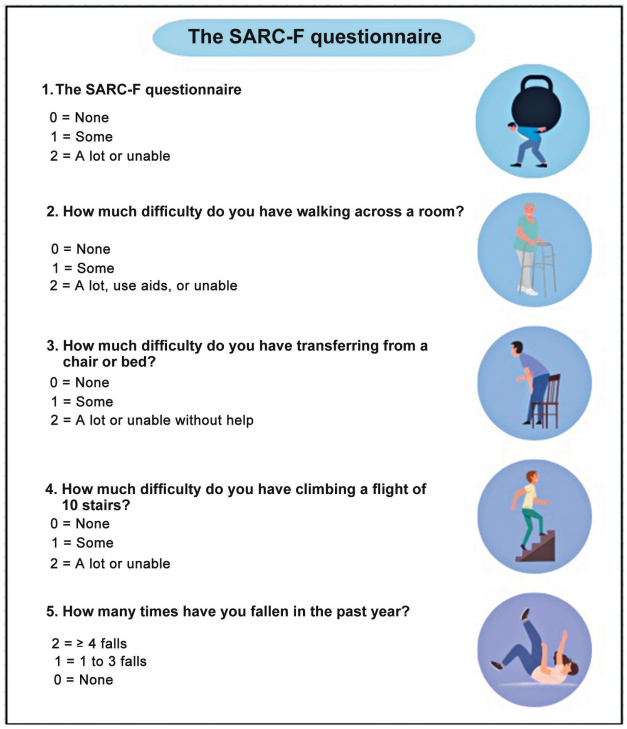


Fig. 1 Strength, Assistance with Walking, Rising from a Chair, Climbing Stairs, and Falls (SARC-F) questionnaire.

We invited the patients to participate in the study and assessed them before surgery. This assessment collected data on comorbidities, fracture type, weight, and height, reported by the participants or their family members, to calculate the body mass index (BMI). Additionally, all participants completed the Strength, Assistance with Walking, Rising from a Chair, Climbing Stairs, and Falls (SARC-F) questionnaire.

The SARC-F (►**Fig. 1**) is a five-item self-report questionnaire designed to screen for sarcopenia risk. It assesses subjects' perceptions of their limitations in key functional areas, including muscle strength, walking ability, ability to rise from a chair, climb stairs, and history of falls. Barbosa-Silva et al.[10] validated the Portuguese-language version of the SARC-F for use in Brazil.

We performed the handgrip strength testing with a portable digital Instrutherm DM-90 (Instrutherm) device while the participant was lying down with the forearm on the dominant side supported along the body. We made 3 attempts with a 1-minute interval and recorded the highest value obtained. We measured the calf circumference 2 cm below the anterior tibial tuberosity with the participant lying down. The ultrasonographic measurement of the thickness and cross-sectional area of the bilateral rectus femoris muscle employed a Philips Lumify (Royal Philips Inc.) device and a linear transducer at a point on the thigh equidistant between the anterior superior iliac spine and the superior pole of the patella. The examiner was a single orthopedic surgeon with > 5 years of experience using ultrasound in clinical practice, blinded to the sarcopenia diagnosis.

Sarcopenia variable

We used the criteria of the European Working Group on Sarcopenia in Older People, revised in 2019 (EWGSOP2),[3] to determine the diagnosis of probable sarcopenia (►**Fig. 2**). This diagnosis considered a SARC-F score > 4 and palmar flexion strength < 27 kg for men and < 16 kg for women.

Muscle mass

To estimate total muscle mass, we used the following equation developed by Lee et al.:[11] total muscle mass = 0.244 x weight + 7.80 x height + 6.6 x gender - 0.098 x age + ethnicity - 3.3. Body weight was registered in kilograms, height in meters, and age in years. This equation assigns values 0 and 1 for women and men, respectively, and - 1.2 to Asians, 1.4 to Blacks, and 0 to Caucasians. This validation of the equation for the Brazilian population employed dual-energy x-ray absorptiometry (DEXA) as the gold standard, and its correlation with the equation was R = 0.86 for men and R = 0.90 for women. The predictive value between DEXA and the

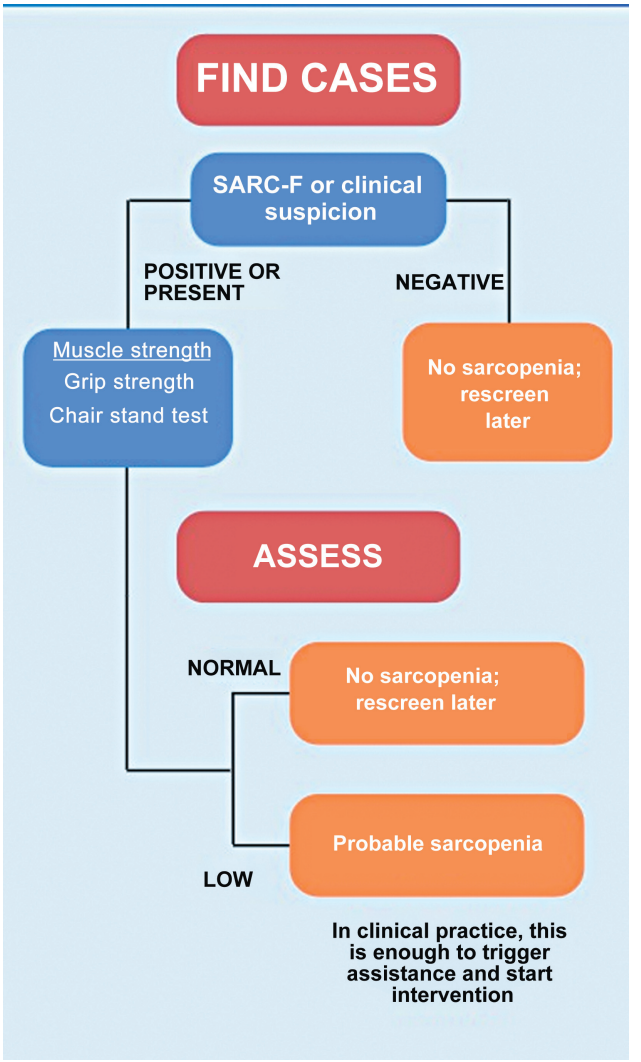


Fig. 2 Algorithm with the initial two steps for sarcopenia diagnosis (European Working Group on Sarcopenia in Older People, EWGSOP2). *SARC-F*, Strength, Assistance with Walking, Rising from a Chair, Climbing Stairs, and Falls questionnaire.

equation was strong (K = 0.74; $p < 0.001$), presenting high sensitivity (89%) and specificity (86%).[11] The equation was adjusted by dividing by height squared, creating a total muscle mass index. The cutoff for identifying reduced muscle mass was $\leq 5.75\,kg/m^2$ for women and $\leq 8.50\,kg/m^2$ for men.[12]

We estimated the muscle mass to investigate the correlation with the diagnosis of sarcopenia and with ultrasound measurements of the rectus femoris muscle.

Data analysis

We performed the statistical analysis using the IBM SPSS Statistics for Windows (IBM Corp.), version 22.0, adopting a significance level of 5% ($p \leq 0.05$) and a 95% confidence interval (CI).

Initially, the normality of continuous variables was assessed using the Shapiro-Wilk test, as it is more appropriate for small to moderate sample sizes. Except for the left rectus femoris area, all variables presented a normal distribution, consistent with the assumptions of parametric tests. Furthermore, sample independence and variance homogeneity were observed through the Levene test, which reinforces the appropriateness of using the t-test for independent samples in comparisons between groups (normal weight versus overweight).

For the left rectus femoris area variable, which presented a nonparametric distribution, we applied the Mann-Whitney test.

We used the chi-squared test to investigate associations between categorical variables. Binary logistic regression was used to analyze the magnitude of these associations, calculating odds ratios (ORs) and their respective 95%CIs

Results

The present study consisted of 65 participants, 22 males and 43 females. The mean age was 77 years old, ranging from 61 to 93 years old. The average BMI was 24.5 (standard deviation [SD], 5.6), with 13 participants classified as overweight (BMI $\geq$ 25). Thirty-eight patients presented with femoral neck fractures, and 27 had pertrochanteric fractures.

The SARC-F questionnaire score was ≥ 4 for 16 subjects, and the mean handgrip strength was 18.8 kg (SD = 7.4). Using the EWGSOP criteria,[3] we identified 13 patients with probable sarcopenia, accounting for 20.6% of the sample. Among these, 9 (69.2%) were females and 4 (30.8%) were males.

The mean thickness of the rectus femoris at ultrasound was 1.03 cm (SD = 0.22) for the right thigh and 1.3 cm (SD = 0.23) for the left thigh. The mean cross-sectional area of the rectus femoris muscle was $2.61\,cm^2$ on the right side and $2.97\,cm^2$ on the left side. The mean calf circumference was 31 cm in the right and left lower limbs. The minimum measurement was 24 cm bilaterally, and the maximum measurements were 42 cm on the right side and 44 cm on the left side. The calculation of the muscle mass index using the Lee formula yielded a mean value of $6.7\,kg/m^2$ for women and $8.8\,kg/m^2$ for men. The statistical analysis showed no correlation between the results of muscle mass index, age, calf circumference, and rectus femoris muscle measurements by ultrasound with the probable diagnosis of sarcopenia (►**Table 1**). However, we observed that subjects with probable sarcopenia had a significantly higher mean BMI ($p = 0.046$) and lower handgrip strength ($p = 0.007$).

Table 1 Comparison of anthropometric, functional, and muscular variables between senior subjects with and without probable sarcopenia after hip fracture

Variable	Probable sarcopenia	*n*	Mean value	SD	*t-value*	*P-value*
Muscle mass index (kg/m^2)	No	50	19	5.6	−1.468	0.147
	Yes	13	21	6.8		
Age (years)	No	50	76	1.1	−0.856	0.395
	Yes	13	78	2.2		
BMI (kg/m^2)	No	50	23	0.613	−2.040	0.046
	Yes	13	27	2.482		
Handgrip strength (kg)	No	50	20	7.3	2.770	0.007
	Yes	13	14	5.4		
Calf circumference (cm)	No	50	31	5.2	−0.190	0.850
	Yes	13	32	41.1		
Rectus femoris thickness (cm)	No	50	1.020	0.218	−0.542	0.590
	Yes	13	1.095	0.225		
Cross-sectional area of the rectus femoris (cm^2)	No	50	2.569	0.672	−1.194	0.237
	Yes	13	2.832	0.841		

Abbreviations: BMI, body mass index; cm, centimeters; cm^2, square centimeters; kg/m^2, kilograms per square meter (unit of BMI and muscle mass index); n, number of participants; *P*-value, statistical significance level; SD, standard deviation; t-value, Student's t-test result for independent samples.

Table 2 Association between nutritional status and probable sarcopenia in senior subjects

		Nutritional status						
		Normal		Excessive				
		n	%	*n*	%	X^2	*P-value*	Phi
Probable sarcopenia	No	32	88.9%	17	65.4%	5.033	0.025	0.285
	Yes	4	11.1%	9	34.6%			
Total		36	100.0%	26	100.0%			

Abbreviations: %, percentage; n, number of participants; *P*-value, statistical significance level; Phi, phi coefficient of association to measure the strength of association between categorical variables; X^2, result from the Pearson's Chi-squared test.

Table 3 Indicators of sarcopenia in senior patients with hip fractures: comparison between eutrophic and overweight subjects

	Nutritional status	*n*	Mean value	SD	*t-value*	*P-value*
Handgrip strength (kg)	Eutrophic	36	19.85	7.18	0.460	0.647
	Overweight	26	18.96	7.98		
Calf circumference (cm)	Eutrophic	27	29.3	3.8	−4.433	< 0.001
	Overweight	22	34.3	3.8		
Right rectus femoris thickness (cm)	Eutrophic	36	1.00	0.20	−1.461	0.149
	Overweight	26	1.08	0.24		
Left rectus femoris thickness (cm)	Eutrophic	36	1.01	0.21	−0.865	0.390
	Overweight	26	1.06	0.26		
Cross-sectional area of the right rectus femoris	Eutrophic	36	2.48	0.64	−1.959	0.055
	Overweight	26	2.83	0.75		
	Nutritional status	*n*	Median	IR	Z	*P*-value
Cross-sectional area of the left rectus femoris	Eutrophic	36	2.45	1.06	−1.405	0.160
	Overweight	26	2.80	1.04		

Abbreviations: IR, interquartile range; n, number of participants; SD, standard deviation; *P*-value, statistical significance level; t-value, Student's t-test result for independent samples; Z, Z-value per the Mann-Whitney test.

We also found an association between the probability of sarcopenia and excessive weight (overweight and obesity) (►**Table 2**). Logistic regression indicated the large magnitude of this association, with an OR of 4.235 (95%CI = 1.135–15.799; $p = 0.032$).

We found no correlation between excessive weight and handgrip strength, or ultrasound measurement of the rectus femoris area and muscle thickness. However, subjects with excessive weight had larger calf circumferences (►**Table 3**).

Discussion

The EWGSOP2[3] sarcopenia diagnostic algorithm consists of four steps (►**Fig. 1**). The first two steps use the criteria of a low SARC-F questionnaire score and low muscle strength to establish a probable diagnosis of sarcopenia. The third step of the algorithm confirms the sarcopenia diagnosis with tests to quantify muscle mass, including body DEXA, computed tomography (CT), or magnetic resonance imaging (MRI) of the thigh. For the evaluation of senior subjects, DEXA offers significant advantages, including low radiation exposure and minimal patient cooperation.[13]

As in clinical practice, for patients hospitalized for fracture treatment, these resources are rarely available to the surgeon. Therefore, we chose to stop at the second step of the algorithm and separate the sample into subjects with or without a diagnosis of probable sarcopenia. According to EWGSOP2, the identification of probable sarcopenia is enough to begin the investigation of its causes and implement clinical interventions. As such, by focusing on probable sarcopenia, we ensure the validity of the diagnosis for our study, that is, the early identification of this condition in a clinical practice setting. We believe that failure to progress to the subsequent steps of the algorithm limits the ability to classify sarcopenia severity, but not the accuracy of its initial identification, which was the focus of our research.

Although the consensus on the definition and diagnostic criteria has evolved,[14] there is still difficulty in comparing the prevalence of sarcopenia in senior subjects. The prevalence of this condition varies based on the criteria used for its characterization, cutoff points, and methods for measuring strength and muscle mass.[15]

In a meta-analysis, Nascimento et al.[16] reported a 10% prevalence of sarcopenia in the general population. In

another meta-analysis, Petermann-Rocha et al.[17] reported a value of 16%. Although both studies analyzed healthy senior subjects, their results showed considerable variation, particularly among articles using different diagnostic criteria. The Health, Well-being, and Aging Study (SABE, from the Portuguese *Saúde, Bem-Estar e Envelhecimento*) study,[18] conducted with senior subjects living in the city of São Paulo, Brazil, found a sarcopenia prevalence of 16.1% for women and 14% for men. The prevalence of sarcopenia is different in groups of patients with specific conditions when compared with the general population, being reported from 18% in diabetic patients to 66% in those with esophageal cancer.[15] In the literature, the prevalence of sarcopenia in senior patients with hip fractures ranged from 17 to 37%.[19,20] We established a diagnosis of probable sarcopenia in 20.2% of our patients, which seems to be a higher rate when compared with healthy senior Brazilians and consistent with other studies with senior subjects with hip fractures.

The EWGSOP2 recommends the palmar flexion strength test with a dynamometer in subjects with lower limb fractures. This test correlates well with lower limb strength, is easy to apply clinically, is used in most publications on the subject, and has better-defined cutoff points for females and males.[3,21] Although we assessed the palmar grip strength with gender-specific cutoff points, our sample size did not allow for gender-stratified analyses of the prevalence of sarcopenia or the evaluation of associations with obesity and ultrasound.

Methods for determining muscle mass for sarcopenia diagnosis, such as MRI, DEXA, or bioimpedance, are expensive or impractical for use in hospitalized patients with acute conditions. In this context, ultrasound has been identified as a practical and accessible alternative for assessing muscle mass and quality.[22] A recent meta-analysis found moderate diagnostic accuracy for sarcopenia using ultrasound to measure the rectus femoris muscle thickness in healthy senior subjects. Data compiled from 5 studies showed a sensitivity of 72% and a specificity of 72%.[23] Ultrasound as an assessment tool for sarcopenia has been advocated in hospitalized patients with critical clinical conditions.[24] For senior subjects with hip fractures, one study found a correlation between quadriceps (rectus femoris and vastus intermedius) thickness and the diagnosis of sarcopenia.[25] In contrast to these data, we found no correlation between the rectus femoris cross-sectional area and thickness at ultrasound with the diagnosis of probable sarcopenia, BMI, handgrip strength, calf circumference, or muscle mass index. Yamada et al.[26] suggested a relationship between the measurement of muscle thickness and muscle volume, and that the assessment of echogenicity relates to muscle function.[26] However, ultrasound measures of muscle quality, such as echogenicity, assessment of fiber angles, elasticity, and vascularity, are more complex and may not be available to the surgeon who will treat the patient.

The lack of correlation may be due to limitations in the ultrasound methodology. First, there is considerable heterogeneity in the literature regarding examination protocols, particularly in patient positioning and the anatomical landmarks.[23] Another potentially influential factor is that our measurements were not made by an ultrasound specialist, as the primary objective was to evaluate the feasibility of utilizing this tool in routine clinical practice. As such, we intended to evaluate the tool in the hands of the attending physician, who, although an orthopedist with ultrasound experience, is not a radiology specialist.

Lower limb muscles are the most commonly evaluated for the ultrasound diagnosis of sarcopenia, probably because they are easier to measure and more directly associated with mobility and activities of daily living compared with the muscles of the trunk or head.[23] Furthermore, ultrasound assessment of the masseter muscle has been associated with the risk of dysphagia, while evaluation of the biceps brachii has been associated with the ability to self-feed.[25]

We observed significant heterogeneity in the cited studies regarding patient characteristics, sites, and muscles examined, especially regarding the diagnostic criteria for sarcopenia, which makes comparison difficult. Although the EWGSOP2 consensus acknowledges that ultrasound demonstrates good validity for determining muscle mass, it emphasizes the need for further research to validate the method for specific clinical conditions. This caveat is largely due to challenges such as the lack of standardized cutoffs for sarcopenia diagnosis using ultrasound, the heterogeneity of examination techniques and sites (upper versus lower limbs, different muscles) across studies, and the limited correlation observed to date between ultrasound measurements and relevant clinical outcomes. These factors hinder the universal application and standardized interpretation of ultrasound for the diagnosis of sarcopenia in clinical practice.

We found a strong positive correlation between excessive weight (BMI > 24.9) and a diagnosis of probable sarcopenia. However, some confounding factors require consideration. Our analysis did not account for gender-specific variations in muscle mass decline or differences in fat distribution between ethnic groups. Moreover, obesity itself is an independent risk factor for falls and fractures in senior subjects. However, this finding makes sense when considering that we did not find significant differences in muscle strength or rectus femoris thickness between normal-weight and overweight patients. Aging is associated with a proportional increase in fat and changes in its distribution across the body, and these changes appear to present a pathogenetic link.[27]

To further understand the association between excessive weight and probable sarcopenia, we characterized the demographic and functional profile of the subgroup of overweight participants diagnosed with probable sarcopenia ($n = 9$). This group consisted of 78% women and 22% men. The mean handgrip strength was 13.4 ± 6 kg, and the mean SARC-F score was 6 ± 2 points, indicating limitation in daily activities. These data complement ►**Table 2**, providing a more detailed overview of the clinical and functional characteristics of the overweight subjects who also had probable sarcopenia in our sample. The mean BMI was 27 ± 2 kg in sarcopenic patients and 23 ± 0.6 kg in nonsarcopenic subjects. The large difference in SD magnitude may be due to sample size.

In our study, the mean BMI of subjects with probable sarcopenia was 27.0 kg/m^2, higher than the mean BMI of

23.0 kg/m^2 in nonsarcopenic patients. However, the greater dispersion of BMI data in the sarcopenic group is noteworthy, evidenced by an SD of 2.482, compared with an SD of 0.613 in the nonsarcopenic group. This high heterogeneity may be attributed to the phenotypic complexity of sarcopenia, since this condition can coexist with excessive weight (characterizing obesogenic sarcopenia) or occur in subjects with normal or low weight. Furthermore, the small sample size, especially in the group with probable sarcopenia ($n = 13$), may have affected the high SD value. Smaller sample sizes are more vulnerable to the influence of extreme values and may limit the representation of populational variability.

Obesity is often associated with chronic low-grade inflammation, which can accelerate muscle breakdown and promote insulin resistance. This inflammatory state can negatively impact muscle protein synthesis, further exacerbating muscle loss. Moreover, excessive adiposity induces hormonal changes that affect muscle metabolism. Elevated levels of adipokines, such as leptin and interleukin-6, can impair muscle function and contribute to the progression of sarcopenia.[27]

Obesity and sarcopenia are two conditions that, by themselves, increase functional limitations and morbidity in the senior population. The addition of a third factor associated with high morbidity and mortality, such as hip fracture, certainly increases treatment complications and deserves attention from a prevention perspective, including diet and physical activity.

Although we did not precalculate the sample size, we tried to mitigate this limitation by presenting CIs and interpreting effect sizes to enhance the transparency and robustness of the analyses. Logistic regression revealed a statistically significant association between excessive weight and a probable diagnosis of sarcopenia, with an OR of 4.235 and a 95%CI ranging from 1.135 to 15.799 ($p = 0.032$), indicating not only statistical significance but also a clinically relevant effect size. Even though the relatively wide CIs reflect the small sample size, the findings suggest a consistent association. In addition, the difference in handgrip strength between the groups with and without probable sarcopenia was statistically significant ($p = 0.004$), with means of 20.7 kg and 14.6 kg, respectively, corresponding to a moderate to large effect size (Cohen's d $\sim$ 0.89), reinforcing its functional relevance. However, we are aware that the relatively small number of participants may have limited the statistical power of the comparisons, especially those involving ultrasound measurements, increasing the risk of type II errors. Therefore, future studies with larger samples are recommended to confirm these findings and broaden the generalizability of the results. Nevertheless, these analytical strategies provide the reader with a more complete understanding of the magnitude and clinical relevance of the observed associations, despite the sample limitations.

Conclusion

The prevalence of probable sarcopenia in our sample was 20.6%, and we found no correlation between ultrasound measurements of the rectus femoris and the diagnosis of probable sarcopenia. Subjects with hip fractures who are overweight are four times more likely to have a probable diagnosis of sarcopenia.

Authors' Contributions

Each author contributed individually and significantly for the present study:

MRM: project administration, investigation, data curation, formal analysis, writing – original draft, and writing – review & editing; JC: formal analysis, writing – original draft, and writing – review & editing; CMMM: project administration, literature review, data curation, formal analysis, visualization, and writing – review & editing; BLB and YAS: project administration, investigation, curation, and writing – original draft; YAS: research project, literature review, data curation, and writing; RACA: project administration, formal analysis, writing – review & editing.

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Conflict of Interests

The authors have no conflict of interests to declare.

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Reverse Posterior Interosseous Artery Flap: Indications, Technique, and Complications in 18 Consecutive Cases

Retalho reverso de artéria interóssea posterior: Indicações, técnica e complicações em 18 casos consecutivos

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Abstract

Objective To evaluate the success rate of the reverse posterior interosseous artery flap, inferring its predictability, reliability, and safety.

Methods We conducted a retrospective observational study including 18 patients with soft-tissue lesions in the distal third of the upper limb who underwent posterior interosseous artery flap surgery. The study analyzed the flap size, the recipient area, the need for additional grafting, the clinical outcome, and the complications.

Results There was one total and one partial loss of the flap, resulting in a success rate of 94.45%. Most cases healed well, and we did not observe major complications. More than half (55.5%) of the cases required grafting. In four cases, the flap was insufficient to cover the defect, requiring skin grafting in areas of granulation. In four cases, we performed thumb coverage, which is essential for hand function. The average flap size was of 9.6 cm in length by 4.4 cm in width, with the length ranging from 5.5 to 13 cm, and the width, from 3 to 7 cm. The flap was beneficial in functional areas such as the thumb and first commissure.

Conclusion The posterior interosseous artery flap is a safe and effective option to cover defects in the distal third of the upper limb, especially on the dorsum of the hand and thumb, with low morbidity and good functional and esthetic outcomes.

Level of Evidence IV, case series.

Keywords
- fascia/ transplantation
- hand injuries
- soft tissue injuries
- surgical flaps

Study developed at the Hand Surgery and Reconstructive Microsurgery Group, Instituto de Ortopedia e Traumatologia, Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo, São Paulo, SP, Brazil.

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Resumo

Objetivo Avaliar a taxa de sucesso do retalho reverso da artéria interóssea posterior e inferir sua previsibilidade, confiabilidade e segurança.

Métodos Conduzimos um estudo retrospectivo observacional de 18 pacientes com lesões de partes moles no terço distal do membro superior submetidos a retalho da artéria interóssea posterior. Foram analisados o tamanho do retalho, a área receptora, a necessidade de enxertia complementar, o resultado clínico e as complicações.

Resultados Houve uma perda total e uma parcial, o que resultou em taxa de sucesso de 94,45%. A maioria dos casos apresentou boa cicatrização e ausência de complicações importantes. Foi necessária enxertia em 55,5% dos casos. Em quatro casos, o retalho mostrou-se insuficiente para a cobertura da falha, sendo necessário enxerto cutâneo em áreas de granulação. Em quatro casos, foi realizada cobertura de polegar, que é fundamental para a funcionalidade da mão. A média do tamanho foi de 9,6 cm de comprimento por 4,4 cm de largura, com variação de comprimento de 5,5 a 13 cm e de largura, de 3 a 7 cm. O retalho demonstrou utilidade em áreas funcionais como o polegar e a primeira comissura.

Conclusão O retalho da artéria interóssea posterior é uma opção segura e eficaz para a cobertura de falhas no terço distal do membro superior, especialmente no dorso da mão e no polegar, com baixa morbidade e bons resultados funcionais e estéticos.

Nível de Evidência IV, série de casos.

Palavras-chave

- fáscia/transplante
- lesões dos tecidos moles
- retalhos cirúrgicos
- traumatismos da mão

Introduction

Soft tissue defects in the hand are challenging injuries, as they often present with exposure of tendons or neurovascular structures,[1] and they require proper skin coverage for early rehabilitation to prevent stiffness and contractures.

The literature describes several coverage options, including local, pedicled, or microsurgical flaps. The surgeon's preference and comfort are key elements in flap selection, considering factors such as the degree of technical difficulty, pedicle length, volume, and potential for primary closure.

The single-stage reconstruction of these defects results in early mobilization, reduces hospital stays, minimizes infection rates, and yields good functional outcomes. Regional flaps offer these advantages, reducing the surgical time and presenting fewer technical difficulties compared with microsurgical flaps.[2]

The most common regional flaps for these cases are the antebrachial fasciocutaneous flaps with a retrograde flow from the radial artery, the ulnar artery, and the posterior interosseous artery (PIA). The first two present the disadvantage of sacrificing significant hand arteries, increasing donor site morbidity. Another disadvantage and limitation of these flaps is the need to preserve the palmar arch to ensure its perfusion. Palmar arch compromise is not uncommon in severe hand injuries.

Two independent groups first described the PIA flap for coverage of elbow defects.[3–5] The PIA flap started to be used in distal defects after its description for retrograde flow,[6,7] based on its anastomosis with the anterior interosseous artery, presenting itself as an interesting option for coverage due to its reliability and predictability,[8] especially in the dorsal region of the hand up to the proximal interphalangeal joints and the first commissure area.[9]

The present study aimed to evaluate the success rate of the PIA flap, inferring its predictability, reliability, and safety.

Methods

The institutional Ethics Committee approved the study under opinion number 7.362.990/2025 (CAAE: 85725225.2.0000.0068).

The current is a primary, retrospective, observational, and descriptive study of a series of 18 consecutive cases of patients with loss of skin coverage in the distal third of the wrist, hand, and first commissure, secondary to trauma or infection. The patients underwent surgery from September 2001 to June 2023, and the same surgeon, a specialist in hand and microsurgery, performed all procedures.

Flap indication resulted from the need for coverage after amputation or coverage failure. Amputation occurred at the carpal level in three cases, at the first metacarpal level in one case, and at the level of the interphalangeal joint of the thumb in one case. The coverage failure site was the dorsal region of the hand in five patients, the dorsal region of the hand at the first metacarpal level in three cases, the dorsoradial region of the wrist in one subject, the volar radial region of the wrist in one case, the first web space in one patient, and the thenar region in one case. One patient required coverage due to scar retraction at the first web space.

We evaluated data such as the size of the defect and the flap, the recipient sites and lesion severity, the need for skin graft at the donor and recipient areas, and the complications (infection and total or partial flap loss). We excluded patients who underwent other coverage options, such as regional or microsurgical flaps.

Surgical Technique

First, the surgeon performed the anatomical markings, drawing a line from the lateral epicondyle of the distal humerus to the distal radioulnar joint (DRUJ). Next, the surgeon marked a point 2 cm close to the DRUJ, indicating the probable location of the anastomosis between the PIA and the anterior interosseous artery, as the rotation point of the flap pedicle.

Then, the surgeon divided the original line into three equal parts; the middle third portion represented the ideal location for fasciocutaneous flap elevation, as it is the site of the most relevant perforator (►**Fig. 1**). The surgeon debrided the coverage defect and measured the distance between the rotation point of the flap and the defect: this measurement determined the length of the flap and pedicle for dissection (►**Fig. 2**).

Dissection always began with a distal incision and the identification of the tendons of the extensor carpi ulnaris (sixth extensor compartment) and the extensor digiti minimi (fifth compartment). The PIA pedicle was between these tendons. Next, the surgeon made a longitudinal incision on the fascia over these tendons and carefully retracted them to identify and confirm the presence of the artery. In all cases, the artery was closest to the fifth compartment tendon. Next, dissection proceeded from distal to proximal up to the point of rotation (►**Fig. 3**). The posterior interosseous nerve was carefully dissected from the artery (►**Fig. 4**). No case required the section of any branch of the nerve.

The flap was sufficient to cover exposed noble structures in all patients (►**Fig. 5**). However, some cases required a partial skin graft in flap-associated marginal areas for complete lesion coverage. Whenever possible, the surgeon performed the primary closure of the donor site. If necessary, the donor-site closure included a partial skin graft. In 12 cases, the flap passed through a subcutaneous tunnel, while 6 cases required an incision.

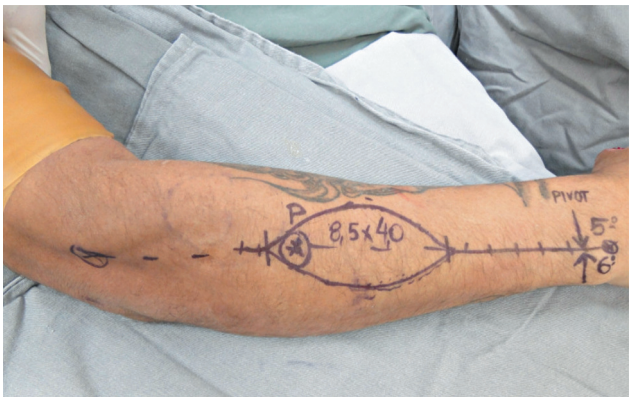


Fig. 1 Anatomical markings.



Fig. 2 Template for flap rotation.

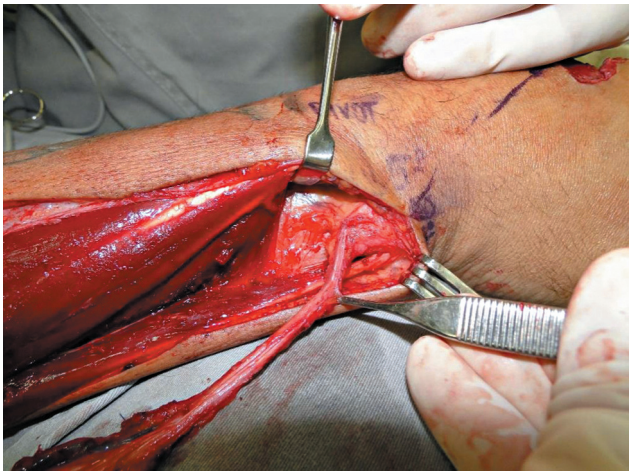


Fig. 3 Pedicle dissected up to the point of rotation.

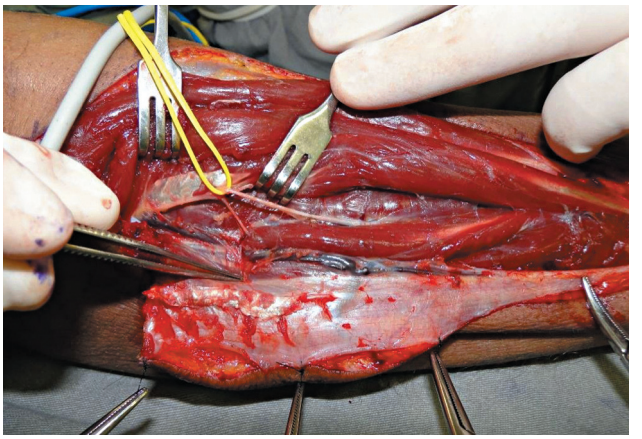


Fig. 4 Posterior interosseous nerve separated from the pedicle.



Fig. 5 Soft tissues defects covered with the flap.

After the surgical procedure, the flap status was regularly checked, using color, bleeding, and capillary refill time as parameters. The patients underwent antebrachiopalmar immobilization for 2 weeks for flap autonomization. Next, they underwent a monthly functional monitoring for a variable follow-up period.

Results

The present study comprised 18 surgical procedures. Of these, 17 coverage failures occurred due to traumatic events, and 1 failure may have resulted from pyoarthritis of the wrist (►**Table 1**). Most patients were male. Injuries were more common in the right hand (11 cases) compared with the left hand (7 cases).

Regarding size, the largest flap measured 13 × 5.5 cm, and the smallest, 7 × 3 cm. The average flap size was of 9.6 × 4.4 cm. Thus, the flaps ranged from 5.5 cm to 13 cm in length and from 3 cm to 7 cm in width (►**Table 1**).

As for the outcomes, flap loss was total in 1 case (5.55%) and partial in another case (5.55%). The total loss occurred in a patient with coverage failure on the dorsum of the hand due to trauma. The removal of the necrotic area of the flap and the creation of a pedicled radial artery antebrachial flap led to a satisfactory outcome (►**Fig. 6**). The partial loss case also involved coverage failure on the dorsum of the hand due to trauma, with partial peripheral necrosis of the distal and radial edges of the flap after epidermolysis. Follow-up with healing by secondary intention was chosen. In terms of effectiveness in covering the exposed area, only the flap with total loss failed its function, resulting in a success rate of 94.45%.

We did not assess the hand or wrist function, since it depends on variables not related to the use of flaps, particularly the initial severity of the trauma. However, in four cases, the flaps were effective in maintaining limb function, especially in severe cases of partial thumb amputation, enabling the preservation of the maximum possible digit length and movements, such as pinch and opposition (►**Fig. 7**). In total, 6 (33.3%) patients received a flap for thumb region coverage.

All donor sites healed without complications. There were no reports of infection, dehiscence, nor compromise of the venous return or the posterior interosseous nerve. The PIA flap was insufficient to completely cover the defect in four cases, requiring a skin graft in areas with no exposed tendons or neurovascular structures. Regarding primary closure of the donor site, 10 (55.5%) cases needed grafting.

Discussion

Cheema et al.[10] reported their experience with 64 flaps, 88.24% of which survived completely; the four flaps that failed in their study presented pedicle skeletonization. Büchler e Frey[11] reported 4 partial losses in 16 cases, all due to surgical site infection. Lee et al.[12] reported 2 losses in 49 cases, both secondary to venous congestion.

In the current study, 16 patients recovered well, while 1 had total and 1 presented with partial flap necrosis. In the case of total necrosis, the pedicle suffered an injury during dissection, and, in the case of partial flap loss, it is estimated that the flap design was excessively proximal due to the need for a long rotation arch.

Thus, it is possible to estimate that the flap is safe for first web space defects and, especially, for the dorsum of the hand. If flap rotation is necessary in regions distal to the metacarpophalangeal joint of the long fingers or beyond the first commissure, as in volar defects, it may not be the best option

Table 1 Descriptive aspects of cases receiving posterior interosseous artery flaps in the upper limbs

Cases ($n = 18$)	Sex	Coverage failure site*	Size (cm)***	Donor area closure	Graft in the recipient area***	Outcome	Etiology
1	Male	First metacarpal amputation	5.5 × 4.0	Primary	–	Favorable	Trauma
2	Male	Amputation at the carpal level	8.0 × 4.5	Grafting	–	Favorable	Trauma
3	Male	Dorsum of the hand	6.5 × 4.0	Primary	–	Favorable	Pyoarthritis
4	Male	Dorsum of the first metacarpal	9.0 × 5.0	Grafting	–	Favorable	Trauma
5	Male	Radial dorsum of the wrist and hand	12 × 4.5	Grafting	–	Favorable	Trauma
6	Male	Thenar region	9.0 × 4.0	Grafting	Yes	Favorable	Trauma
7	Male	Dorsum of the hand	12.0 × 7.0	Grafting	–	**Partial loss**	Trauma
8	Male	Thumb, at the level of the interphalangeal joint	9.0 × 4.0	Primary	–	Favorable	Trauma
9	Male	Amputation at the carpal level	13.0 × 4.5	Grafting	Yes	Favorable	Trauma
10	Male	Amputation at the carpal level	13.0 × 4.5	Grafting	Yes	Favorable	Trauma
11	Male	Radial dorsum of the hand	11.0 × 5.0	Grafting	–	Favorable	Trauma
12	Male	Dorsum of the first metacarpal	13.0 × 5.5	Primary	–	Favorable	Trauma
13	Male	Dorsum of the first metacarpal	8.5 × 4.0	Primary	–	Favorable	Trauma
14	Male	Dorsum of the hand	7.5 × 4.0	Grafting	–	**Total loss**	Trauma
15	Female	Radial dorsum of the wrist	7.0 × 3.0	Primary	–	Favorable	Trauma
16	Male	Volar radial region of the wrist	12.5 × 5.0	Primary	–	Favorable	Trauma
17	Male	First web space	5.5 × 4.0	Grafting	–	Favorable	Trauma
18	Female	First web space	11.0 × 3.0	Primary	–	Favorable	Trauma

Notes: *Indication or location of coverage failure; **flap in centimeters (length x width); ***supplementary grafting to the flap in the recipient area.

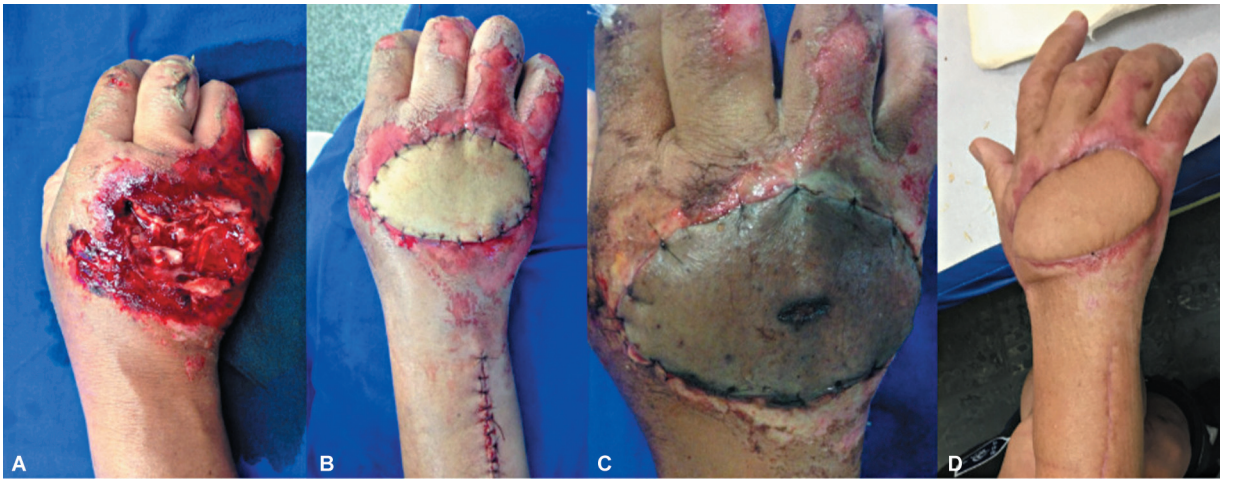


Fig. 6 (**A**) Initial soft tissue defect; (**B**) aspect immediately after covering with a posterior interosseous artery flap; (**C**) total flap necrosis; and (**D**) aspect in the late postoperative period of covering with a posterior interosseous artery flap; the patient presents with wrist flexion-extension and preserved fingers.

due to the risk of loss. However, Wu et al.[13] described eight cases of successful coverage of defects in long fingers.

The volar region of the hand with the best flap coverage capacity was the thenar region, with one case achieving good coverage of the recipient region and a good functional prognosis (►**Fig. 8**). We do not recommend palm areas beyond this limit for coverage.

The flap was also essential for the functional prognosis of the limb in cases of mutilating hand injuries. In one case with complex loss of hand structures, the flap was created to provide bony coverage to the radius, enabling the patient to perform a pinch movement (►**Fig. 9**).

In a severe case of bilateral traumatic amputation at the carpal level, we used the flap for more robust coverage of the



Fig. 7 Thumb flaps.

bilateral carpus. This coverage was an initial stage for a more adequate prosthetic fitting in the future, a factor that directly influences the functionality of the affected limb (►**Fig. 10**).

The literature shows wide variations in flap sizes. Zhou et al.[14] used different flap sizes; the largest flap was of 11 × 8.5 cm, and the smallest, 5.3 × 2.6 cm. In the series by Kumaraswamy et al.,[15] the largest flap measured 10 × 4 cm. Mago[16] described a series of 20 cases, with 2 cases of total loss, with sizes ranging from 4 × 4 cm to 10 × 8 cm. Balakrishnan et al.[17] used the smallest flap, measuring 5 × 2.5 cm, and the largest, measuring 21 × 10 cm. Ren et al.[8] considered flap width as the greatest limiting factor for its use, with a risk of loss in flaps larger than 6 cm; the authors achieved primary closure in 16.7% of cases in a sample of 30 patients. In the present study, one flap was wider than 6 cm (7 cm), and it did not suffer any loss. However, it is worth emphasizing that absolute measurements do not consider the dimensions of each patient's forearm, which vary according to the body type.

As reported by several authors, dissection should begin distally, and surgeons should seek the anastomosis of the perforating vessel between the PIA and the anterior interosseous artery at least 2 cm proximal to the dorsal wrist crease. The current study followed the same principle, and we found the perforating vessel in all cases.

Although surgeons should be aware of anatomical variations in vessels, few authors have reported their experiences with them. During dissection, Penteado et al.[4] found no anterior interosseous artery beyond the middle third of the forearm in four cases, and no anastomotic perforator in one case. In 2 out of 36 cases, Büchler e Frey[11] found no PIA beyond the middle third of the forearm. In the current study, we found a single anatomical variation (a duplicated pedicle), which did not negatively affect the dissection or outcome of the case.

The disadvantage of the PIA flap is the technical difficulty of dissection due to its thin and delicate pedicle. Furthermore, it requires identification and neurolysis of the posterior

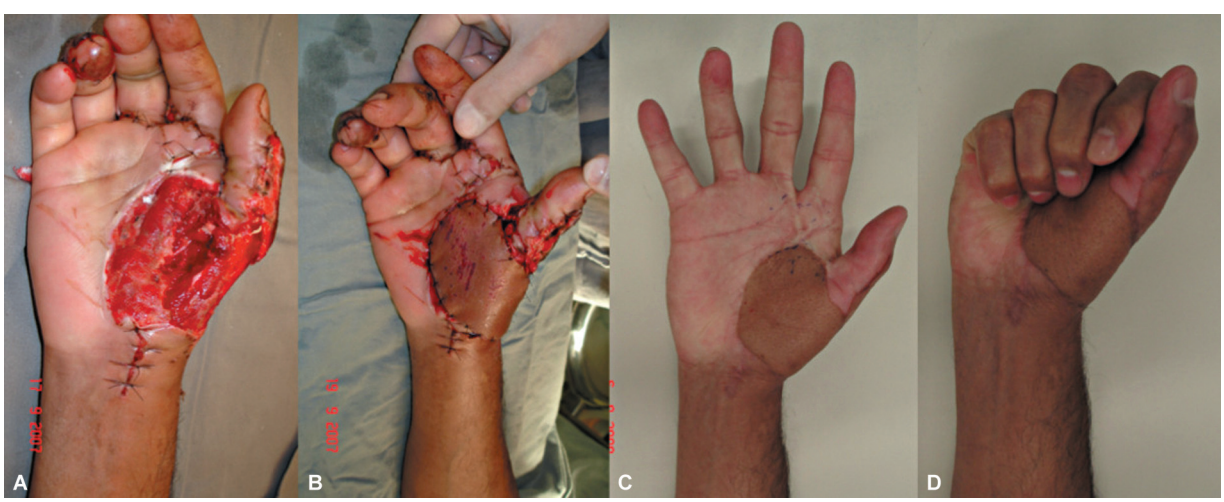


Fig. 8 (**A**) Initial soft tissue defect; (**B**) aspect immediately after covering; and (**C**,**D**) functionality 11 months after surgery.

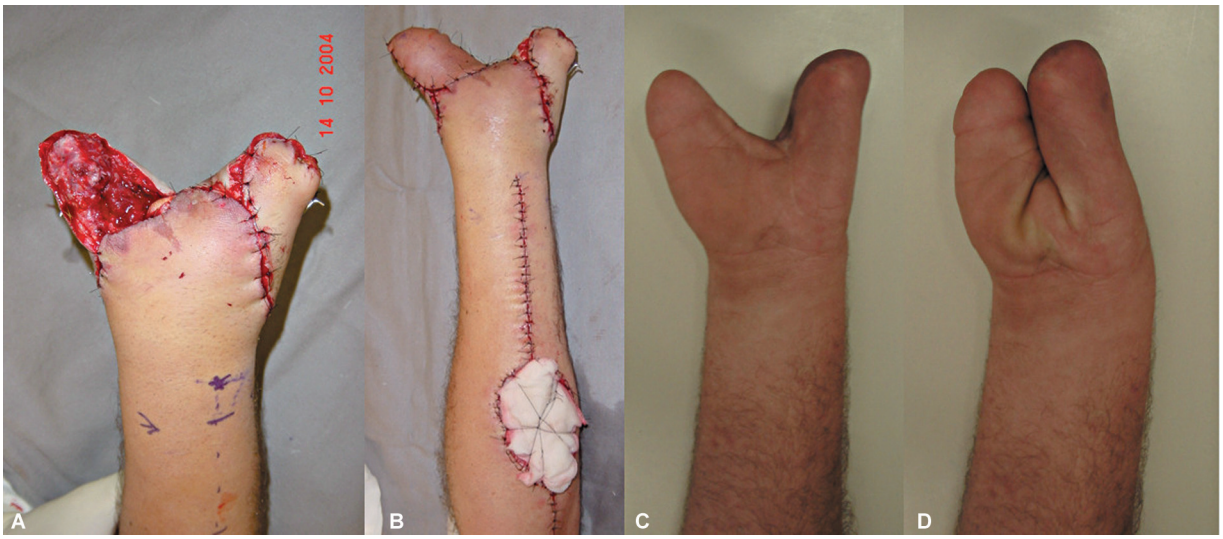


Fig. 9 (A) Initial soft tissue defect; (B) aspect immediately after covering; and (C,D) functionality 3 years after surgery.

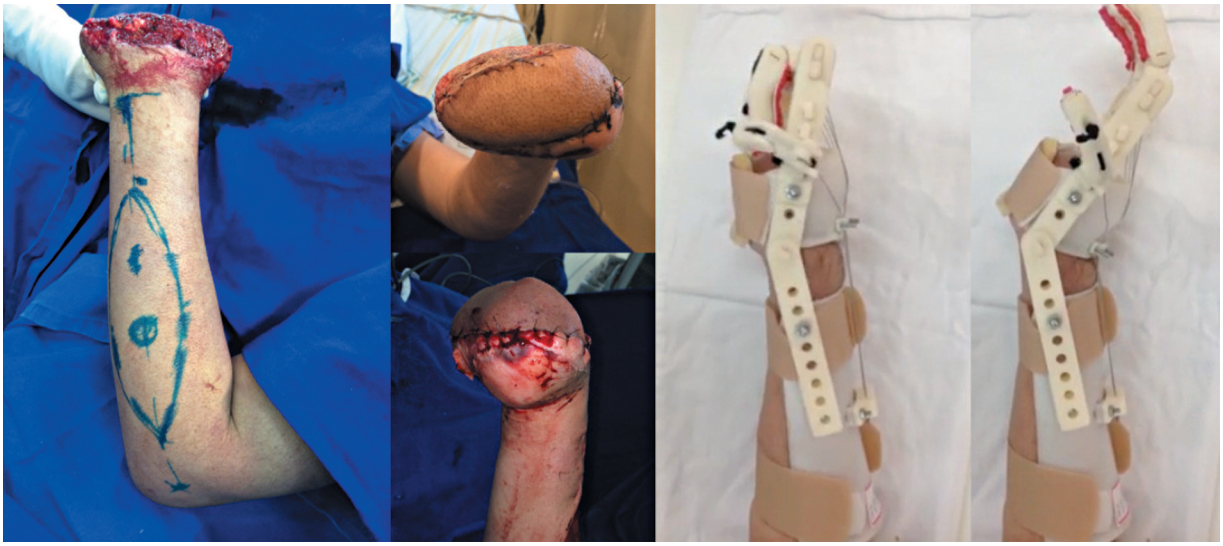


Fig. 10 Flap to help the prosthetic fitting after a complex hand amputation.

interosseous nerve to avoid finger-extension deficits. As an advantage, this flap presents good esthetic acceptance, as the thickness of the dorsal skin from the forearm is similar to that of the dorsal skin of the hand. All patients in the present study were satisfied with the cosmetic outcome.

The current study has limitations, including its small sample size and retrospective nature, which prevent drawing definitive conclusions, unlike studies with higher levels of evidence. However, it was possible to estimate parameters that aid in the surgical technique and indicate the best choice of recipient areas for the flap, reducing the likelihood of flap failure.

Conclusion

The PIA flap is a safe, predictable, and versatile option to cover defects in the hand and distal forearm, especially the dorsum, first commissure, and thumb. The morbidity is lower compared with that of other local and microsurgical flaps, resulting in shorter operative time and hospital stay, early rehabilitation, good esthetic acceptance by the patients, and good postoperative outcomes.

Authors' Contributions

Each author contributed individually and significantly to the development of the present article: ABC: conceptualization, supervision, final approval, and data collection; AISN: writing – original draft, writing – review and editing, and visualization; KCSF: writing – original draft, data analysis, and methodology; MRZ: writing – review and editing; THW: writing –review & editing, and data curation; and RMJ: visualization and validation.

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Conflict of Interests
The authors have no conflicts of interest to declare.

Acknowledgments
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Arthroplasty in Thumb (CMC Joint) Osteoarthritis: Avoiding Trapeziectomy

Artroplastia na osteoartrite do polegar (articulação CMC): Evitando a trapezectomia

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Abstract

Objective To show the postoperative clinical results, including the patient-reported time to return to the activities of daily living (ADLs), the radiographic aspects, and the grip strength of total joint arthroplasty in patients with stage-III rizarthrosis.

Methods In the present single-center and prospective study, we analyzed total joint arthroplasty with an uncemented, metal-on-polyethylene prosthesis (Maia, Groupe Lepine). The inclusion criteria were patients with stage-III carpometacarpal (CMC) joint osteoarthritis, aged >60 years, initially treated through non-surgical procedures. The exclusion criteria were patients presenting mental illness, alcohol abuse, rheumatological arthritis.

Results During the study period (from January 2018–October 2023), 34 patients met the patient selection criteria. Three eligible patients received a different implant, and two were simultaneously submitted to surgery in another joint (metacarpophalangeal joint with Z-deformity); these subjects were not included in the study. After 25.1 months of the surgery, grip strength was of 87.75% regarding the opposite side, the scores on the Visual Analogue Scale (VAS) and on the short form of the Disabilities of the Arm, Shoulder, and Hand (QuickDASH) questionnaire were of 1, and the range of motion was of 81% compared to the unaffected side. On the X-ray examination, initial metacarpal subsidence was observed in 100% of the patients. Complications were observed in 2 (6.9%) patients

Conclusion The choice of total joint arthroplasty to treat active patients aged >60 years with stage-III CMC joint arthritis preserves independence to perform ADLs and improves quality of life in the first 12 months of the procedure.

Keywords
- arthroplasty
- carpometacarpal joints
- osteoarthritis
- thumb
- trapezium bone

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Resumo

Objetivo Mostrar os resultados clínicos pós-operatórios, incluindo o tempo de retorno às atividades da vida diária (AVDs) relatado pelo paciente, os aspectos radiográficos e a força de preensão, da artroplastia total em pacientes com rizartrose em estágio III.

Métodos Neste estudo prospectivo e unicêntrico, analisou-se a artroplastia total com prótese não cimentada de metal-polietileno (Maia, Groupe Lepine). Os critérios de inclusão foram pacientes com osteoartrite da articulação carpometacarpal (CMC) em estágio III, idade acima de 60 anos, tratados inicialmente com procedimentos não cirúrgicos. Os critérios de exclusão foram pacientes com doenças mentais, abuso de álcool e artrite reumatológica.

Resultados Durante o estudo (de janeiro de 2018 a outubro de 2023), 34 pacientes atenderam aos critérios de seleção. Três pacientes elegíveis receberam outro implante, e dois foram simultaneamente submetidos a cirurgia em outra articulação (metacarpofalangiana com deformidade em Z); estes indivíduos não foram incluídos no estudo. Após 25,1 meses da cirurgia, a força de preensão era de 87,75% em relação ao lado oposto, as pontuações na Escala Visual Analógica (EVA) e na versão curta do questionário de Incapacidade do Braço, Ombro e Mão (Quick Disabilities of the Arm, Shoulder and Hand, QuickDASH) eram de 1, e a amplitude de movimento era de 81% em comparação ao lado não acometido. No exame radiográfico, observou-se subsidência inicial do metacarpo em 100% dos pacientes. Dois pacientes (6,9%) apresentaram complicações.

Conclusão A escolha da artroplastia total para o tratamento de pacientes ativos com mais de 60 anos e artrite da articulação CMC em estágio III preserva a independência para a realização de AVDs e melhora a qualidade de vida nos primeiros 12 meses após o procedimento.

Palavras-chave

- articulações carpometacarpais
- artroplastia
- osteoartrite
- polegar
- trapézio

Introduction

The prevalence of thumb basal joint arthritis increases with age and affects the ability to perform daily life activities (DLAs).[1] The number of patients seeking treatment for this condition is likely to increase.[2] However, there is no consensus regarding the prevention of total trapeziectomy in stage-III arthritis, according to the Eaton classification III.

There is doubt regarding the increase in complications and costs due to the complexity of the surgery.[2] Total joint arthroplasty (TJA) in trapeziometacarpal joint osteoarthritis can be a safe procedure in patients older than 60 years of age and in stage III after failure of the first non-surgical treatment.[3–6]

In these cases, TJA is convenient; it does not hinder the performance of other techniques in case of failure, and it is a reproducible method that avoids stiffness, preserves the length of the thumb, increases the initial range of motion (RoM), enables a faster recovery, and it is an alternative to total trapeziectomy.[7]

The objective of the present study was to present the postoperative clinical outcomes of ATJ,[2] including patient-reported time to return to DLAs, radiographic features and hand grip strength, in patients with stage-III rhizarthrosis.

Increased Cost

The need for an implant (Maia prosthesis, Groupe Lepine) increases the cost of the treatment and makes health insurers reluctant to provide coverage to the patients, despite the growing evidence of its benefits.

Methods

The current research followed the ethical standards and was approved by the institutional Ethics Committee on Human Experimentation. An informed consent form was provided to all research participants, who read and signed it according to their will.

In the present single-center prospective study, we analyzed TJA with an uncemented metal-on-polyethylene prosthesis (Maia, Groupe Lepine). The institutional Ethics in Research committee approved the free and informed consent form, which the patients signed before being included in the study. The inclusion criteria were patients with stage-III carpometacarpal (CMC) joint osteoarthritis, aged $>$ 60 years, initially treated through non-surgical procedures. The exclusion criteria were patients presenting mental illness, alcohol abuse, and rheumatological arthritis.

During the study period (from January 2018 to December 2023), 34 patients met the selection criteria. Three eligible patients received a different implant, and two were simultaneously submitted to surgery in another joint (metacarpophalangeal joint with Z-deformity); these subjects were not included in the study.



Fig. 1 Dorsal thumb approach between the abductor pollicis longus and the short extensor tendons.

Post-hoc Analysis

The post-hoc analysis showed that 29 of the patients included did not show differences regarding age, sex, or CMC joint arthritis stage, with a statistical power of 85% according to a two-sided test and level of significance of 5%.[8,9] The sample was composed of 25 women and 4 men with a mean age of 64 (range: 60–74) years. Rhizarthrosis was classified according to the Eaton classification.[10] Follow up period was 25.1 [12-66] months.

Surgical Technique

The goal of the treatment is to improve the balance between the mobility and stability of the CMC joint. Total joint arthroplasty must be perfectly positioned/fixated to enable osteointegration.[7]

The dorsal approach was chosen (►**Fig. 1**). The first step was to remove the joint surface of the base of the thumb, including the volar and medial beak osteophytes. Next, we prepared the medullary canal of the metacarpal with specific maneuver drills of increasing size until achieving press-fit stability and proper stem alignment along the metacarpal axis. The final implant was inserted, flush with the metacarpal base (►**Fig. 2**). Subsequently, we performed the cup placement in the trapezium taking care to avoid mechanical fixation of the cementless cup with the central subchondral bone and distal articular surface of the trapezium. The cup must be perfectly centered in the trapezium and in the center of motion of the CMC joint. To pass guide wire into trapezium center and the best direction that guide wire is 30° radially between the longitudinal axis of the diaphyses of the first and second metacarpals (coronal plane) and the anterior axis (sagittal plane), aided by fluoroscopy (►**Figs. 3**–**4**). Partial resection of the joint capsule was performed, with removal of free bodies and preservation of the palmar ligaments. A balance between soft tissues and implants is necessary to improve stabilization and avoid stiffness. The length of the thumb CMC joint can be assessed by comparing the length of the first and second rays before and after implanting the components. This can also be assessed by fluoroscopy, with analysis of the congruence of the first metacarpal arch on anteroposterior views with the thumb in 45° abduction, such as the "gothic arc" (►**Fig. 5**).

Total joint arthroplasty allows the restoration of the length (►**Video 1**), tendon balance, stabilization of the CMC joint and increases the best range of motion of the thumb.[7]

Video 1

Thumb dynamic fluoroscopy: total joint arthroplasty enables the restoration of the length of the thumb and of tendon balance, the stabilization of the base of the thumb, and the increase in thumb abduction. Online content including video sequences viewable at: https://www.thieme-connect.com/products/ejournals/html/10.1055/s-0045-1812997.

Postoperative Care

A long thumb thumb splint was applied at the end of surgery and maintained for two weeks postoperatively. Skinsutures were removed so that the patient could actively move the thumb. A removable short thumb plaster cast was placed to be worn at nighttime and during DLAs. Pinching movement should be encouraged after 3 weeks, after which patients have no further restrictions.

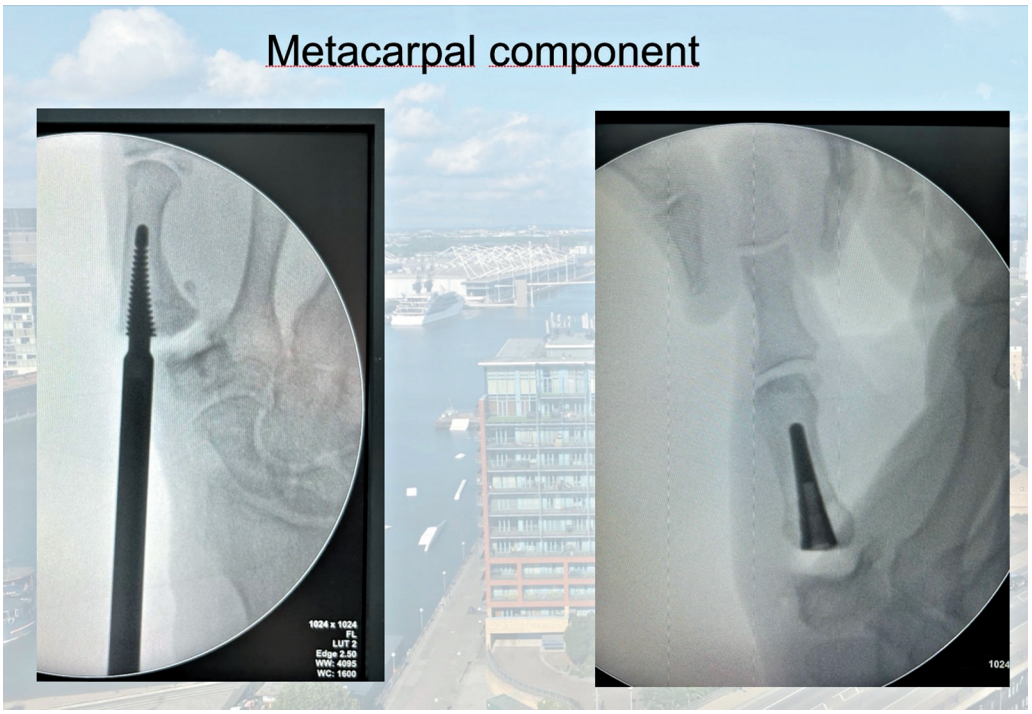


Fig. 2 Metacarpal component.

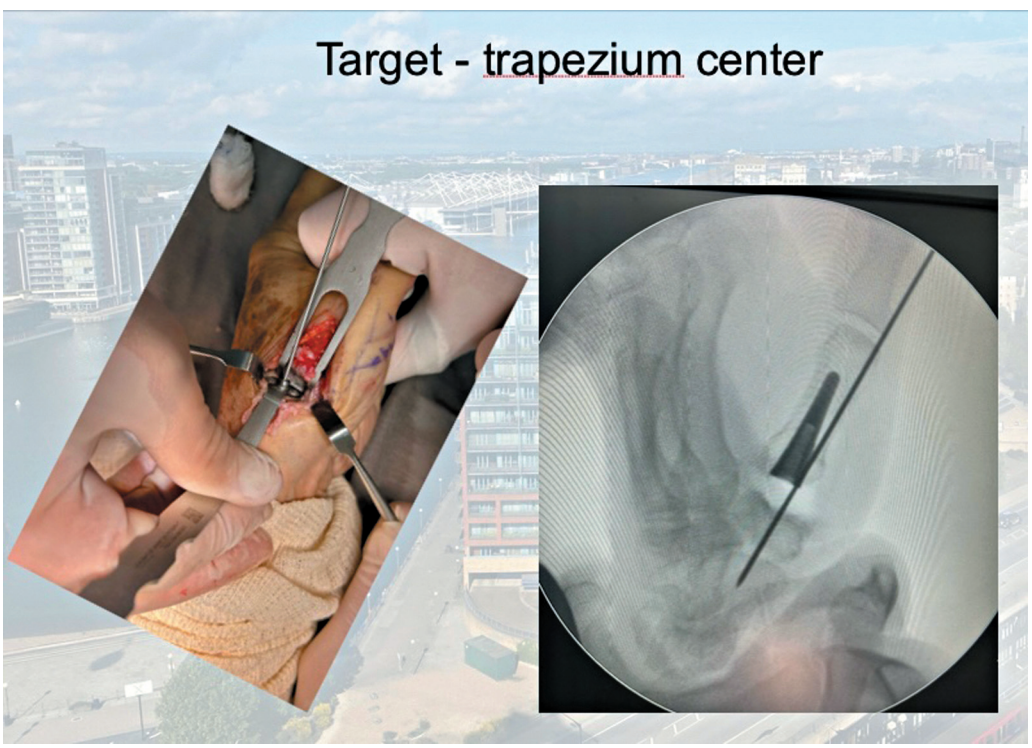


Fig. 3 Trapezium component: center of motion of the carpometacarpal joint (procedure assisted by fluoroscopy).

All patients were assessed radiographic and clinically at 6 weeks, and again at 6 and 12 months after the procedure.[11] Range of motion (RoM) was evaluated with a single tool (goniometer). Grip strength was measured with a specific Jamar hand dynamometer (Sammons Preston, Bolingbrook, IL) and value obtained was expressed as a percentage of that presented on the opposite side.[12,13] These values were classified into 4 groups according to the grip strength quartiles to in relation to the time of return to DLAs.[14]

The clinical outcomes were assessed using the Visual Analog Scale (VAS) for pain (range: 1–10, according to which 1 indicates no pain). Quality of life was determined by the Disabilities of the Arm, Shoulder and Hand (QuickDASH) questionnaire (range: 0–100, according to which 1 indicates

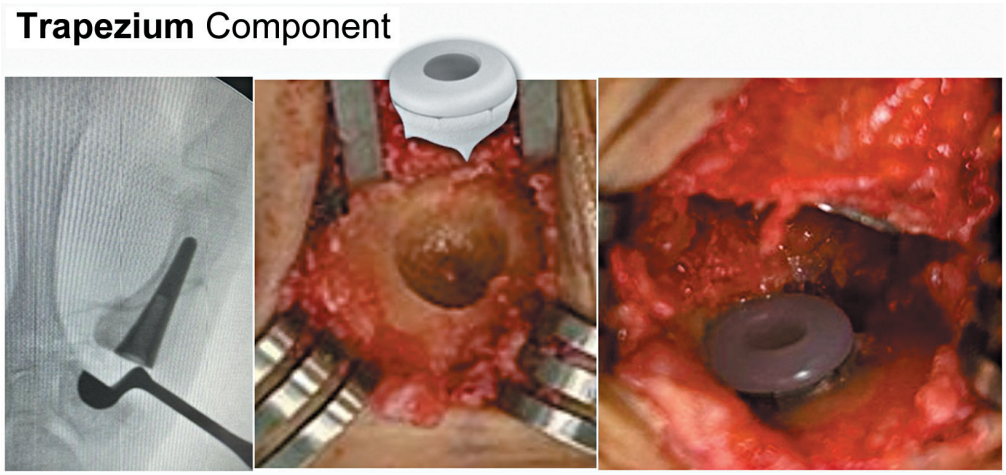


Fig. 4 Trapezium component: the cup needs to be well centered and fixed ("press fit") in the trapezium.



Fig. 5 "Gothic arc": congruency of the first and second metacarpal arches on anteroposterior view with the thumb at 45° of abduction.

the best result).[15,16] The rate of complications was assessed 6 weeks, and again at 6 and 12 months after the procedure.

Radiographic Parameters

The main parameters were dorsal subluxation, implants aspect, and metacarpal subsidence (to maintain the trapezium-metacarpal joint space), which were evaluated at 6 weeks, and 6 and 12 months after the surgery.

Statistical Methods

►**Table 1** shows the baseline demographics and the details of the injuries of the sample. The data were presented as mean or median according to the type of variable and its distribution. The objective and patient-reported outcomes are presented in ►**Table 2**. The mean VAS and QuickDASH scores were of 1 point. The RoM was 81% compared with the nonaffected side. Radiographic examination to preserve the initial parameters (implants without dislocation and without failure) showed metacarpal subsidence in 100% of patients. Complications were observed in 2 (6.9%) patients. These included trapezium fracture during surgery, which was treated with K-wire fixation and bone consolidation. Another patient presented pain and decreased thumb abduction and was treated with rehabilitation exercises, but maintained VAS = 3.

Discussion

In recent years, several studies have considered the outcomes of multiple total trapeziectomy techniques with suspensionplasty to be successful. However, recent studies[1,2,11] have proven unsuccessful and suggested other procedures (which do not prevent other techniques from being performed in case of failure) to allow for faster recovery, with less pain and greater thumb strength, such as arthroscopy/button suture or total arthroplasty..

Table 1 Demographics of the sample, side of the lesions, and associated diseases

Identification	Age (years)	Profession	Side	Sex	Associated diseases
1	69	Cook	Right	Female	—
2	63	Secretary	Right	Female	—
3	64	Designer	Right	Female	—
4	63	Designer	Left	Female	—
5	61	Secretary	Left	Female	—
6	60	Teacher	Left	Female	—
7	63	Teacher	Right	Female	—
8	60	Businesswoman	Right	Female	—
9	66	Accountant	Left	Female	—
10	62	Secretary	Left	Female	—
11	66	Nurse	Left	Female	—
12	60	Saleswoman	Right	Female	CTS
13	63	Dressmaker	Right	Female	—
14	70	Judge	Left	Female	—
15	64	Businesswoman	Left	Female	CTS
16	67	Maid	Right	Female	—
17	62	Maid	Right	Female	De Quervain tenosynovitis
18	63	Cook	Right	Female	—
19	67	Accountant	Right	Female	—
20	70	Judge	Right	Male	De Quervain tenosynovitis
21	64	Pastry chef	Right	Female	—
22	60	Driver	Right	Male	—
23	62	Seller	Right	Female	Ganglion
24	60	Businesswoman	Left	Female	—
25	70	Judge	Left	Male	CTS
26	64	Maid	Left	Female	De Quervain tenosynovitis
27	63	Designer	Left	Female	DIP arthritis
28	66	Maid	Right	Female	CTS
29	62	Businessman	Right	Male	—

Abbreviations: CTS, carpal tunnel syndrome; DIP, distal interphalangeal.

Grip strength is a valid and reliable method used to evaluate objective outcomes and is an independent predictor of of patients' inability to perform DLAs. Grip strength in the lower quartiles (first or second) increases the risk of inability to perform DLAs compared to strength in the higher quartiles (third or fourth).[13,14] In the present study, all patients showed values in the fourth quartile.

Bricout and Rezzouk[17] reported a failure rate of 7.7% in the implementation of the MAIA prosthesis in a series of 156 patients. Maeda et al.[11] showed a complications rate of 9.3%. We observed a lower incidence of complications (6.9%), and the clinical outcomes showed best RoM, shorter return time to DLAs, and a lower VAS than other studies.[2,6,7]

A criticism of the reduction in pain, complication, and costs of traditional total trapeziectomy is clear, but nowadays, it is not only about reducing pain but also maintaining grip strength, range of motion and functional capacity to perform ADLs is to maintain trapezialmetacarpal length and reducing the dorsal subluxation of the thumb metacarpal[18] because increasing grip strength and it is appropriate to perform procedures that preserve the biomechanics of the thumb joint and, if it fails, we can perform another salvage procedure, such as preserving the trapezium by performing this prosthesis and, if this fails, a total trapeziectomy can be performed and thus we do not skip treatment steps. ("no burnt bridges" concept). Newton and Talwalkar,[2] Duerinckx and Verstreken,[7] and this study have demonstrated that TJA has certain advantages over other options, including stabilization and alignment of the CMC joint and preservation of the ability to perform DLAs and thumb length. Hustedt et al.[8] showed that the time of return to work was 4.5 months in patients who had undergone total trapeziectomy. In our study, 93.1% of those who underwent the procedure returned to work within 2 months.

Table 2 Objective and patient-reported outcomes

Identification	Follow-up (months)	RoM (% opposite side) at 12 months	Quick DASH score	VAS score	Grip strength (% opposite side)	ǀReturn to ADLs (months)	Complications
1	39	81	1	1	96	1	—
2	40	90	1	1	97	2	—
3	34	84	1	1	94	1	—
4	34	88	1	1	96	1	—
5	31	91	1	1	94	2	—
6	31	90	1	1	94	2	—
7	29	82	1	1	98	1	—
8	29	78	1	1	97	2	—
9	20	82	1	1	99	1	—
10	66	88	1	2	83	5	Trapezium fracture
11	76	91	1	1	91	1	—
12	36	80	1	1	96	1	—
13	14	78	1	1	92	1	—
14	12	74	1	1	94	2	—
15	17	79	1	1	96	1	—
16	16	82	1	1	98	1	—
17	18	83	1	1	87	2	—
18	19	91	1	1	98	2	—
19	14	90	1	2	96	1	—
20	14	90	1	1	96	1	—
21	14	82	5	3	87	6	—
22	24	88	1	1	96	1	—
23	21	73	1	1	91	1	—
24	20	89	1	2	83	1	—
25	12	70	11	2	82	5	Pain
26	12	64	1	1	81	1	—
27	12	63	1	1	96	2	—
28	12	66	1	1	92	1	—
29	12	62	1	1	97	1	—
Mean	**25.10**	**81**	**1**	**1**	**87.75**	**2**	

Abbreviations: ADL, activities of daily living; DASH, Disabilities of the Arm, Shoulder and Hand; RoM, range of motion; VAS, visual analog scale.

Farkash et al.[19] reported a failure rate 11,32%, with these failed procedures in patients treated with partial arthroplasty of the CMC joint. The disadvantages of this method include costs, technical difficulty of the surgery, and the possible complication rate.

Currently, the concept "no burnt bridges" is accepted, and early definitive surgery in CMC joint arthritis, such as, total trapeziectomy, is controversial, because their exhausts surgical treatment options. This concept recommends the use of thumb arthroscopy or arthroplasty[20,21] whenever possible. This approach improves the patients' quality of life and reduces recovery time for DLAs and work-related activities. In addition, in case of failure, all surgical revision methods can be performed.

The present study is a prospective clinical trial, and all patients were operated on by a single hand surgeon, constituting a uniform group with complete follow-up. Nonetheless, some limitations need to be recognized. The present study is a case series and not a randomized clinical trial, the inclusion criterion was stage III according to the Eaton classification, and the sample size was small for QuickDASH, VAS, and grip strength analysis.

The increased cost is the main reason behind the difficulty in performing TJA. The method and implant for the treatment of thumb arthritis have evolved exponentially, generating excellent and are an option before comparative studies can consider them the gold standard and procedure of choice.[21]

Conclusion

The choice of TJA to treat active patients > 60 years old, with stage-III CMC joint arthritis, helps to preserve independence to perform DLAs and improve the patients' life quality in the first 12 months after the procedure.

Author Contributions

Each author contributed individually and significantly to the development of this article. ML: validation of the translation; CR: review, visualization, writing, conceptualization, data curation, formal analysis, investigation, methodology, validation, review, and final editing; SS: review; SCP: data collection and analysis; MAA: data collection and analysis, visualization, writing, conceptualization, data curation, formal analysis, investigation, methodology, validation, review, and final editing; and GAA: visualization, writing, conceptualization, data curation, formal analysis, investigation, methodology, validation, review, and final editing.

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Conflict of Interests

The authors have no conflict of interests to declare.

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Fat Harvesting for Micro-Fragmented Adipose Tissue Injections: A Pilot Study Comparing Safety in Procedures Performed by Orthopedic and Plastic Surgeons

Coleta de gordura para injeções de tecido adiposo microfragmentado: Estudo piloto de comparação da segurança de procedimentos realizados por cirurgiões ortopédicos ou plásticos

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Abstract

Objective To compare short-term complication rates of small-volume adipose tissue harvesting for micro-fragmented adipose tissue (mFAT) knee injections performed by orthopedic surgeons with those performed by plastic surgeons. Additionally, to evaluate the orthopedic surgeon's learning curve.

Methods The present case-control study enrolled patients with knee osteoarthritis. All patients underwent a single-stage procedure consisting of abdominal adipose tissue harvesting, processing of the extracted material using the Lipogems (Lipogems International SpA) device to obtain mFAT, which was then injected intra-articularly into the knee. The patients were divided into a test group, with harvesting being performed by a recently trained orthopedic surgeon, and a control group, in which the procedure was performed by an experienced plastic surgeon. Short-term adverse effects, minor and major complications related to harvesting, were assessed intra-operatively and at 7-day follow-up.

Keywords
- adipose tissue
- osteoarthritis
- osteoarthritis, knee

The present work was developed at Grupo de Joelho, Instituto de Ortopedia e Traumatologia, Hospital das Clínicas (HCFMUSP), Faculdade de Medicina, Universidade de São Paulo, São Paulo, SP, Brazil.

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Results No major complications (fat embolism, thromboembolic events, abdominal perforation, wound infection, dehiscence, or cosmetic changes) were observed in either group. Abdominal discomfort during harvesting, classified as a minor complication, showed no statistically significant difference between groups ($p = 0.362$). Postoperative adverse effects, such as abdominal ecchymosis ($p = 0.362$) and discomfort ($p = 0.342$), were equivalent in both groups and resolved within 7 days.
Conclusion The present pilot study suggests that, with adequate training, orthopedic surgeons can perform small-volume adipose tissue harvesting with low complication rates, comparable to those achieved by plastic surgeons experienced in liposuction.

Resumo

Objetivo Este estudo teve como objetivo comparar as taxas de complicações em curto prazo da coleta de tecido adiposo em pequeno volume para injeções de tecido adiposo microfragmentado (mFAT) no joelho realizada por um cirurgião ortopédico ou um cirurgião plástico, além de avaliar a curva de aprendizado de cirurgiões ortopédicos.
Métodos Este estudo de caso-controle incluiu pacientes com osteoartrite de joelho. Todos os pacientes foram submetidos a um procedimento em estágio único composto por coleta de tecido adiposo abdominal, processamento do material extraído com o dispositivo Lipogems (Lipogems International SpA) para obtenção de mFAT, que foi injetada via intra-articular no joelho. Os pacientes foram divididos em grupo teste, no qual a coleta foi realizada por um cirurgião ortopédico recém-treinado; e grupo controle, no qual o procedimento foi feito por um cirurgião plástico com experiência. Efeitos adversos em curto prazo e complicações mais e menos sérias relacionadas à coleta foram avaliados no período intraoperatório e à consulta de acompanhamento 7 dias após a cirurgia.
Resultados Nenhum paciente apresentou complicações mais sérias (embolia gordurosa, eventos tromboembólicos, perfuração abdominal, infecção da ferida, deiscência ou alterações estéticas). A taxa de desconforto abdominal durante a coleta, classificado como complicação menor, não apresentou diferença estatisticamente significativa entre os grupos ($p = 0{,}362$). Os efeitos adversos pós-operatórios, como equimoses ($p = 0{,}362$) e desconforto ($p = 0{,}342$) abdominais, foram equivalentes em ambos os grupos e se resolveram em 7 dias.
Conclusão Este estudo piloto sugere que, com treinamento adequado, cirurgiões ortopédicos podem realizar a coleta de tecido adiposo em pequeno volume com baixas taxas de complicações, comparáveis às observadas em procedimentos realizados por cirurgiões plásticos experientes em lipoaspiração.

Palavras-chave
- osteoartrite
- osteoartrite do joelho
- tecido adiposo

Introduction

Knee osteoarthritis (KOA) is a highly prevalent condition that affects a significant share of the global population. The overall prevalence of symptomatic KOA is estimated at 30%, with rates reaching 44% in men and 28% in women aged 55 to 64 years.[1] Treatments vary according to symptom severity and patients' needs. Injectable therapies are widely used to provide intermediate-term pain relief. Among the available injectable options, micro-fragmented adipose tissue (mFAT) has gained attention for its promising results in pain reduction.[2,3] Several studies, including clinical trials, have reported superior outcomes in KOA patients treated with mFAT compared to those receiving conservative treatment or hyaluronic acid injections.[4–8]

In aesthetic and reconstructive settings, liposuction is considered a minor procedure when the extracted volume is less than 1,000 mL. It is typically performed under local anesthesia, being associated with low complication rates. In contrast, large-volume liposuctions (i.e. > 10% of body weight) generally require general anesthesia and are associated with higher risks, including infection, hematoma, ecchymosis, and fat or pulmonary embolism.[9]

However, in orthopedic practice, the volume of adipose tissue required is minimal. Studies suggested that harvesting less than 50 mL is sufficient to produce 5 to 10 mL of mFAT, an adequate volume for injections into large joints such as the knee.[10,11] Given the small volume and minimally invasive natures of the procedure, local anesthesia is usually sufficient—supporting the notion

that, with proper training, orthopedic surgeons could be well suited to perform it safely.

While small-volume liposuction may be feasible for orthopedic surgeons, assessing its safety when performed by nonplastic surgery specialists remains essential. Therefore, this study aims to compare the short-term complication rates of small-volume adipose tissue harvesting for mFAT injections in KOA, when performed by orthopedic versus plastic surgeons. We hypothesize that complication rates are comparable between the two specialties.

Methods

The present case-control study was approved by the local ethics committee (CAAE: 52440821.5.0000.0068), and all participants provided written informed consent. We assessed adverse effects and complications related to abdominal adipose tissue harvesting in patients with KOA. In the test group, the procedure was performed by a recently trained orthopedic surgeon and, in the control group, by a plastic surgeon. All patients underwent a single-stage procedure consisting of abdominal adipose tissue harvesting, processing with the single-use Lipogems device (Lipogems International SpA) to obtain mFAT, followed by intra-articular injection into the affected knee.

Patients were eligible to receive unilateral or bilateral intra-articular knee injections based on clinical symptoms. Inclusion criteria were patients with symptomatic KOA confirmed by radiographic evaluation, with all Kellgren-Lawrence grades (1–4) accepted. Exclusion criteria were varus or valgus deformity greater than 10° and body mass index (BMI) above 40kg/m^2.

A total of 33 procedures were performed. In the first 13 cases, adipose tissue harvesting was conducted by a board-certified plastic surgeon with extensive liposuction experience, while a board-certified orthopedic surgeon observed and received hands-on training. The remaining 20 procedures were conducted independently by the orthopedic surgeon. All intra-articular knee injections were performed under ultrasound guidance.

Adipose Tissue Harvesting and mFAT Processing

Abdominal adipose tissue harvesting, processing with the Lipogems device, and ultrasound-guided injections were performed in a single-stage procedure. Patients were placed in a supine position under sterile conditions in the operating room and received local anesthesia. The lower abdomen was chosen as the standardized harvest site due to accessibility and consistent adipose tissue volume. Skin portals were marked bilaterally above the inguinal line (►**Fig. 1A**), and 1 mL of 2% lidocaine was administered at each portal (►**Fig. 1B**). After allowing time for anesthetic onset, small incisions of approximately 4 mm were made using an 11-blade scalpel.

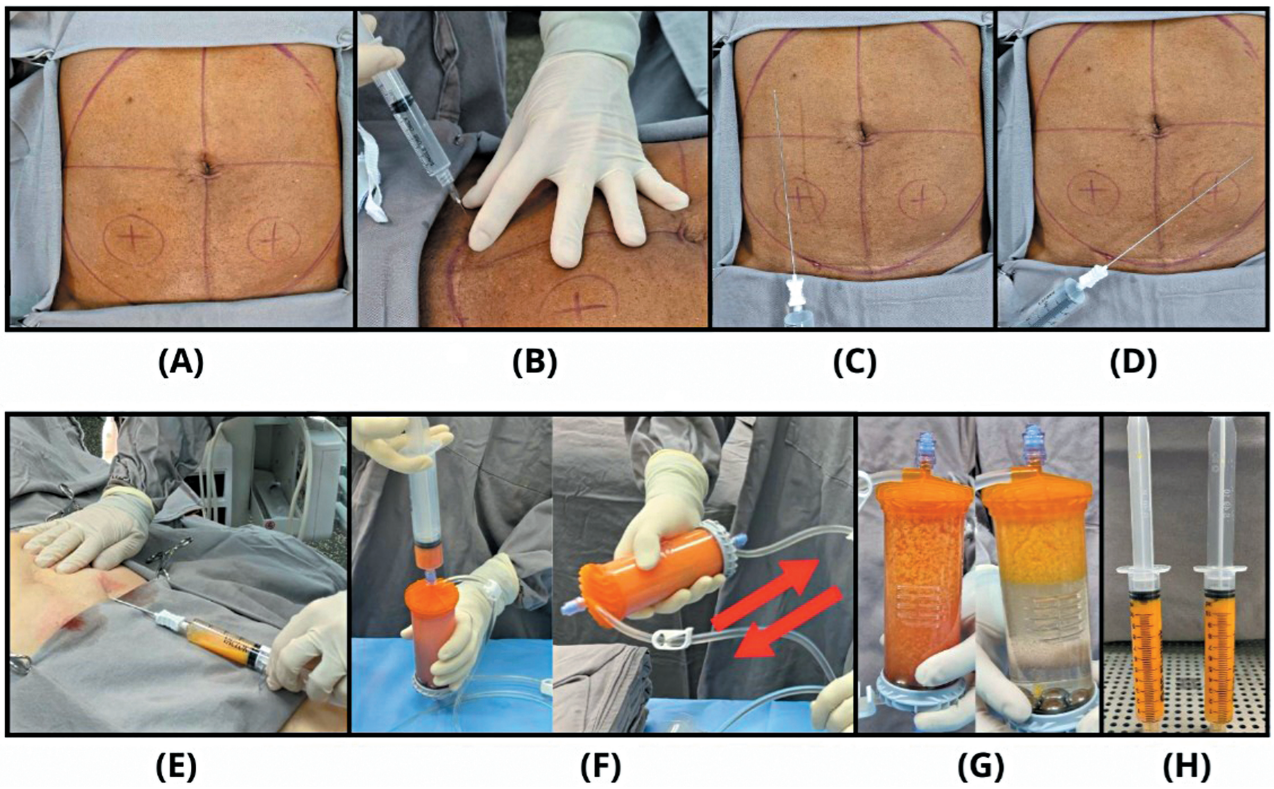


Fig. 1 (**A**) Skin portals were marked bilaterally above the inguinal line. (**B**) 1 mL of 2% lidocaine was administered at each portal. (**C, D**) Anesthetic solution was infiltrated into each hemi-abdomen. (**E**) Adipose tissue was harvested using a 13G cannula connected to a VacLock syringe. (**F**) Mechanical microfragmentation of the harvested adipose tissue. (**G**) Changes in tissue appearance following successive washes and fragmentation. (**H**) Final mFAT product ready for intra-articular injection into the knee.

Adipose tissue was harvested using a two-stage tumescent technique.[12] Anesthetic infiltration involved introducing a cannula through each portal to distribute the solution throughout the subcutaneous harvest area. Infiltration was performed using a 19G cannula provided in the Lipogems kit. The injected anesthetic solution was composed of 20 mL of 2% lidocaine, 20 mL of 0.5% bupivacaine, 1 mL of 1 mg/mL adrenaline, and 250 mL of 0.9% saline, yielding a total volume of 291 mL. This total was split into 120 mL for each hemiabdomen, with the remaining 51 mL reserved for additional anesthesia if necessary (►**Figs. 1C** and **D**). Following an appropriate latency period, adipose tissue was harvested using a 13G cannula (also provided in the Lipogems kit) connected to a VacLock syringe (Merit Medical Systems Inc.), as shown in ►**Fig. 1E**. Harvesting was performed uniformly, avoiding repeated extraction near the portal sites to minimize potential cosmetic concerns.

The remaining subcutaneous fat was assessed by repeatedly pinching the area, a reliable technique to ensure an adequate tissue layer remained and to avoid cosmetic alterations.[13] For patients with unilateral KOA, 60 mL of adipose tissue was harvested, while those with bilateral underwent harvesting of 120 mL. These volumes were standardized based on previous studies indicating the amount of adipose tissue required to yield 10 mL of mFAT per knee.[14]

After harvesting, the skin portals were closed using 5.0 nylon sutures. Adipose tissue processing was performed with the single-use Lipogems device, following protocols established by previous studies (►**Figs. 1F–H**).[2] The resulting mFAT was injected into the knee via a superolateral approach under ultrasound guidance using a 16G needle. Immobilization was not required, and patients were encouraged to begin knee range of motion exercises on the first day after the procedure.

Data Collection

Demographic data, including age, sex and BMI were collected from each patient. The volume of adipose tissue harvested and the amount of mFAT obtained were also recorded. Complications related to the harvesting procedure were assessed on the same day and again at a scheduled 7-day follow-up visit. Complications were categorized according to the Clavien-Dindo system, as follows:

- Major complications (Clavien-Dindo grade III or higher) included fat embolism, venous thromboembolic events, abdominal perforation, wound infection requiring surgical intervention, intra-articular infection, and significant cosmetic alterations.
- Minor complications (Clavien-Dindo grades I and II) included expected or mild adverse events such as abdominal ecchymosis, discomfort, or other complications resulting in no residual impairment.

Statistical Analysis

Categorical variables were reported as the number of events and corresponding percentages, while continuous variables were presented as mean ± standard deviations (SDs). The Shapiro-Wilk test was used to assess the normality of continuous variables. Depending on distribution, comparisons between continuous variables were made using either the t-test or Mann-Whitney test. Fisher's exact test was utilized for comparing categorical variables. Statistical significance was defined as p-value < 0.05.

Results

A total of 33 patients were included in the study. Of those, 13 underwent adipose tissue harvesting by a plastic surgeon, and 20 by an orthopedic surgeon, divided into groups. The mean age was 61.2 ± 10.2 years in the plastic surgeon group, and 60.4 ± 8.6 years in the orthopedic surgeon group ($p = 0.802$). The mean BMI was 27.7 ± 4.5 kg/m^2 in the plastic surgeon group and 29.3 ± 4.6 kg/m^2 in the orthopedic one ($p = 0.349$).

The mean volume of adipose tissue harvested did not differ significantly between groups (plastic: 117.7 ± 15.4 mL vs. orthopedic: 123.0 ± 33.8 mL; $p = 0.245$). Similarly, the volume of mFAT obtained after processing the adipose tissue

Table 1 Patient characteristics and adverse events according to surgeon specialty

	Orthopedic surgeon	Plastic surgeon	*p*-value
Number of cases	20	13	
Age, years	60.4 ± 8.6	61.2 ± 10.2	0.802
Sex, female/male	17/3	10/3	0.659
BMI, kg/m^2	29.3 ± 4.6	27.7 ± 4.5	0.349
Bilateral KOA	12 (60)	11 (84.6)	0.246
Adipose tissue volume, ml	123.0 ± 33.8	117.7 ± 15.4	0.245
mFAT volume, ml	27.4 ± 11.1	28.5 ± 3.1	0.645
Minor complications	2 (18.2)	2 (10)	0.362
Abdominal ecchymosis	17	12	0.362
Abdominal discomfort	16	11	0.342

Abbreviations: BMI, body mass index; KOA, knee osteoarthritis; mFAT, micro-fragmented adipose tissue.
Note: Values are expressed as mean ± SD or number (percentage).

was comparable between the groups (28.5 ± 3.1 mL vs. 27.4 ± 11.1 mL; $p = 0.645$).

No major complications were observed in either group. There were two minor complications—described as patient discomfort during the harvesting procedure—reported in each group. At the 7-day follow-up, abdominal ecchymosis was observed in 12 patients (92.3%) in the plastic surgeon group and 17 (85.0%) in the orthopedic one. Abdominal discomfort was reported in 11 (84.6%) in the plastic surgeon group and 16 (80.0%) in the orthopedic surgeon group. Baseline characteristics and outcomes are summarized in ►**Table 1**.

Discussion

The main finding of this pilot study is that, with proper training, orthopedic surgeons can safely and effectively perform adipose tissue harvesting for mFAT injections. There were similarly low complication rates in procedures performed by orthopedic and plastic surgeons. Additionally, the similar volumes of adipose tissue harvested and processed in both groups support the feasibility of this procedure when performed by orthopedic surgeons.

Notably, the average volume of mFAT obtained per patient was nearly three times greater than the amount typically required for a single large-joint injection, such as in the knee. This is particularly relevant for patients undergoing unilateral injections, for whom smaller harvest volumes may suffice.

Previous studies have reported low complication rates for liposuction, even with larger volumes. For instance, Aljerian et al.[15] conducted a meta-analysis including 60 studies and 21,776 patients, reporting an overall complication rate of 12%, primarily due to ecchymosis and edema. When these side effects were excluded, the rate of minor complications dropped to 5%, and major complications were observed in only 1% of cases. Minor complications included cosmetic changes, seroma, hematoma, ecchymosis, and edema, while major complications encompassed deep venous thrombosis, sepsis, visceral damage, hypovolemia, and pulmonary complications. It is important to note that their analysis focused on high-volume liposuction procedures for aesthetic purposes.

Chow et al.[16] investigated thresholds for liposuction safety and concluded that exceeding 100 mL per unit of BMI may increase risk of complications. Consequently, in a patient with a BMI of 30 kg/m^2, volumes of up to 3,000 mL were still considered safe. Notably, those procedures were performed under general anesthesia by board-certified plastic surgeons.

Another important consideration involves the potential risk of anesthetic toxicity. The literature suggests the safe use of lidocaine up to 35 mg/kg and, despite the relatively high dose used in tumescent techniques, this approach remains considered safe for several reasons.[17] First, although the technique requires a large volume of dilute anesthetic solution, the addition of epinephrine slows lidocaine absorption, with peak plasma levels typically occurring 12 to 14 hours after the infiltration. Furthermore, liposuction itself reduces the total amount of lidocaine absorbed systemically. The technique also minimizes blood loss due to the vasoconstrictor effects of epinephrine. Taking these factors into account, we chose to employ the tumescent technique, which proved effective in minimizing abdominal discomfort during adipose tissue harvesting.

Regarding the injected volume, in our study, 10 mL of mFAT was injected in each affected knee. While this volume appears appropriate for large joints, smaller ones may require even less. In a case series of patients with hip osteoarthritis, Dall'Oca et al.[18] reported harvesting 60 mL of adipose tissue, which yielded 5 to 10 mL of mFAT; this amount effectively reduced pain and improved clinical outcomes. Similarly, D'Ambrosi et al.[19] harvested 45 mL of adipose tissue and injected 5 mL of mFAT into arthritic ankles, also with favorable clinical results. These examples highlight that orthopedic applications typically require smaller volumes than for cosmetic purposes, even for bilateral procedures involving large joints. This distinction is important, as it supports the feasibility of performing such procedures in outpatients' settings—an especially relevant point given the high prevalence of osteoarthritis and the importance of cost containment. Therefore, by reducing hospitalization, operating room time, and anesthesia costs, this approach may broaden access to regenerative treatments.

In our study, patient discomfort during the procedure—including inadequate positioning or harvesting-related—was classified as a minor complication. Because all procedures were performed under local anesthesia, these events were more frequent during the early learning curve. However, as both the orthopedic and plastic surgeons gained experience, such occurrences became less common. We attribute this initial discomfort to a slower procedural pace in the first cases. This highlighted the importance of optimal and ergonomic patient positioning, particularly under local anesthesia. Additionally, careful mapping of the harvesting area and complete infiltration with the tumescent solution appeared important for minimizing discomfort during the harvesting. Although we prepared 291 mL of Klein's solution for local anesthesia, only 240 mL were administered (120 mL per hemiabdomen). The remaining volume was reserved for use if additional anesthesia became necessary.

No major complications were observed in our pilot study. Other studies assessing the safety of mFAT for KOA have reported similarly low complication rates related to adipose tissue harvesting.[20–23] Likewise, Aljerian et al. estimated major complication rates as low as 1%, even in large-volume liposuction procedures.[15]

Visceral and vascular injuries caused by infiltration needles or liposuction cannulas are rare and have mostly been reported in patients with abdominal scars or hernias, or in high-volume cases performed under general anesthesia.[24–26] In our study, all patients underwent thorough preoperative evaluation, and previous abdominal incisions were avoided by employing the two-portal technique. Furthermore, abdominal discomfort and ecchymoses were anticipated as common side effects. These events were discussed with all patients during the consent process, and topical or pain

medications were used to attenuate ecchymosis or abdominal discomfort.

Our study is not without limitations. The plastic surgeon performed the initial 13 procedures, while the subsequent 20 were carried out by the orthopedic surgeon. As such, it is plausible that the surgical team gained familiarity with the protocol over time, potentially improving efficiency in the later cases. However, it is important to note that the plastic surgeon already had prior experience with liposuction in other clinical contexts. In contrast, the orthopedic surgeon had no prior hands-on experience and only limited observational training during the initial cases, making it unlikely that this brief exposure surpassed the expertise of the plastic surgeon.

Another limitation is the absence of a formal sample size calculation, which, although acceptable for a pilot study, limits the generalizability of the findings. Therefore, randomized clinical trials specifically designed to compare outcomes of adipose tissue harvesting between surgical specialties could provide more robust evidence. Nevertheless, to our knowledge, this is the first study to compare complication rates between orthopedic and plastic surgeons. Our findings contribute to the literature by showing that small-volume adipose tissue harvesting can be safely performed by trained orthopedic surgeons.

Conclusions

Assessing the safety of small-volume adipose tissue harvesting performed by orthopedic surgeons is essential to broaden access to this treatment. Our findings support the notion that, with appropriate training, orthopedic surgeons can achieve low complication rates when harvesting limited volumes of adipose tissue for orthopedic applications. As an exploratory study, these results provide a foundation for future research aimed at evaluating the learning curve and comparing outcomes across different harvesting sites.

Authors' Contributions

BBV: conceptualization, methodology, investigation, writing – original draft, and writing – review & editing. RBC: formal analysis, writing – original draft, and writing – review & editing. CBGL: writing – original draft, supervision, and validation. PNG: writing – original draft, methodology, and supervision. RGG: writing – original draft, supervision, and resources. MKD: writing – original draft, and project administration.

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Conflict of Interests

The authors have no conflict of interests to declare.

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Value of Clinical Tests in Diagnosing Anterior Cruciate Ligament Tears: What Is New?

Valor dos exames clínicos para o diagnóstico de rupturas do ligamento cruzado anterior: O que há de novo?

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Abstract

Objective To investigate the value of clinical diagnostic tests for diagnosing anterior cruciate ligament (ACL) tears with the anterior drawer, Lachman, Pivot-shift, lever sign, and Forced Active Buckling (FAB)-sign tests.

Methods A cross-sectional study was conducted on 165 knee injury patients who were indicated for knee arthroscopy from January to December 2022. The clinical examination results were compared with the procedure's gold standard to determine the value of clinical diagnostic tests.

Results The sensitivity and specificity values, respectively, were anterior drawer test: 77.5% and 86.1%; Lachman: 87.6% and 88.9%; Pivot-shift: 65.9% and 94.4%; Lever sign: 93.8% and 94.4%; and FAB sign: 81.4% and 97.2%.

Conclusion There are various clinical diagnostic tests for ACL tears. The Lever sign is a useful clinical test for physicians to examine and diagnose this condition.

Keywords

- anterior cruciate ligament injuries
- knee injuries
- meniscus
- rupture

Resumo

Objetivo Investigar o valor dos exames clínicos para diagnóstico de rupturas do ligamento cruzado anterior (LCA) com os testes da gaveta anterior, Lachman, *pivot-shift*, sinal de alavanca e sinal de flambagem ativa forçada (FAB, do inglês *forced active buckling*).

Métodos Este estudo transversal foi conduzido com 165 pacientes com lesão no joelho e indicação para artroscopia, entre janeiro e dezembro de 2022. Os resultados dos exames clínicos foram comparados ao padrão-ouro do procedimento para determinar o valor dos testes diagnósticos.

Resultados Os valores de sensibilidade e especificidade foram, respectivamente: teste da gaveta anterior: 77,5% e 86,1%; Lachman: 87,6% e 88,9%; *pivot-shift*: 65,9% e 94,4%; sinal de alavanca: 93,8% e 94,4%; e sinal de FAB: 81,4% e 97,2%.

Conclusão Há diversos exames clínicos para rupturas do LCA. O sinal da alavanca é um teste clínico útil para exame e diagnóstico dessa condição.

Palavras-chave

- lesões do ligamento cruzado anterior
- lesões do joelho
- menisco
- ruptura

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Introduction

The anterior cruciate ligament (ACL) plays a pivotal role in stabilizing the knee joint by preventing excessive forward movement and internal tibia rotation. An ACL tear, whether partial or complete, constitutes a substantial knee injury. The annual incidence rate within the general population ranges from 30 to 80 cases per 100,000 person-years. This injury is notably prevalent among younger individuals, with approximately 70% of cases stemming from sports-related trauma.[1,2]

Early diagnosis of ACL injuries is crucial for selecting the appropriate treatment regimen and optimizing outcomes.[3] The gold standard for this condition is direct arthroscopic imaging, though magnetic resonance imaging (MRI) findings are also considered a reference standard, with sensitivity and specificity ranging from 94 to 98%.[4] However, not every healthcare facility in less developed countries has access to the necessary diagnostic equipment. Therefore, clinical examination for detecting ACL injuries remains highly valuable.

The three most widely accepted clinical methods for diagnosing ACL tears include the anterior drawer, Lachman, and pivot-shift tests. In 2014, Italian physician Allesandro Lelli published a research report on the lever sign test (also known as the Lelli test), conducted on 400 patients. Compared with MRI, preliminary results showed nearly 100% sensitivity in diagnosing partial or complete ACL tears, both acute and chronic. This is a clinically feasible method that is not dependent on the acuteness of the injury.[3]

In 2020, Fabian Blanke, a German orthopedic surgeon, introduced a new clinical method for diagnosing ACL tears in the subacute phase called the Forced Active Buckling (FAB) sign. This method is believed to have higher sensitivity and specificity than the Lachman and pivot-shift tests.[5] To enhance the diagnostic arsenal for ACL tears in clinical practice, the present research was conducted to investigate the value of various clinical methods in diagnosing ACL injuries.

Materials and Methods

Participants

This was a cross-sectional study conducted on 165 knee injury patients who were indicated for knee arthroscopy surgery at Danang Hospital from January to December 2022. The inclusion criteria were as follows: individuals (1) who are 14-years or older, (2) with history of knee injury, and (3) having a scheduled unilateral arthroscopic surgery. Individuals were excluded from the study if they had a history of knee surgery, knee infection, bilateral knee diseases, or fractures around the knee.

All participants provided written informed consent. The study was conducted in accordance with the Declaration of Helsinki and approved by the review board under the number HDYD2021/45, on December 15, 2021.

Study Design

Patients were selected for the study from the daily surgery schedule. The general information recorded was age, gender, knee injury, cause of injury, stages of injury (acute < 3 weeks, subacute 3–12 weeks, chronic ≥ 12 weeks). Then, we evaluated clinical preoperative examinations by only one orthopedic surgeon (without knowing the patient's diagnosis).

Knee arthroscopies were performed by our senior surgeon, who specialized in knee surgery and was not aware of physical examination results. The intraoperative results (whether the ACL is torn or not) were documented. Then, we compared the clinical examination results with the gold standard to determine the value of clinical tests.

Physical Examinations

Anterior drawer, Lachman, and pivot-shift tests were conducted, as described in the literature.[2]

For the lever sign test (or Lelli), the patient was laid in a supine position on a rigid surface with the knee fully extended. The examiner placed one hand under the lower third of the calf and exerts a moderate downward force on the lower third of the quadriceps with the other hand. A positive test is indicated when the heel does not lift off the examination table. This suggests an ACL tear, as the tibia fails to lever forward with the applied force on the femur. Conversely, a negative test occurs when the heel lifts off the table.[6]

In the FAB-sign test (describing examination of the left leg), the patient was placed in a supine position. The examiner stood at their left side, flexing the left hip until the knee is around 20 to 30° of flexion. The left hand grasped the patient's ankle and applied an internal rotation to the leg, while the right hand was placed over the knee, exerting a slight external torsional force. The patient was then instructed to actively extend the knee. The test is considered positive if there is a distinct anterior tibial subluxation, indicating an ACL tear. A negative test occurs if the patient can fully extend the knee without tibial subluxation.[5]

Statistical Analysis

The IBM SPSS Statistics for Windows (IBM Corp.), version 20.0, was used for statistical analysis. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy were used to describe diagnostic performance.

Results

The age of 165 patients averaged 37.3 ± 12.4 years (17–65 years). A total of 107 male and 58 female patients, with 90 left and 75 right involved knees were included in the study. The primary causes of injury were traffic accidents (41.3%) and sports injuries (44.2%), as shown in ►**Table 1**.

Clinical tests with high sensitivity in diagnosing ACL tears are the Lever sign (93.8%), Lachman (87.6%), and FAB-sign (81.4%). The ones with highest specificity are FAB-sign (97.2%), Lever sign (94.4%), and Pivot-shift (94.4%). All five clinical tests have a high positive predictive value of over 90% (►**Table 2**).

Table 1 Basic demographic and epidemiologic data

Variables	Number (%)
Age, years (mean ± SD)	37.3 ± 12.4 [17;65]
Gender (male/female)	107(64.5) / 58 (35.2)
Side (left/right)	90 (54.5) / 75 (45.5)
Causes of injury	
Traffic accident	68 (41.3)
Sports injuries	73 (44.2)
Personal accident	18 (10.9)
Work accident	6 (3.6)
Stages of injury	
Acute	54 (32.7)
Subacute	61 (37.0)
Chronic	50 (30.3)
Arthroscopic diagnosis (ACL injury yes/no)	129 (78.2) / 36 (21.8)

Abbreviations: ACL, anterior cruciate ligament; SD, standard deviation.

Discussion

The ACL is a crucial structure for maintaining knee joint stability, making early diagnosis of such injuries essential for effective treatment and prevention of further damage. Traditionally, clinical diagnosis of ACL tears relies on three tests: anterior drawer, Lachman, and pivot-shift.

Historically, the anterior drawer test has been considered the most popular and widely used method. However, it lacks the sensitivity required to diagnose acute ACL tears compared with chronic cases. The Lachman test is regarded as the most accurate and reliable method for diagnosis, while the Pivot-shift one is considered the most specific but least sensitive of the three.[7,8]

In our study, we observed the sensitivity and specificity of the anterior drawer test to be 77.5% and 86.1%, the Lachman's to be 87.6% and 88.9%, and the Pivot-shift's to be 65.9% and 94.4%. In the most recent meta-analysis by Huang et al.,[9] the results for the sensitivity and specificity of the anterior drawer test were 64% and 87%, the Lachman test's was 76% and 89%, and the Pivot-shift's was 59% and 97%. Sokal et al.[10] found that the sensitivity and specificity of the anterior drawer test were 83% and 85%, the Lachman's was 81% and 85%, and the Pivot-shift's was 55% and 94%.

Our results regarding classic tests are consistent with the literature. These studies all indicate that the accuracy of classic tests is influenced by various factors, such as swelling, reactive joint inflammation, and muscle guarding due to pain.[11] Furthermore, a small hand size of the examiner or a large foot size of the patient can make it difficult to perform these tests and lead to inaccurate results.[12]

In our study, we introduced two recently developed clinical tests, the lever sign and FAB-sign, which have several advantages. Their simplicity, ease of administration, and independence from the examiner's experience make them particularly valuable in challenging clinical scenarios. The results showed that the FAB-sign test has a high specificity in diagnosis, at 97.2%, similar to the Lever sign (94.4%) and Pivot-shift (94.4%). On the other hand, the FAB-sign test has a higher sensitivity (81.4%) compared with the pivot-shift, at 65.9%.

Both the FAB-sign and Pivot-shift tests share a common mechanism for detecting ACL injuries, which is tibial subluxation relative to the femoral condyle. However, the FAB-sign is less painful for the patient, making it potentially easier to elicit a positive response during the examination. The FAB-sign test, developed by Blanke et al.,[5] reported a sensitivity and specificity of 78 and 95%. The differences in results compared with our study may be attributed to the original study only including patients with a time period of 6 weeks or more after the injury,[5] while we did not apply a time limitation.

Among the tests, the Lever sign is the one with highest sensitivity and specificity (93.8% and 94.4%, respectively). The authors of the Lever sign test, Lelli et al.,[6] reported 100% sensitivity. However, Kulwin et al.[13] showed the results for the sensitivity and specificity of the lever sign test were quite low, at 44.4% and 88.3%, when compared with MRI.

Table 2 The diagnostic values of the five tests detecting an ACL tears

Items	ADT	LT	PST	LST	FABST
True-positive, n	100	113	85	121	105
True-negative, n	31	32	34	34	35
False-positive, n	5	4	2	2	1
False-negative, n	29	16	44	8	24
Sensitivity, %	77.5	87.6	65.9	93.8	81.4
Specificity, %	86.1	88.9	94.4	94.4	97.2
Accuracy, %	79.4	87.9	72.1	93.9	84.8
PPV, %	95.2	96.6	97.7	98.4	99.1
NPV, %	51.7	66.7	43.6	81.0	59.3

Abbreviations: ACL, anterior cruciate ligament; ADT, Anterior Drawer Test; FABST, Forced Active Buckling Sign Test; LST, Lever Sign Test; LT, Lachman Test; NPV, negative predictive value; PPV, positive predictive value; PST, Pivot-Shift Test.

In the meta-analysis studies, the lever sign test has shown relatively favorable results. Huang et al.[9] reported its sensitivity and specificity to be of 79% and 92%, while in a study by Sokal et al.,[10] the figures were 83% and 91%, respectively.

In clinical practice, we found that the examination results are influenced by the examination table. If the patient is placed on a padded examination table, it may lead to a false negative result. Therefore, we examine patients on a hard examination table or place a board under the patient's foot, to achieve more accurate results. Additionally, the choice of hand placement under the calf is also crucial in the examination. Our experience is to examine the healthy leg first, select a point under the calf, where lifting the heel results in the highest point, and then use it as a reference to examine the injured leg.

Another factor that can affect the results of the lever sign test is the presence of chondral lesions. Massey et al.[14] observed that its accuracy decreases from 89 to 74% when there is a chondral lesion, with statistical significance. Therefore, this may explain why some studies report a relatively low sensitivity of the lever sign test.

Conclusion

There are various clinical diagnostic tests for diagnosing ACL tears. An ideal diagnostic method should be easy to perform, highly sensitive, and specific. From this perspective, the lever sign is a useful clinical diagnostic test for physicians to examine and diagnose this condition. Our findings demonstrate that it is not only a practical and simple test but also exhibits superior diagnostic accuracy compared with traditional methods. This makes it an invaluable tool, especially in settings where access to advanced imaging is limited.

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Conflict of Interests
The authors have no conflict of interests to declare.

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Does Arterial Blood Gas Analysis Predict an Adverse Course in Patients Admitted with Isolated Diaphyseal Femur Fractures?

A análise da gasometria arterial prevê uma evolução desfavorável em pacientes internados com fraturas diafisárias isoladas do fêmur?

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Abstract

Objective To evaluate the role of arterial blood gas (ABG) parameters in predicting adverse in-hospital outcomes among patients with isolated diaphyseal femur fractures.

Methods A retrospective study was conducted at a tertiary care hospital between April 2020 and June 2021. Patients aged 18 to 70 years of both sexes with isolated diaphyseal femur fractures were included. The ABG parameters were assessed upon admission and 24 hours postadmission. Their association with systemic complications, intensive care unit admission, and length of hospital stay was evaluated.

Results The study included 55 patients with a mean age of 53.8 years. The ABG parameters upon admission and at 24 hours were significantly associated with adverse outcomes, specifically pH < 7.35, bicarbonate (HCO_3^-) < 22 mmol/L, partial pressure of carbon dioxide (PCO_2) < 35 mmHg, partial pressure of oxygen (PO_2) < 83 mmHg, and lactate > 1.8 mmol/L. Elevated lactate levels upon admission were additionally correlated with prolonged hospital stay and systemic arterial hypertension.

Conclusion The ABG parameters assessed upon admission and 24 hours postadmission serve as early predictors of adverse outcomes in patients with isolated diaphyseal

Keywords
- arterial blood gas analysis
- femoral neck fractures
- intensive care units
- patient admission

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femur fractures. These findings suggest that ABG analysis may be a valuable tool in guiding the clinical management of such patients.

Resumo

Objetivo Avaliar o papel dos parâmetros da gasometria arterial (GA) na predição de desfechos desfavoráveis intra-hospitalares em pacientes com fraturas diafisárias isoladas do fêmur.

Métodos Foi realizado um estudo retrospectivo em um hospital terciário entre abril de 2020 e junho de 2021. Foram incluídos pacientes de 18 a 70 anos, de ambos os sexos, com fraturas diafisárias isoladas do fêmur. Os parâmetros da GA foram avaliados à admissão e 24 horas após a admissão. Sua associação com complicações sistêmicas, sua admissão em unidade de terapia intensiva e o tempo de internação foram avaliados.

Resultados Foram incluídos 55 pacientes, com idade média de 53,8 anos. Os parâmetros da GA à admissão e em 24 horas foram significativamente associados a desfechos desfavoráveis, especificamente pH < 7,35, bicarbonato (HCO_3^-) < 22 mmol/L, pressão parcial de dióxido de carbono (PCO_2) < 35 mmHg, pressão parcial de oxigênio (PO_2) < 83 mmHg e lactato > 1,8 mmol/L. Níveis elevados de lactato à admissão foram correlacionados, adicionalmente, com internação prolongada e hipertensão arterial sistêmica.

Conclusão Os parâmetros da GA avaliados à admissão e 24 horas após a admissão servem como preditores precoces de desfechos desfavoráveis em pacientes com fraturas diafisárias isoladas do fêmur. Esses achados sugerem que a GA pode ser uma ferramenta valiosa para orientar o manejo clínico desses pacientes.

Palavras-chave

- admissão do paciente
- análise de gases sanguíneos
- fraturas do colo femoral
- unidades de terapia intensiva

Introduction

Trauma is the leading cause of death worldwide.[1] Premature deaths and disability resulting from trauma impose a substantial economic burden.[2,3] The most frequent major trauma sites involve the extremities (particularly long bone fractures), followed by craniocerebral, abdominopelvic, thoracic, and spinal injuries.[4,5] Long bone fractures can be fatal due to severe hemorrhage.[6] The concept of the "golden hour," which forms the cornerstone of advanced trauma life support (ATLS), emphasizes early recognition of hemorrhagic shock and prompt intervention to prevent tissue hypoperfusion.[7]

Diaphyseal femur fractures (DFFs) are associated with an acute mortality rate of 0.04% but may lead to significant mortality and morbidity if not managed promptly in the initial hours.[8] Systemic complications commonly associated with these fractures include transient desaturation (TD), hemorrhagic shock, fat embolism syndrome (FES), acute respiratory distress syndrome (ARDS), and pulmonary thromboembolism (PTE). Therefore, early identification of prognostic indicators is critical for preventing such complications.

At present, we rely on traditional vital signs such as blood pressure and heart rate to guide the initial workup of these fractures. However, vital signs should only be surrogate markers and not direct measures of oxygen delivery. Better markers for the presence and extent of ongoing hemorrhage may be the actual metabolic products of tissue hypoperfusion such as base deficit (BD) and serum lactic acid (LA) level.[9,10] Studies have shown that the mortality of trauma patients can be predicted by the levels of base deficit within the first 24 hours.[11–13]

Arterial blood gas (ABG) parameters have been identified as useful predictors of the severity of traumatic brain injury and for prognosticating patient outcomes.[14,15] In orthopedic trauma, only a limited number of studies have examined the prognostic role of ABG parameters, and these were primarily conducted in patients with pelvic fractures either isolated or combined with long bone fractures.[16,17] To the best of our knowledge, no previous studies have specifically evaluated the role of ABG values in predicting adverse in-hospital outcomes among patients with isolated DFFs.

Therefore, the primary objective of this study was to assess the role of various ABG parameters in predicting adverse in-hospital outcomes in patients with isolated DFF. A secondary objective was to analyze the association of demographic factors and comorbidities with ABG parameters in the study population.

Materials and Methods

This retrospective observational study was conducted in the Department of Orthopedics at a tertiary care hospital between April 2020 and June 2021.

The inclusion criteria were patients aged 18 to 70 years, presenting within 48 hours of trauma, with open or closed

isolated DFF or unilateral or bilateral subtrochanteric femur fractures (STFFs).

We excluded cases with presentation after 48 hours, severe head injury (Glasgow Coma Scale score < 8), intracranial bleeding, polytrauma, chest injuries, prehospital cardiac arrest, prior stabilization/oxygen therapy elsewhere, and preexisting conditions affecting LA levels (heart failure, chronic obstructive pulmonary disease, liver disease, active coronavirus disease 2019 (COVID-19) infection, or antiretroviral therapy).

The data collected retrospectively included age, sex, mode of injury, fracture type, time since injury, comorbidities, Intensive Care Unit (ICU) admission, need for ventilatory support upon admission, length of hospital stay, and systemic complications. Systemic complications were defined as the occurrence of sepsis, acute kidney injury, ARDS, multi-organ dysfunction syndrome (MODS), deep vein thrombosis (DVT), PTE, or myocardial infarction during hospitalization.

The ABG analysis was performed at two standardized periods: upon admission (within 2 hours of hospital arrival) and at 24 hours postadmission using the Cobas b 221 system (Roche Diagnostics). Parameters recorded included pH, bicarbonate (HCO_3^-), partial pressure of carbon dioxide (PCO_2), partial pressure of oxygen (PO_2), LA, and base excess.

The reference ranges were pH: 7.35 to 7.45; HCO_3^-: 22 to 26 mEq/L; PCO_2: 35 to 45 mmHg; PO_2: 75 to 100 mmHg; LA: 0.20 to 1.80 mmol/L; and base excess: -2 to $+2$ mmol/L. Abnormal values were defined as: pH < 7.35 (acidemia) or > 7.45 (alkalemia); $PCO_2 > 45$ mmHg with pH < 7.35 (respiratory acidosis), or $PCO_2 < 35$ mmHg with pH > 7.45 (respiratory alkalosis); $HCO_3^- < 22$ mEq/L with pH < 7.35 (metabolic acidosis), or $HCO_3^- > 26$ mEq/L with pH > 7.45 (metabolic alkalosis); base excess < -2 or $> +2$ mmol/L; and LA > 1.80 mmol/L (lactic acidosis).

Data were entered using the Epicollect5 software (Centre for Genomic Pathogen Surveillance) and analyzed with the IBM SPSS Statistics for Windows (IBM Corp.), version 26. Descriptive statistics were reported as mean $\pm$ standard deviation (SD) for continuous variables and as frequencies with percentages for categorical variables. The normality of continuous variables was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests, with $p > 0.05$ considered indicative of normal distribution, supported by quantile-quantile (Q–Q) plots. Associations between ABG parameters and demographic or clinical variables were evaluated using the Chi-squared test. Multivariate logistic regression was performed to identify independent predictors of systemic complications, incorporating ABG abnormalities, mode of injury, and comorbidities. Values of $p < 0.05$ were considered statistically significant.

A sample size calculation was based on an assumed 25% incidence of systemic complications among femur fracture patients. To detect a significant difference with 80% power and a 95% confidence level, a minimum of 120 patient records was required. The Institutional Ethics Committee's approval was obtained prior to study initiation, with the reference number CSP-MED/21/NOV/72/138. As this was a retrospective study utilizing anonymized data from existing records, the requirement for informed consent was waived by the institutional authorities.

Results

Among the study population, 29 patients (52.7%) had subtrochanteric fractures and 26 patients (47.3%) had shaft fractures. Males predominated (n = 31, 56.4%) compared to females (n = 24, 43.6%). The mean age was 53.84 $\pm$ 17.75 years, with the largest proportion of patients (n = 21, 38.2%) in the 66 to 70 years age group, followed by 16 (29.1%) in the 51 to 65 years group, 10 (18.2%) in the 31 to 50 years group, and 8 (14.5%) in the 18 to 30 years group.

Slip and fall was the most common mode of injury (n = 30, 54.5%), followed by road traffic accidents (n = 25, 45.5%). Right-sided femur fractures (n = 36, 65.5%) were more common than left-sided fractures (n = 19, 34.5%). The delay in ABG analysis from the time of injury was distributed as follows: 1 to 3 hours in 17 patients (30.9%), 4 to 6 hours in 16 (29.1%), 7 to 9 hours in 11 (20.0%), 10 to 12 hours in 6 (10.9%), and more than 12 hours in 5 (9.1%). No significant associations were observed between ABG parameters and demographic variables (age and sex). Similarly, no significant associations were found between ABG parameters and clinical factors (type of fracture, mode of injury, side of injury, time since injury).

Of the study population, 21 patients (38.2%) had no medical comorbidities, 18 (32.7%) had systemic arterial hypertension (SAH) alone, and 16 (29.1%) had multiple comorbidities such as diabetes mellitus (DM), SAH, and hypothyroidism. Comparisons of ABG parameters were made between patients with and without these comorbidities. Among the parameters analyzed, significant differences were observed in LA levels between hypertensive and non-hypertensive patients (►**Table 1**). At admission, patients with systemic hypertension had significantly higher LA levels ($>$ 1.8 mmol/L) compared to non-hypertensive patients ($p = 0.013$). This difference persisted at 24 hours, with LA levels remaining significantly elevated in the hypertensive group ($p < 0.0001$). No other ABG parameters showed significant variation across comorbidity groups (DM, SAH, and hypothyroidism).

Among the 55 study subjects, 19 patients (34.5%) required ICU admission, of whom 9 (47.4%) had shaft fractures and 10 (52.6%) had subtrochanteric ones. No significant association was observed between ICU admission and fracture type.

The most common complication was TD, occurring in 19 patients (34.5%) across both DFF and STFF groups. This was followed by FES and ARDS, each reported in 4 patients (7.3%). Also, PTE was observed in only 1 patient (1.8%) with a subtrochanteric fracture. No significant association was found between the occurrence of systemic complications and the type of fracture.

Among patients with DFF, 14 (53.8%) had a hospital stay of $<$ 10 days, while 12 (46.2%) stayed $\geq$ 10 days. Among patients with STFF, 17 (58.6%) had a stay of $<$ 10 days, and 12 (41.4%) stayed $\geq$ 10 days. However, no statistically

Table 1 Association between ABG parameters and SAH

Variables	SAH	Non-SAH	*p*-value*
pH upon admission			
< 7.35	5	9	0.402
7.35–7.45	18	20	
> 7.45	1	2	
pH at 24 hours			
< 7.35	3	9	0.107
7.35–7.45	19	21	
> 7.45	2	1	
HCO_3^- upon admission (mEq/L)			
< 22	10	14	0.082
22–26	10	16	
> 26	4	1	
HCO_3^- at 24 hours (mEq/L)			
< 22	9	10	0.053
22–26	14	14	
> 26	1	7	
PCO_2 upon admission (mmHg)			
<35	4	5	0.155
35–45	19	21	
> 45	1	5	
PCO_2 at 24 hours (mmHg)			
< 35	4	7	0.052
35–45	19	11	
> 45	1	3	
PO_2 upon admission (mmHg)			
< 83	11	20	0.068
83–108	9	5	
> 108	4	6	
PO_2 at 24 hours (mmHg)			
< 83	4	10	0.154
83–108	17	19	
> 108	3	2	
Base upon admission (mmol/L)			
Base deficit (< −2.0)	11	12	0.143
Normal (−2.0– + 2.0)	12	18	
Base excess (> 2.0)	1	1	
Base at 24 hours (mmol/L)			
Base deficit (< −2.0)	10	12	0.751
Normal (−2.0– + 2.0)	13	18	
Base excess (> 2.0)	1	1	

Table 1 (*Continued*)

Variables	SAH	Non-SAH	*p*-value*
LA upon admission (mmol/L)			
0.2–1.8	4	26	**0.013****
> 1.8	20	5	
LA at 24 hours (mmol/L)			
0.2–1.8	6	19	< **0.001****
> 1.8	18	2	

Abbreviations: ABG, arterial blood gas analysis; HCO_3^-, bicarbonate; LA, serum levels of lactic acid; PCO_2, partial pressure of carbon dioxide; PO_2, partial pressure of oxygen; SAH, systemic arterial hypertension. **Notes:** *Chi-squared test; **statistically significant ($p < 0.05$).

significant association was observed between fracture type and length of hospital stay.

►**Tables 2**, **3**, and **4** present the associations between ABG parameters and systemic complications, ICU admission, and length of hospital stay. Patients with systemic complications demonstrated significant abnormalities across multiple ABG parameters: 1) lower pH levels at 24 hours ($p = 0.026$), indicating ongoing acidosis; 2) reduced HCO_3^- levels both upon admission ($p = 0.019$) and at 24 hours ($p = 0.025$), suggesting inadequate metabolic compensation; 3) elevated LA levels upon admission ($p = 0.038$); 4) impaired oxygenation with lower PO_2 upon admission ($p = 0.048$) and at 24 hours ($p < 0.0001$); and 5) significant differences in PCO_2 levels upon admission ($p = 0.011$) and at 24 hours ($p = 0.029$), reflecting combined respiratory and metabolic disturbances.

Patients requiring ICU admission exhibited significant derangements in ABG parameters: 1) lower pH levels at both admission ($p = 0.038$) and 24 hours ($p = 0.006$), reflecting persistent acidosis; 2) reduced HCO_3^- levels at 24 hours

Table 2 Association between ABG parameters and systemic complications

Variables	No systemic complications	Systemic complications	*p*-value*
pH upon admission			
< 7.35	4	10	0.146
7.35–7.45	19	19	
> 7.45	1	2	
pH at 24 hours			
< 7.35	2	10	**0.0260****
7.35–7.45	25	16	
> 7.45	1	1	
HCO_3^- upon admission (mEq/L)			
< 22	8	16	**0.019****
22–26	18	8	
> 26	4	1	
HCO_3^- at 24 hours (mEq/L)			
< 22	6	13	**0.025****
22–26	20	8	
> 26	4	4	
PCO_2 upon admission (mmHg)			
<35	1	8	**0.011****
35–45	26	14	
> 45	4	2	

(*Continued*)

Table 2 (*Continued*)

Variables	No systemic complications	Systemic complications	*p*-value*
PCO_2 at 24 hours (mmHg)			
< 35	2	9	**0.029****
35–45	24	16	
> 45	1	3	
PO_2 upon admission (mmHg)			
< 83	15	16	**0.048****
83–108	12	2	
> 108	2	8	
PO_2 at 24 hours (mmHg)			
< 83	1	13	**0.001****
83–108	26	10	
> 108	1	4	
Base upon admission (mmol/L)			
Base deficit (< −2.0)	9	14	0.388
Normal (−2.0– + 2.0)	17	13	
Base excess (> 2.0)	1	1	
Base at 24 hours (mmol/L)			
Base deficit (< −2.0)	7	15	0.168
Normal (−2.0– + 2.0)	18	13	
Base excess (> 2.0)	1	1	
LA upon admission (mmol/L)			
0.2–1.8	18	12	**0.038****
> 1.8	8	17	
LA at 24 hours (mmol/L)			
0.2–1.8	20	14	0.417
> 1.8	10	11	

Abbreviations: ABG, arterial blood gas analysis; HCO_3^-, bicarbonate; LA, serum levels of lactic acid; PCO_2, partial pressure of carbon dioxide; PO_2, partial pressure of oxygen. **Notes:** *Chi-squared test; **statistically significant ($p < 0.05$).

($p = 0.004$), indicating inadequate metabolic compensation; 3) elevated LA levels upon admission ($p = 0.027$); 4) impaired oxygenation with lower PO_2 upon admission ($p = 0.039$) and at 24 hours ($p < 0.0001$); and 5) significant differences in PCO_2 at 24 hours ($p = 0.046$), suggesting combined respiratory and metabolic disturbances associated with ICU requirement.

Prolonged hospital stay was associated with significant ABG abnormalities: 1) lower pH levels at both admission ($p = 0.003$) and 24 hours ($p = 0.001$), indicating persistent acidosis; 2) elevated LA levels upon admission ($p = 0.005$); and 3) impaired oxygenation (PO_2) at 24 hours ($p = 0.038$), reflecting ongoing metabolic and respiratory compromise. Although HCO_3^- and PCO_2 did not reach statistical significance, they showed a trend toward abnormal values in patients with extended hospitalization.

Discussion

Pelvic and long bone fractures, particularly femoral shaft fractures, are severe injuries due to their proximity to major vascular structures and the effect of strong muscle contractions, which exacerbate tissue damage.[18] Hemorrhage from these fractures can rapidly lead to shock, while complications such as FES, ARDS, pneumonia, and PTE significantly contribute to morbidity and mortality. Patients with long bone fractures have been reported to have a 2.35-fold higher risk of ARDS in the early hospital period. The ABG abnormalities have been identified as reliable indicators of trauma severity.[19–23] This study aimed to evaluate the clinical relevance of these parameters in predicting adverse outcomes in patients with isolated DFFs.

Table 3 Association between ABG parameters and ICU admission

Variables	No ICU admission	ICU admission	*p*- value*
pH upon admission			
< 7.35	6	8	**0.038****
7.35–7.45	29	9	
> 7.45	1	2	
pH at 24 hours			
< 7.35	6	8	**0.006****
7.35–7.45	17	8	
> 7.45	1	1	
HCO_3^- upon admission (mEq/L)			
< 22	14	10	0.636
22–26	17	9	
> 26	4	1	
HCO_3^- at 24 hours (mEq/L)			
< 22	7	12	**0.004****
22–26	23	5	
> 26	6	2	
PCO_2 upon admission (mmHg)			
< 35	3	6	0.052
35–45	29	11	
> 45	5	1	
PCO_2 at 24 hours (mmHg)			
< 35	4	7	**0.046****
35–45	30	10	
> 45	2	2	
PO_2 upon admission (mmHg)			
< 83	18	13	**0.039****
83–108	13	1	
> 108	5	5	
PO_2 at 24 hours (mmHg)			
< 83	3	11	**0.001****
83–108	32	4	
> 108	1	4	
Base upon admission (mmol/L)			
Base deficit (< −2.0)	13	10	0.261
Normal (−2.0– + 2.0)	23	7	
Base excess (> 2.0)	1	1	
Base at 24 hours (mmol/L)			
Base deficit (< −2.0)	10	12	0.053
Normal (−2.0– + 2.0)	24	7	
Base excess (> 2.0)	1	1	

(*Continued*)

Table 3 (*Continued*)

Variables	No ICU admission	ICU admission	*p*- value*
LA upon admission (mmol/L)			
0.2–1.8	23	7	**0.027****
> 1.8	12	13	
LA at 24 hours (mmol/L)			
0.2–1.8	24	10	0.308
> 1.8	12	9	

Abbreviations: ABG, arterial blood gas analysis; HCO_3^-, bicarbonate; ICU, intensive care unit; LA, serum levels of lactic acid; PCO_2, partial pressure of carbon dioxide; PO_2, partial pressure of oxygen. **Notes:** *Chi-squared test; **statistically significant ($p < 0.05$).

Table 4 Association between ABG parameters and length of hospital stay

Variables	< 10 days stay	≥ 10 days stay	*p*-value*
pH upon admission			
< 7.35	6	8	**0.038****
7.35–7.45	29	9	
> 7.45	1	2	
pH at 24 hours			
< 7.35	6	8	**0.006****
7.35–7.45	17	8	
> 7.45	1	1	
HCO_3^- upon admission (mEq/L)			
< 22	14	10	0.636
22–26	17	9	
> 26	4	1	
HCO_3^- at 24 hours (mEq/L)			
< 22	7	12	**0.004****
22–26	23	5	
> 26	6	2	
PCO_2 upon admission (mmHg)			
< 35	3	6	0.052
35–45	29	11	
> 45	5	1	
PCO_2 at 24 hours (mmHg)			
< 35	4	7	**0.046***
35–45	30	10	
> 45	2	2	
PO_2 upon admission (mmHg)			
< 83	18	13	**0.039****
83–108	13	1	
> 108	5	5	
PO_2 at 24 hours (mmHg)			
< 83	3	11	**0.001****
83–108	32	4	
> 108	1	4	

Table 4 (*Continued*)

Variables	< 10 days stay	≥ 10 days stay	*p*-value*
Base upon admission (mmol/L)			
Base deficit (< −2.0)	13	10	0.261
Normal (−2.0– + 2.0)	23	7	
Base excess (> 2.0)	1	1	
Base at 24 hours (mmol/L)			
Base deficit (< −2.0)	10	12	0.053
Normal (−2.0– + 2.0)	24	7	
Base excess (> 2.0)	1	1	
LA upon admission (mmol/L)			
0.2–1.8	23	7	**0.027****
> 1.8	12	13	
LA at 24 hours (mmol/L)			
0.2–1.8	24	10	0.308
> 1.8	12	9	

Abbreviations: ABG, arterial blood gas analysis; HCO_3^-, bicarbonate; LA, serum levels of lactic acid; PCO_2, partial pressure of carbon dioxide; PO_2, partial pressure of oxygen. **Notes:** *Chi-squared test; **statistically significant ($p < 0.05$).

The lack of correlation between ABG values and demographic or fracture-related variables in this study indicates that adverse outcomes are not determined by age, sex, or fracture type alone. Instead, systemic and metabolic stress responses, reflected in ABG derangements, appear to play a central role in determining clinical progression.

One notable observation was the strong association between SAH and elevated LA levels at both admission and 24 hours. Hypertension is known to cause endothelial dysfunction and microvascular impairment, which may reduce tissue perfusion and delay LA clearance during acute trauma. This finding is consistent with previous studies demonstrating the prognostic impact of LA and perfusion markers in trauma patients.[24,25]

Mohsenian et al.[17] highlighted the prognostic value of ABG indices such as O_2 saturation, base excess, and PCO_2 in trauma patients with femoral and pelvic fractures. In line with their observations, the present study underscores that abnormalities in PO_2, pH, and LA can serve as early warning signs for systemic complications and critical care needs. Although mortality was not observed in this cohort, a decline in oxygenation and metabolic compensation mirrored trends described in previous studies, suggesting that ABG monitoring can provide prognostic information even in isolated fracture cases.

Interestingly, hypocapnia rather than hypercapnia was observed in association with adverse outcomes. This likely reflects compensatory hyperventilation in response to metabolic acidosis. Clinically, this finding is important because hypocapnia may mask the severity of metabolic stress if interpreted in isolation. Recognizing this compensatory mechanism is essential, as it may identify patients at high risk of deterioration despite apparently normal ventilation parameters.[26] Ross et al.[27] previously demonstrated that severe acidosis (pH < 7.0) correlates with poor outcomes, and our findings reinforce the concept that even milder derangements in pH (< 7.35) should not be overlooked in trauma care.

Prior studies have emphasized the prognostic value of LA and base deficit in trauma patients. Ward et al.[28] demonstrated significantly poorer survival among patients with elevated LA or base deficit on arrival, while Oladipo et al.[29] linked these elevations to postoperative morbidity and prolonged hospitalization in orthopedic trauma. These observations align with the present findings, where elevated LA and impaired acid–base balance were predictive of adverse outcomes and prolonged hospital stay.

The high incidence of inapparent hypoxemia, particularly TD, further highlights the subclinical respiratory complications that accompany long bone fractures. Rosenkrantz et al.[30] documented similar patterns, attributing them to FES, microvascular plugging, and inflammatory responses. This underlines the importance of routine oxygen monitoring and serial ABG assessments in seemingly stable fracture patients.

Taken together, these findings suggest that ABG analysis is not merely a laboratory adjunct but a clinically relevant tool for early risk stratification in femoral fractures. Persistent derangements in pH, LA, and PO_2 reflect inadequate tissue oxygenation and impaired compensatory mechanisms, which can guide decisions on ICU monitoring, aggressive resuscitation, and complication surveillance.

The present study has limitations. Its retrospective design and modest sample size may limit generalizability. The impact of surgical fixation timing and intramedullary reaming on ABG derangements was not evaluated. Future prospective studies incorporating serial perioperative ABG monitoring may clarify these aspects further.

Conclusion

The ABG values at both admission and 24 hours were found to play a role in the early prediction of adverse outcomes in patients with isolated DFF. Therefore, routine monitoring of ABG parameters is recommended in such patients. Given the retrospective design and limited sample size of this study, future prospective studies with larger cohorts are warranted to validate these findings.

Data Availability

Data will be available upon request to the corresponding author.

Authors' Contributions

DS: conceptualization, methodology, and software; TS: data curation and writing – original draft; AAX: visualization and investigation; LC: software and validation; and SA: writing – review and editing.

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Conflict of Interests

The authors have no conflict of interests to declare.

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Mobile-Bearing versus Fixed-Bearing Total Knee Arthroplasty: A Comparative Analysis of Long-Term Clinical and Implant Survival Outcomes

Artroplastia total do joelho com plataforma móvel versus plataforma fixa: Uma análise comparativa dos desfechos clínicos de longo prazo e de sobrevida do implante

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Abstract

Objective The present study compared clinical outcomes, implant survival, and axial mobility between mobile-bearing (MB) and fixed-bearing (FB) prostheses in patients with medial knee osteoarthritis.

Methods A retrospective cohort study of 1,289 patients who underwent primary cemented total knee arthroplasty (TKA) from 2003 to 2022 was conducted. Mobile-bearing prostheses were used in 820 patients (mean follow-up: 8.1 years), and FB in 469 patients (mean follow-up: 15.2 years). Functional outcomes were assessed using the International Knee Documentation Committee (IKDC) and Kujala scores. Range of motion and axial tibial rotation were clinically evaluated. Statistical tests included analysis of variance, *t*-tests, and Fisher's F-test (significance $p < 0.05$).

Results Both groups showed significant functional improvement ($p < 0.001$). At the final follow-up, no significant differences were found between MB and FB in the IKDC or Kujala scores. Implant survival was 96.3% (MB) versus 95.7% (FB) ($p = 0.67$). Axial tibial

Keywords
- arthroplasty, replacement, knee
- knee joint
- knee prosthesis
- prosthesis design

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rotation was significantly higher in MB (23.1 ± 4.5°) than in FB (19.4 ± 4.2°) ($p = 0.003$). No bearing dislocations occurred.

Conclusion Mobile-bearing and FB designs offer durable functional benefits. Although MB provided greater axial mobility, it did not result in superior functional outcomes or implant longevity. Prosthesis selection should be tailored to individual patient needs, surgeon preference, and cost. Further prospective studies are needed to define the clinical relevance of enhanced kinematics.

Resumo

Objetivo Este estudo comparou os desfechos clínicos, a sobrevida do implante e a mobilidade axial entre próteses de plataforma móvel (PM) e de plataforma fixa (PF) em pacientes com osteoartrite medial do joelho.

Métodos Foi realizado um estudo de coorte retrospectivo de 1.289 pacientes submetidos à artroplastia total cimentada primária do joelho (ATJ) entre 2003 e 2022. As próteses PM foram utilizadas em 820 pacientes (seguimento médio de 8,1 anos) e as PF em 469 pacientes (seguimento médio de 15,2 anos). Os desfechos funcionais foram avaliados com os escores International Knee Documentation Committe (IKDC) e Kujala. A amplitude de movimento e a rotação axial da tíbia foram avaliadas clinicamente. Os testes estatísticos incluíram análise de variância, testes *t* e F de Fisher (significância de $p < 0,05$).

Resultados Ambos os grupos apresentaram melhora funcional significativa ($p < 0,001$). No seguimento final, não foram encontradas diferenças significativas entre PM e PF nos escores IKDC ou Kujala. A sobrevida do implante foi de 96,3% (PM) *versus* 95,7% (PF) ($p = 0,67$). A rotação tibial axial foi significativamente maior em PM (23,1 ± 4,5°) do que em PF (19,4 ± 4,2°) ($p = 0,003$). Não ocorreram deslocamentos da plataforma.

Conclusão Os modelos PM e PF oferecem benefícios funcionais duráveis. Embora a PM tenha proporcionado maior mobilidade axial, ela não resultou em desfechos funcionais superiores ou longevidade do implante. A seleção da prótese deve ser adaptada às necessidades individuais do paciente, à preferência do cirurgião e ao custo. Mais estudos prospectivos são necessários para definir a relevância clínica da cinemática aprimorada.

Palavras-chave
- articulação do joelho
- artroplastia do joelho
- desenho de prótese
- prótese do joelho

Introduction

Knee osteoarthritis (KO) is a degenerative joint disease with a multifactorial origin. It results from progressive wear and damage of articular cartilage. Knee osteoarthritis, or gonarthrosis, is a common condition in older adults. Its prevalence continues to rise due to increased life expectancy and obesity. Estimates vary depending on the source, with an average prevalence of 13% in women and 10% in men at age 60, increasing to 40% in patients in their 70s.[1]

Treatment depends on the severity of symptoms and the degree of joint degeneration, classified according to the Kellgren and Lawrence system.[2] Non-surgical and surgical options are available; among the latter, total knee arthroplasty (TKA) is indicated for severe cases in highly symptomatic patients.[3]

In the United States, TKA is the second most frequently performed surgical procedure, with a 134% increase over the past 20 years.[4]

Two common TKA designs are fixed-bearing (FB) and mobile-bearing (MB) implants. Fixed-bearing designs have a polyethylene insert fixed to the tibial baseplate, while MB implants allow axial rotation or slight anteroposterior translation.[5,6] Mobile-bearing designs, introduced in the 1980s, aimed to mimic physiological mechanics, reduce shear stress, increase conformity, and minimize wear.[7,8]

Biomechanically, MB designs may reduce contact stress and accommodate surgical misalignments, potentially preserving rollback and tibial rotation during flexion.[9–11] Some kinematic studies show better axial rotation with MB, but without consistent clinical benefits. This type of implants also poses risks, such as insert dislocation, increased surgical complexity, and higher cost.[12]

Long-term data are crucial. While earlier reviews suggested small MB advantages, recent studies with longer follow-ups show mixed results.[13]

There is no consensus on whether MB implants offer superior longevity, biomechanics, or patient outcomes.

The present study aimed to compare long-term results of MB and FB TKA designs over 15- and 20-year periods. We evaluated implant survival, function, and revision rates, hypothesizing no significant differences in prosthesis longevity, function, or complications between the two designs.

Materials and Methods

The present work was approved by our Institutional Review Board (IRB) on January 20, 2025.

Study Design and Population

The current retrospective single-center study included 1,289 patients who underwent primary TKA for medial compartment osteoarthritis between 2003 and 2022, all operated by the same orthopedic team at a high-volume academic center. Patients were grouped by implant type: 820 received MB prostheses (mean follow-up: 8.1 years), and 469 received FB prostheses (mean follow-up: 15.2 years). All presented with varus alignment (hip–knee–ankle angle $< 180°$) and combined medial and patellofemoral osteoarthritis, with prior conservative treatment failure.

The inclusion criteria were Kellgren-Lawrence grade $\geq$ III, primary cemented TKA (MB or FB), and ≥ 2 years of follow-up. Exclusion criteria included inflammatory arthritis, prior osteotomy or trauma, severe deformity ($> 15°$ varus/valgus or $> 20°$ contracture), major bone loss, revision surgery, or incomplete follow-up data.

Surgical Technique

All surgeries followed a standardized protocol using a medial parapatellar approach[14] under tourniquet. Cefazolin (2 g) was given 30 minutes before the incision. Both cruciate ligaments were resected. Bone cuts followed preoperative templating; femoral rotation was set at 3° to 5° for patellar tracking. Mechanical alignment aimed for a neutral axis. Trial components ensured proper balance and stability. All components were cemented with pressurization; patellae were resurfaced. No drains were used. Postoperatively, patients received multimodal analgesia, began mobilization at 24 hours, and underwent thromboprophylaxis with enoxaparin. Discharge medication included analgesics (acetaminophen and non-steroidal antiinflammatory drugs [NSAIDs]), muscle relaxants, and gastric protection for 10 days besides thromboprophylaxis with direct oral anticoagulants (rivaroxaban 10 mg) for 30 days. All followed a standardized rehab protocol with progressive loading.

Functional Outcome Assessment

Clinical outcomes were assessed using two validated patient-reported measures: the International Knee Documentation Committee (IKDC) subjective score and the Kujala Anterior Knee Pain Scale. Evaluations were performed at 1, 3, 6, and 12 months, and at 3, 5, 10, 15, and 20 years postoperatively. The IKDC score (0–100) assesses symptoms, function, and knee performance; higher scores indicate better outcomes.[15] The Kujala score evaluates patellofemoral function, including pain, limping, and instability, with higher scores indicating better function.[16] Flexion–extension range of motion was measured with a goniometer. Axial tibial rotation was assessed clinically at 90° flexion using a visual analog scale (VAS).

Statistical Analysis

Statistical analysis was conducted using R software (R Foundation for Statistical Computing). Descriptive statistics summarized demographic and clinical variables. One-way analysis of variance (ANOVA) or unpaired t-tests compared continuous variables, while paired t-tests assessed within-group functional improvement. The Kaplan-Meier analysis evaluated implant survivorship. To reduce bias from unequal follow-up durations, sensitivity analysis truncated follow-up at 10 years. Multivariable linear regression examined the independent effect of implant type on IKDC and Kujala scores, adjusting for age, sex, body mass index (BMI), alignment, and follow-up. Propensity score matching (1:1 nearest neighbor; caliper = 0.2 standard deviation [SD]) created balanced cohorts. Cox proportional hazards models evaluated revision-free survival, adjusting for the same covariates. Proportional hazards assumptions were checked via Schoenfeld residuals and graphical methods. Significance was set at $p < 0.05$.

Results

Baseline Characteristics

A total of 1,289 patients who met inclusion criteria were analyzed: 820 in the MB group and 469 in the FB group. The two cohorts were statistically comparable at baseline. Mean age at surgery was 68.3 ± 7.2 years in the MB group and 68.6 ± 6.8 years in the FB group ($p = 0.41$), and the female proportion was similar (72.4% versus 68.0%, respectively; $p = 0.09$). Laterality distribution (left, right, or bilateral procedures) and Kellgren-Lawrence osteoarthritis grades also showed no significant differences ($p > 0.05$ for all comparisons). A one-way ANOVA confirmed homogeneity in age distribution ($F = 1.27$; F-critical = 3.84; $p = 0.26$), supporting the comparability of both cohorts.

Functional Outcomes: Intragroup Improvement

Both implant designs demonstrated significant functional improvement over time. In the FB group, the mean IKDC score increased from 45.2 preoperatively to 84.9 at 20 years. In parallel, the Kujala score improved from 48.1 to 90.0. In the MB group, IKDC scores improved from 46.1 at baseline to 90.0 at 15 years, and Kujala scores from 47.6 to 90.1 (►**Table 1**).

Paired *t*-tests showed these improvements were statistically significant within both groups at all time points ($p < 0.001$), reflecting robust intragroup recovery trajectories (►**Table 2**).

Intergroup Functional Comparison

Throughout the follow-up, IKDC and Kujala scores were consistently higher in the MB than in the FB group, though differences were not statistically significant ($p > 0.05$). Repeated-measures ANOVA showed no significant interaction

Table 1 Mean and standard deviation of IKDC and Kujala scores over time (TKA with FB versus MB)

Timepoint	IKDC FB (mean ± SD)	IKDC MB (mean ± SD)	Kujala FB (mean ± SD)	Kujala MB (mean ± SD)
Preoperative	45.2 ± 3.1	46.1 ± 3.2	48.1 ± 3.1	47.6 ± 3.2
1 month	52.5 ± 4.7	52.5 ± 4.5	52.5 ± 4.8	52.7 ± 4.6
3 months	67.4 ± 4.5	67.6 ± 4.7	67.7 ± 4.6	67.5 ± 4.5
6 months	77.2 ± 3.2	75.1 ± 3.2	75.4 ± 3.2	75.2 ± 3.2
1 year	80.2 ± 3.2	80.1 ± 3.1	79.9 ± 3.0	79.9 ± 3.2
3 years	85.1 ± 3.1	84.9 ± 3.2	84.9 ± 3.2	84.8 ± 3.2
5 years	85.2 ± 3.1	85.1 ± 3.1	84.8 ± 3.2	85.1 ± 3.3
10 years	90.2 ± 3.1	90.0 ± 3.2	89.9 ± 3.2	90.0 ± 3.2
15 years	87.5 ± 1.7	90.0 ± 3.1	90.0 ± 3.2	90.1 ± 3.2
20 years	84.9 ± 3.1	—	90.0 ± 3.1	—

Abbreviations: FB, fixed bearing; IKDC, International Knee Documentation Committee; MB, mobile bearing; SD, standard deviation; TKA, total knee arthroplasty.

Table 2 Within-group comparison: preoperative period versus final follow-up

Outcome Score	Group	Preoperative period (mean ± SD)	Final follow-up	Mean Δ	*p*-value (paired *t*-test)
IKDC	FB	45.2 ± 3.1	84.9 ± 3.1	+39.7	< 0.001
IKDC	MB	46.1 ± 3.2	88.3 ± 3.1	+42.2	< 0.001
Kujala	FB	48.1 ± 3.1	89.9 ± 3.2	+41.8	< 0.001
Kujala	MB	47.6 ± 3.2	90.0 ± 3.2	+42.4	< 0.001

Abbreviations: IKDC, International Knee Documentation Committee; SD, standard deviation.

Table 3 Between-group comparison of functional improvement (Δ preoperative period to final follow-up)

Outcome score	Δ FB (mean ± SD)	Δ MB (mean ± SD)	Mean difference	*p*-value (independent *t*-test)
IKDC	39.7 ± 3.4	42.2 ± 3.5	+2.5	0.08
Kujala	41.8 ± 3.5	42.4 ± 3.6	+0.6	0.41

Abbreviations: FB, fixed bearing; IKDC, International Knee Documentation Committee; MB, mobile bearing; SD, standard deviation.

between implant type and score progression ($p = 0.18$), indicating similar functional trajectories. However, mean IKDC improvement was 42.2 points in MB versus 39.7 in FB, and Kujala improvement was 42.4 versus 41.8, suggesting a nonsignificant trend favoring MB implants in patient-reported outcomes (►**Table 3**).

After propensity score matching, 392 matched pairs were identified with balanced baseline characteristics. In this matched cohort, no significant difference was observed in the final IKDC (MB: 87.6 ± 8.2 versus FB: 86.3 ± 8.5, $p = 0.21$) or Kujala scores (MB: 84.7 ± 7.6 versus FB: 82.9 ± 8.2, $p = 0.18$), mirroring results from the unmatched population.

In the multivariable regression model, the MB design was not an independent predictor of improved IKDC (β = 1.23; 95% CI: −0.85–3.31; $p = 0.24$) or Kujala scores (β = 1.46; 95%CI: −0.74–3.67; $p = 0.19$) after adjusting for confounders. However, MB implants remained significantly associated with greater axial tibial rotation (β = 3.4°; 95%CI: 1.7–5.1°; $p < 0.001$).

Range of Motion and Rotational Mobility

Postoperative range of motion (ROM) was comparable between groups. At 15 years, mean flexion was 122.7 ± 6.8° in the MB group and 121.9 ± 7.1° in the FB group ($p = 0.21$). Extension deficits were minimal in both groups (−1.3 ± 1.1° versus −1.4 ± 1.0°; $p = 0.48$), with no statistically significant difference in the flexion–extension arc. Importantly, tibial axial rotation, assessed clinically at 90° flexion, revealed a significant difference between cohorts: the MB group exhibited a mean total rotation arc of 23.1 ± 4.5°, compared to 19.4 ± 4.2° in the FB group ($p = 0.003$). This suggests superior preservation of physiological rotational motion in MB implants, aligning with their theoretical kinematic design advantage (►**Table 4**).

Implant Survivorship and Complications

Cumulative revision-free survival at the final follow-up was 96.3% for the MB group and 95.7% for the FB group. The

Table 4 Range of motion and axial rotation at the 15-year follow-up

Variable	FB group (mean ± SD)	MB group (mean ± SD)	*p*-value
Maximum knee flexion (°)	121.9 ± 7.1	122.7 ± 6.8	0.21
Extension deficit (°)	−1.4 ± 1.0	−1.3 ± 1.1	0.48
Tibial axial rotation (°)	19.4 ± 4.2	23.1 ± 4.5	0.003

Abbreviations: FB, fixed bearing; MB, mobile bearing; SD, standard deviation.

difference was not statistically significant (log-rank test, $p = 0.67$). Revision causes included aseptic loosening (n = 4 MB; n = 5 FB), polyethylene wear (n = 3 MB; n = 2 FB), and patellar tracking complications (n = 2 FB). No cases of bearing dislocation were reported in the MB group, and no deep infections occurred in either group.

When truncating follow-up at 10 years to account for differences in observation time, cumulative revision-free survival remained high in both groups: 96.1% for MB and 95.4% for FB (log-rank test, $p = 0.72$). Kaplan-Meier curves showed overlapping confidence intervals, confirming stability of the survival trend over time (►**Fig. 1**).

Multivariable Regression and Adjusted Survival Analysis

In the multivariable linear regression model for IKDC score, the MB design was not independently associated with better outcomes (β = 1.17; 95%CI: −0.73–3.07; $p = 0.23$). Likewise, in the Kujala score model, the association remained statistically non-significant (β = 1.32; 95%CI: −0.62–3.26; $p = 0.18$). These findings confirm that crude score differences between groups were largely attributable to baseline variations and follow-up duration rather than implant type itself.

Notably, axial tibial rotation was a significant independent predictor of IKDC score (β = 0.51 per degree increase; 95 CI: 0.19–0.83; $p = 0.002$), indicating that preservation of rotational motion may have functional relevance beyond the implant design per se.

In the Cox proportional hazards model adjusted for age, sex, BMI, alignment, and follow-up time, the hazard ratio (HR) for revision in the MB group compared to FB was 0.94 (95%CI: 0.62–1.41; $p = 0.76$), suggesting no significant difference in implant survivorship after controlling for confounding factors. Age, sex, and alignment were not significantly associated with revision risk, although BMI showed a borderline association (HR = 1.03 per unit; 95% CI: 0.99–1.07; $p = 0.08$).

Subgroup Analysis and Correlation between Axial Rotation and Function

Subgroup analyses were conducted by age (< 65 versus ≥ 65 years), sex, BMI (< 30 versus ≥ 30 kg/m^2), and baseline

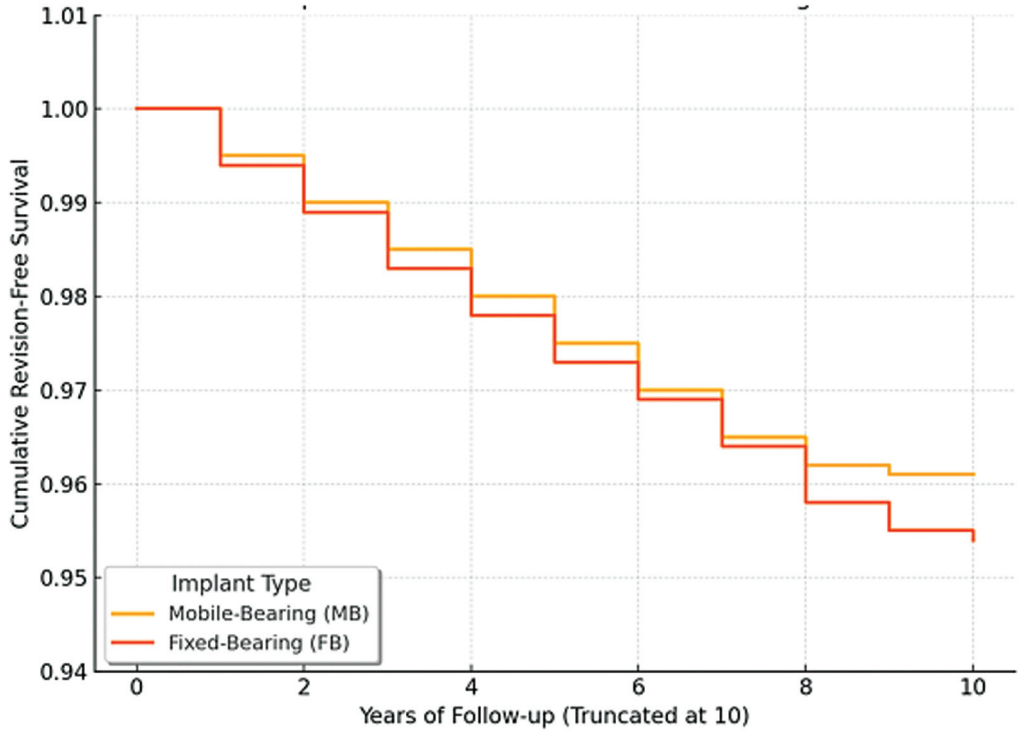


Fig. 1 Kaplan–Meier survival curve.

function (IKDC < 50 versus ≥ 50) to assess the clinical impact of MB implants. In patients < 65 years, MB implants showed slightly higher final IKDC (89.4 ± 7.6 versus 86.7 ± 8.3; $p = 0.048$) and Kujala scores (86.2 ± 6.9 versus 83.1 ± 7.4; $p = 0.044$) than FB implants. Differences were not significant in patients $\geq$ 65 years ($p > 0.1$). No significant differences were seen by sex or BMI.

In patients with better preoperative function (IKDC ≥ 50), MB implants resulted in greater axial tibial rotation ($24.5 \pm 4.1°$ versus $20.1 \pm 4.4°$; $p < 0.001$) and higher Kujala scores (85.4 ± 7.1 versus 82.5 ± 7.6; $p = 0.035$). These effects were not significant in those with IKDC < 50. Correlation analysis showed moderate associations in younger ($r = 0.34$; $p < 0.01$) and high-functioning patients ($r = 0.29$; $p = 0.016$), but not overall ($r = 0.11$; $p = 0.14$).

Hypothesis Testing and Statistical Validation

A Fisher's F-test comparing variance in long-term IKDC and Kujala scores between the MB and FB groups yielded an observed F-value of 1.18, below the critical threshold of 3.84 ($p = 0.28$). Thus, the null hypothesis—stating that there is no significant difference in functional outcomes between the two prosthesis designs—could not be rejected.

However, the post-hoc subgroup analysis revealed a statistically significant advantage of the MB design in preserving tibial rotational capacity, as discussed above. While overall functional outcomes were statistically equivalent, this specific biomechanical advantage may have clinical relevance in younger or more active patients.

Discussion

The principal finding of this retrospective study is that both MB and FB TKA designs provided significant and durable functional improvements in patients with medial compartment osteoarthritis. No statistically significant differences were observed in patient-reported outcome measures (PROMs), including IKDC and Kujala scores. However, MB implants demonstrated greater axial tibial rotation at long-term follow-up (23.1° versus 19.4°; $p = 0.003$), suggesting a potential kinematic advantage.

Mobile-bearing designs permit relative movement between the polyethylene insert and tibial baseplate, allowing controlled axial rotation and limited translation. These features may reduce shear forces and better replicate native knee motion. Our results are consistent with prior kinematic studies. Fransen et al.[17] reported improved rotational control and greater flexion with MB implants during gait. Hanusch et al.,[18] Harrington et al.,[19] and Hasegawa et al.[20] found enhanced tibial rotation and axial mobility under dynamic conditions.

Despite these biomechanical benefits, clinical relevance remains debatable. Systematic reviews and meta-analyses have shown that MB implants do not consistently outperform FB in functional scores, survivorship, or complication rates.[20,21] Our findings support this: improved rotational mobility did not translate into better overall outcomes over up to 20 years of follow-up.

The current study adds novel evidence by evaluating axial rotation, rarely assessed in large series. In younger or highly active patients, MB implants may offer modest but meaningful benefits. However, the small rotational gain, combined with similar PROMs and survival, does not justify routine MB use in all TKA cases.

In a 2021 meta-analysis by Hantouly et al.,[22] randomized trials comparing TKA with MB versus FB implants with a follow-up of $\geq$ 12 months were included. No differences were found in revision rates, loosening, functional scores, range of motion, or radiographic findings. In conclusion, both designs achieved excellent outcomes, and the theoretical advantages of the mobile-bearing insert were not confirmed.[22]

In 2022, a prospective, randomized, controlled trial by Sohn et al.[23] compared 49 FB TKAs versus 49 MB TKAs, evaluating joint awareness and crepitus, as well as range of motion, functional scores, implant position, and joint line level. The results showed no significant differences between groups in Forgotten Joint Score, incidence or severity of crepitus, range of motion, functional scores, or radiographic outcomes. They concluded that MB TKA showed no benefits over FB TKA; the theoretical advantages of the mobile-bearing insert were not confirmed, leaving implant selection to the surgeon.[23]

Finally, the most recent study, conducted in 2024 by Kim et al.,[24] compared 88 patients with a mean age of 66 years who received either rotating-platform MB or FB TKA, assessed clinically (VAS, ROM, Knee Society Score [KSS], and Western Ontario and McMaster Universities Osteoarthritis Index [WOMAC]) and radiographically at 13 years of follow-up. No significant differences were found between the MB and FB groups in clinical or radiographic outcomes, nor in complication incidence ($p > 0.05$). They concluded that although clinical and radiographic outcomes were similar, the potentially higher risk of osteolysis or aseptic loosening in MB TKA could influence implant selection.

Clinical Implications

Implant selection should be individualized based on factors like age, activity, alignment, and soft-tissue balance. Mobile-bearing implants may benefit patients who need enhanced axial mobility, while FB designs remain reliable and cost-effective for most TKA cases. Secondary analyses—truncated follow-up, multivariable adjustment, and propensity matching—confirmed no significant differences in long-term function or survivorship. Axial rotation remained consistently greater in the MB group, reinforcing its biomechanical relevance. While the MB design was not an independent predictor of outcomes, greater tibial rotation correlated with higher IKDC scores, highlighting the role of joint kinematics in optimizing results.

Limitations

The present study has several limitations. First, follow-up duration differed between cohorts, potentially biasing

comparisons. Although addressed with truncated Kaplan-Meier analysis and adjusted models, residual bias may persist. Second, the retrospective, non-randomized design introduces confounding factors. Propensity score matching balanced groups, but unmeasured variables remain possible. Third, outcome measures (IKDC and Kujala scores), though validated, are less common in arthroplasty research, limiting comparability with studies using Oxford Knee Score (OKS) or KSS. Additionally, axial tibial rotation was assessed clinically, not via dynamic imaging, reducing measurement precision. Future research using motion analysis or radiostereometric tracking could improve accuracy. Finally, variables like activity level, rehab adherence, or surgical technique details were not captured and may have influenced outcomes despite multivariable adjustment.

Conclusion

In this long-term retrospective study of MB vs. FB TKA for medial osteoarthritis, both designs showed significant and lasting functional improvement. Mobile-bearing implants demonstrated greater axial tibial rotation, indicating potential kinematic advantages, but no significant differences were found in patient-reported outcomes or implant survival. These results do not support routine MB use over FB in primary TKA. Implant selection should be based on patient activity, expectations, cost, and surgical experience. Further prospective studies are needed to clarify whether improved axial mobility offers meaningful long-term clinical benefits.

Data Availability

Data will be available upon request to the corresponding author.

Authors' Contributions

Each author contributed individually and significantly to the development of this article: PARG: validation, visualization, writing – original draft, writing – review and editing; PDRM: validation, visualization, writing – original draft, research; CPPC: conceptualization, research, methodology, validation, visualization, writing – original draft, writing – revision and editing; FEU: conceptualization, data curation, formal analysis, research, methodology, validation, visualization, writing – original draft, writing – revision and editing; DARM: validation, visualization, writing – original draft, research; AXBC: validation, visualization, writing – original draft, research.

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Conflict of Interests

The authors have no conflict of interests to declare.

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Lesser Metatarsals Load after Minimally-Invasive Surgery for Hallux Valgus Correction: A Finite Element Model

Carga sobre os metatarsos menores após cirurgia minimamente invasiva para correção de hallux valgus: Um modelo de elementos finitos

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Abstract

Objective To analyze the biomechanical consequences on the lesser metatarsals using different screw configurations for fixation of the minimally-invasive Chevron-Akin (MICA) osteotomy, through the finite element method (FEM).

Methods A FEM model was developed from a computed tomography scan of a moderate hallux valgus (HV) deformity. Five different screw configurations were tested. We measured the maximal tension in the lesser metatarsals for each screw configurations, in physiological and supraphysiological loads.

Results The lesser metatarsals received the lowest loads when the first metatarsal osteotomy was fixed with one intramedullary and one bicortical screw, with tensile load values varying between 30 and 70 MPa in physiological loads, and 50 to 350 MPa in supraphysiological loads. In all fixing techniques, the 2nd and 4th metatarsals received the highest loads, especially in groups 3 (two bicortical screws) and 5 (only one bicortical screw), with values reaching up to 230 and 600 MPa in physiological and supraphysiological loads, respectively. Regardless of the fixation technique, the region of the lesser metatarsals that received the most load was the diaphysis.

Keywords
- finite element analysis
- foot deformities, congenital
- hallux valgus
- minimally invasive surgical procedures

This paper was developed at Hospital Santa Helena, SHLN 516 Conjunto D - Asa Norte – Brasília, DF, Brazil.

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Conclusion After MICA surgery to correct HV, there is an increase in tension forces on the lesser metatarsals, especially the second and fourth. The technique of fixing the first metatarsal with one bicortical and one intramedullary screw showed the lowest values on the lesser metatarsals load. Furthermore, for physiological and supraphysiological loads, independently of the technique, the forces were concentrated mainly on the metatarsal shaft.

Resumo

Objetivo Analisar as consequências biomecânicas nos metatarsos menores do uso de diferentes configurações de parafusos para fixação da osteotomia minimamente invasiva em Chevron e Akin (MICA, do inglês *minimally-invasive Chevron-Akin*) por meio do método dos elementos finitos (MEF).

Métodos Um modelo de MEF foi desenvolvido a partir de uma tomografia computadorizada de uma deformidade hallux valgus (HV) moderada. Cinco configurações diferentes de parafusos foram testadas. A tensão máxima nos metatarsos menores de cada configuração de parafuso, em cargas fisiológicas e suprafisiológicas, foi medida.

Resultados Os metatarsos menores receberam as menores cargas quando a osteotomia do primeiro metatarso foi fixada com um parafuso intramedular e um bicortical, com carga de tração entre 30 e 70 MPa em cargas fisiológicas e 50 a 350 MPa em cargas suprafisiológicas. Em todas as técnicas de fixação, o 2º e o 4º metatarsos receberam as maiores cargas, especialmente nos grupos 3 (2 parafusos bicorticais) e 5 (apenas 1 parafuso bicortical), com valores de até 230 e 600 MPa em cargas fisiológicas e suprafisiológicas, respectivamente. Independentemente da técnica de fixação, a região dos metatarsos menores submetida à maior carga foi a diáfise.

Conclusão Após a cirurgia MICA para correção de HV, houve aumento das forças de tensão nos metatarsos menores, especialmente no segundo e quarto. A técnica de fixação do primeiro metatarso com um parafuso bicortical e um intramedular apresentou os menores valores de carga nos metatarsos menores. Além disso, em cargas fisiológicas e suprafisiológicas, independentemente da técnica, as forças concentraram-se principalmente na diáfise metatársica.

Palavras-chave
- análise de elementos finitos
- deformidades congênitas do pé
- hallux valgus
- procedimentos cirúrgicos minimamente invasivos

Introduction

The term hallux valgus (HV) refers to a complex three-dimensional (3D) deformity, which consists of medial deviation of the first metatarsal and lateral deviation of the hallux. Although its etiology is multifactorial and not yet fully understood, this is a very common pathology in the population, especially in women.[1] These deformities in the first ray can lead to several changes in the gait biomechanics and mechanical overload on the forefoot, depending on HV severity.[2,3]

The definitive treatment of HV is surgical. However, there are several techniques described in the literature. More recently, minimally invasive techniques have been gaining popularity due to their potential for deformity correction and low morbidity, faster recovery, and lower cost.[1]

Several studies have highlighted the outcomes of the third generation minimally-invasive Chevron-Akin (MICA) technique for correcting HV.[4] It is known that after surgery, one of the possible complications is the transfer metatarsalgia, caused mainly by excessive shortening and insufficiency of the first metatarsal.[5,6] Another concern is the choice of first metatarsal fixation type and its biomechanical influence on the foot. Although the classical MICA fixation uses two screws (one proximal bicortical and one distal and intramedullary), some authors described modifications using only one screw.[7,8] However, few studies investigated the load in the forefoot after HV correction using this technique.[9,10]

The finite element model (FEM) has been used to evaluate the biomechanics of the foot and ankle in various situations. Through validated predefinitions,[11] we can simulate pathologies or surgical procedures, and thus evaluate biomechanical results effectively.[12] A previous study[13] using FEM analysis demonstrated that, after Chevron osteotomy in the first metatarsal, the first ray received less pressure with deviations of 2 to 4 mm and increased pressure with a deviation of 6 mm. Meanwhile, the second ray received less pressure in all degrees of translation, and the other metatarsals received greater pressure, regardless of the first

metatarsal's degree of translation. Despite evaluating different degrees of osteotomy translation, they did not analyze the behavior with different fixation techniques of the first metatarsal.[13]

The objective of this study is to analyze the biomechanical consequences on the lesser metatarsals after MICA surgery to correct HV, with different techniques for fixation of the osteotomy, through FEM.

Methods

Dimensional Characteristics and Screw Insertion Technique

The implants were applied as indicated by the manufacturer's dimensional characteristics (Novastep). The MICA osteotomy was performed at the base of the flare of the distal metaphysis/neck of the first metatarsal, according to Redfern and Vernois's original description of the technique.[14] The head of the first metatarsal was translated laterally 75%, achieving a 5° HV angle (HVA) and a 4° intermetatarsal angle (IMA), as shown in ►**Fig. 1**.

Five groups were categorized based on the technique used for the fixation of the MICA osteotomy. In group 1, named MICA, we fixed the osteotomy with two screws, one bicortical and one monocortical (intramedullary); in 2, two intramedullary screws; in 3, two bicortical screws; in 4, only one intramedullary screw; and in group 5, only one bicortical screw (►**Fig. 2**).

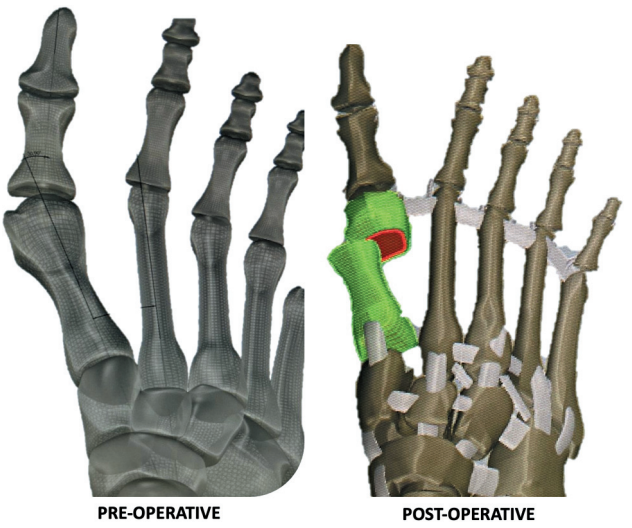


Fig. 1 Graphical representation of the pre- and postoperative simulated model for the finite element analysis. Source: Lewis et al.[10]

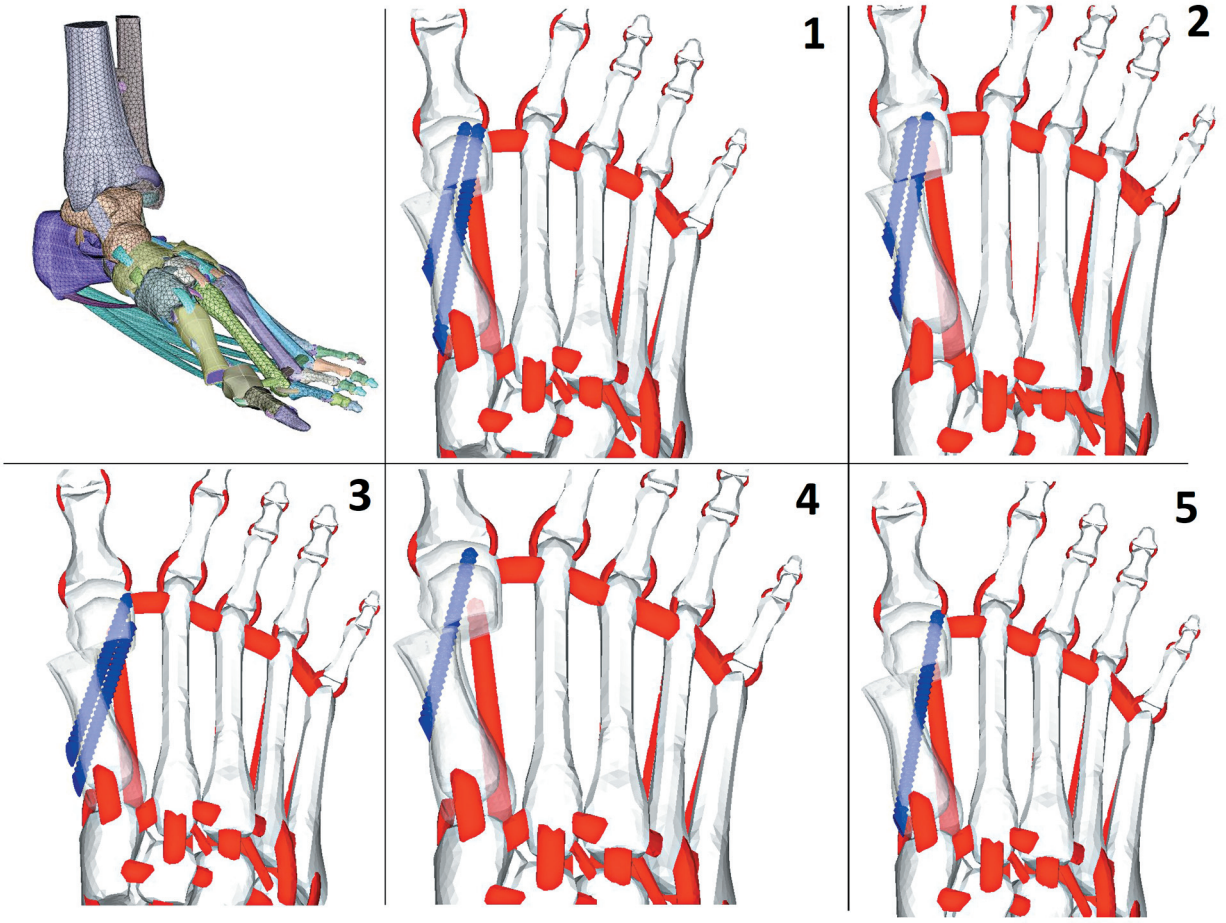


Fig. 2 Screw fixation configuration tested by the finite element analysis model: group 1, one bicortical and one intramedullary screw (MICA); group 2, two intramedullary screws; g roup 3 two bicortical screws; group 4, one intramedullary screw; and group 5, one cortical screw. Source: Lewis et al.[10].

Biocad Preparation

The program Rhinoceros 6 (Robert McNeel & Associates) created the 3D virtual models of each system (bone and screws). The finite element analysis was performed by the program SimLab (HyperWorks), applying the Optistruct solver (Altair Engineering Inc.). The computed tomography (CT) scans were obtained from the left foot of a 46-years-old female, with a moderate HV deformity (HVA: 30°; and IMA: 14°), without other deformities. The two-dimensional images obtained through CT were used for the 3D reconstruction of the anatomical structure of the surface geometry of the foot by the InVesalius (Centro de Tecnologia da Informação Renato Archer) and STereo Lithography (STL, 3D Systems Inc.) softwares. The CT scan machine used was Emotion (16 channels, Siemens Healthineers) with a slice interval of 2 mm. The Considerations for Reporting Finite Element Analysis Studies in Biomechanics guidelines were followed.[15]

Simulation

To simulate the loading of the metatarsals, FEM was used following fixation of the MICA with five different techniques. First, the files were imported into the SimLab software and each part of the digital models was identified, ensuring that the size of the element was maintained to avoid any issues of contact between the different parts during the simulations.

The discretization of the geometric domain was performed using second-order tetrahedral elements with an average edge length of 3 mm in the cortical and trabecular bones, 0.5 mm in the area, 2 mm in the ligaments, and refinement in the contact regions with an average edge size of 0.8 mm. All tissues were defined as homogeneous, isotropic, and linearly elastic. A tetrahedral element was adopted to form the meshes. The properties of the materials used for simulations were Young's modulus and Poisson's coefficient, following a previous study.[1] A standard mesh sensitivity analysis was performed to ensure that the density used in the FEM was sufficient to reach the converged numerical results and that no further refinement was necessary.

Boundary and Load Conditions

Considering the physiological conditions, with the forefoot and hindfoot fixed, a vertical ground reaction force (GRF) was applied to the midfoot. No load has been applied on the X and Y-axis. The upward vertical force of the Achilles tendon was also created with half of the value of the GRF. All models were tested for two different physiological conditions (150 and 300 N). The FEM model was applied to measure the maximal tension in each of the lesser metatarsals.

Results

It was observed that when subjected to physiological load, the different methods for fixing the first metatarsal osteotomy presented varied maximum main tension (traction forces) in the lesser metatarsals. Group 1 presented the lowest values, ranging from around 30 to 70 MPa. The highest values were seen in the second and fourth metatarsals in groups 2, 3, and, mainly, in group 5, whose values were around 150 MPa in the second metatarsal and 230 MPa in the fourth. In group 4, the second and fourth metatarsals presented maximum tension of roughly 70 and 115 MPa, respectively (►**Fig. 3**).

When the MEF models were submitted to supraphysiological load, it was observed that the maximum tension presented higher values in the lesser metatarsals, mainly in the second and fourth. Groups 3 and 5 presented values of around 600 MPa in these metatarsals. In groups 2 and 4, those same metatarsals presented maximum tension of around 300 and 600 MPa, respectively. In group 1 (MICA), the lesser metatarsals presented the lowest maximum tension values, ranging from around 50 to 350 MPa (►**Fig. 4**).

Lastly, it was observed that, in both physiological and supraphysiological loads, the diaphysis was the region of the lesser metatarsals that received the greatest concentration of loads, regardless of the technique used for fixation of the osteotomy of the first metatarsal.

Discussion

In the present study, we assessed, through the FEM, the metatarsals load after MICA technique to correct HV with different techniques for fixation of the osteotomy. The main findings were the lowest values presented in the lesser metatarsals for group 1 for physiological and supraphysiological loads. Furthermore, for both loads, all other fixation techniques presented the highest values in the second and fourth metatarsals, especially in groups 3 and 5. These results confirm the relevance of using intramedullary screws, together with bicortical ones, which might avoid lesser metatarsal overload.

Minimally-invasive Chevron-Akin osteotomy is a technique used in HV correction that has promising results, with good radiological and clinical outcomes.[4] A prospective study[9] including 31 feet of 25 patients with moderate and severe HV, without metatarsalgia, used pedography to evaluate the load transfers to the lesser metatarsals after surgical correction of HV, with the fourth generation minimally invasive technique. The study demonstrated a reduction in loads on the first ray, with a decrease in central metatarsal loading, 3 months after the surgery. The authors concluded that the technique may not prevent or correct metatarsalgia. Differently, in our study, the MICA technique for correction of HV presented high loads on the lesser metatarsals, especially on the second and fourth.

Previous studies investigated the fixation of the first metatarsal after MICA osteotomy with just one bicortical screw, showing good clinical and radiological results.[7,8] However, none of these studies analyzed load transfer to the lesser metatarsals, postoperatively. In our study, the use of one or two intramedullary (groups 2 and 4) or bicortical (groups 3 and 5) screws showed similar results, with higher loads on the second and fourth metatarsals. Such load transfers to the lesser metatarsals were not observed in the MICA technique, which presented the best biomechanical results.

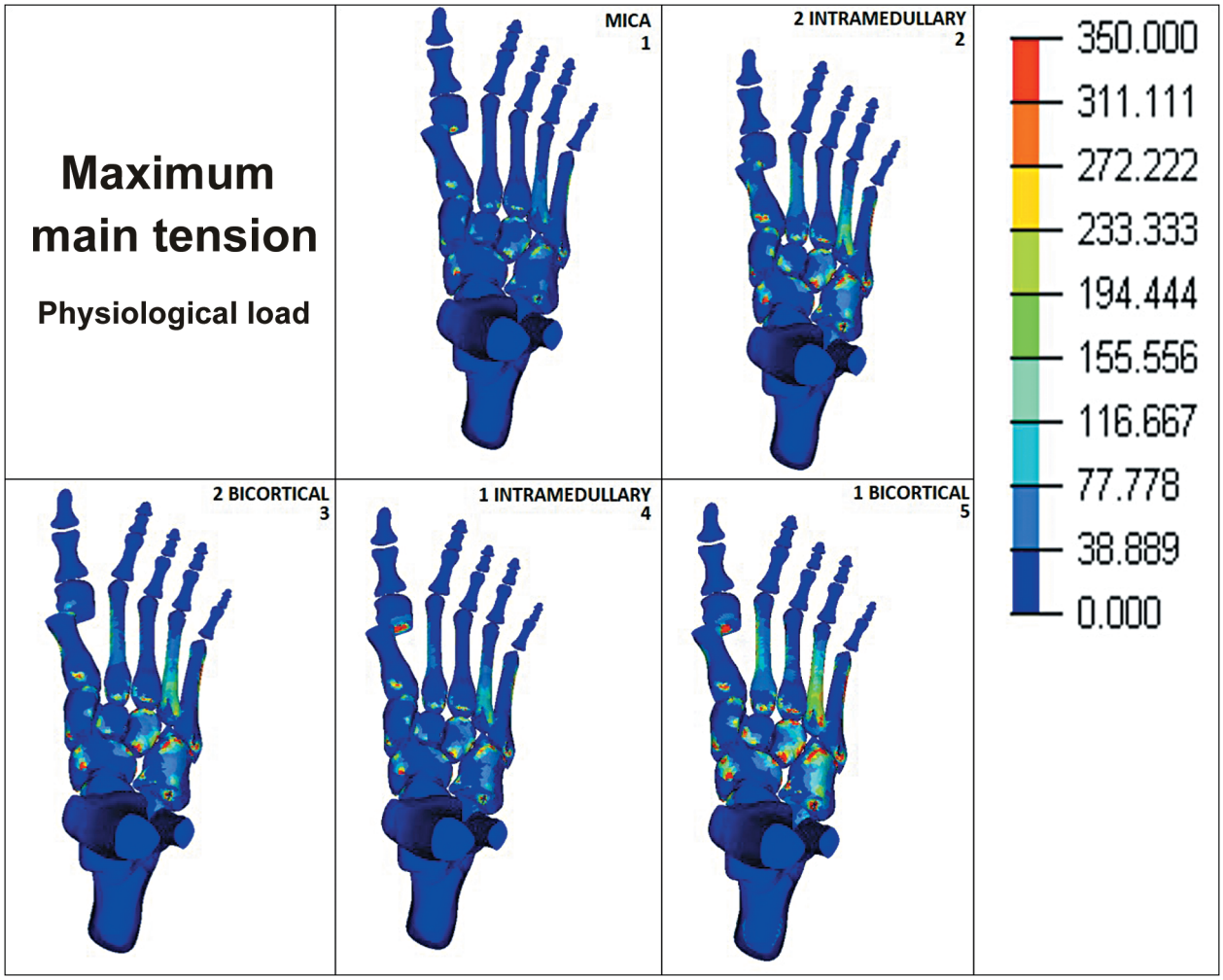


Fig. 3 Maximum main tension in physiological load (150 N) in 5 different fixation techniques.

This suggests that adding a second screw with the same position (i.e. intramedullary or bicortical) did not prove to be advantageous in relation to lesser metatarsals' load transfer. Therefore, the use of two screws with different positioning is ideal, according to the MICA technique.

Several complications were described after the first metatarsal osteotomy for HV deformity correction. One of them is transfer metatarsalgia, with an estimated occurrence of 5.4% in percutaneous surgeries.[16] One of its likely causes would be insufficiency of the first ray, either due to excessive shortening or fixation in a dorsiflexion position.[5,6,17] In our study, once the osteotomy was constructed by FEM, there was no deviation on the sagittal plane, nor shortening. That fact could explain increased tension on the lesser metatarsals. Furthermore, curiously, in all fixation types the loads were concentrated more on the lesser metatarsal diaphysis, which may result in transfer metatarsalgia, stress fracture, or toe deformities (claw toes). Therefore, surgeons must be attentive with excessive shortening and deviations of the first metatarsal head in the sagittal plane, avoiding possible overloads on metatarsals.

We are aware of several limitations of our study, most of them related to the FEM analysis. First, not all readers are familiar with this analysis tool. Also, we considered the anatomy from a single foot, only a 75% translation of the first metatarsal head with one model loading type. Further, for modeling purposes, it was considered that the mechanical properties of the materials, cortical bone, trabecular bone, ligaments, and syntheses were continuous, isotropic, and uniform linear elastic materials.

The accuracy of FEM results depends on the input parameters and assumptions made during model development. As such, inaccurate material properties can lead to divergent results. Simplifications in modeling, such as assuming linear material behavior or limited anatomy, may affect the accuracy of predictions. Furthermore, it is important to highlight that different results may arise in a dynamic simulation, different from the static simulation performed in this study. Also, it's impossible to consider the interindividual variability and other in vivo compensatory mechanisms. This model also could not account for different osteotomy configurations or percentage metatarsal head shifts. Therefore, the results presented here may vary from in vivo studies. However, as our objective was to evaluate only the fixation methods, we tried to recreate a test excluding the variations found in human or cadaveric studies.

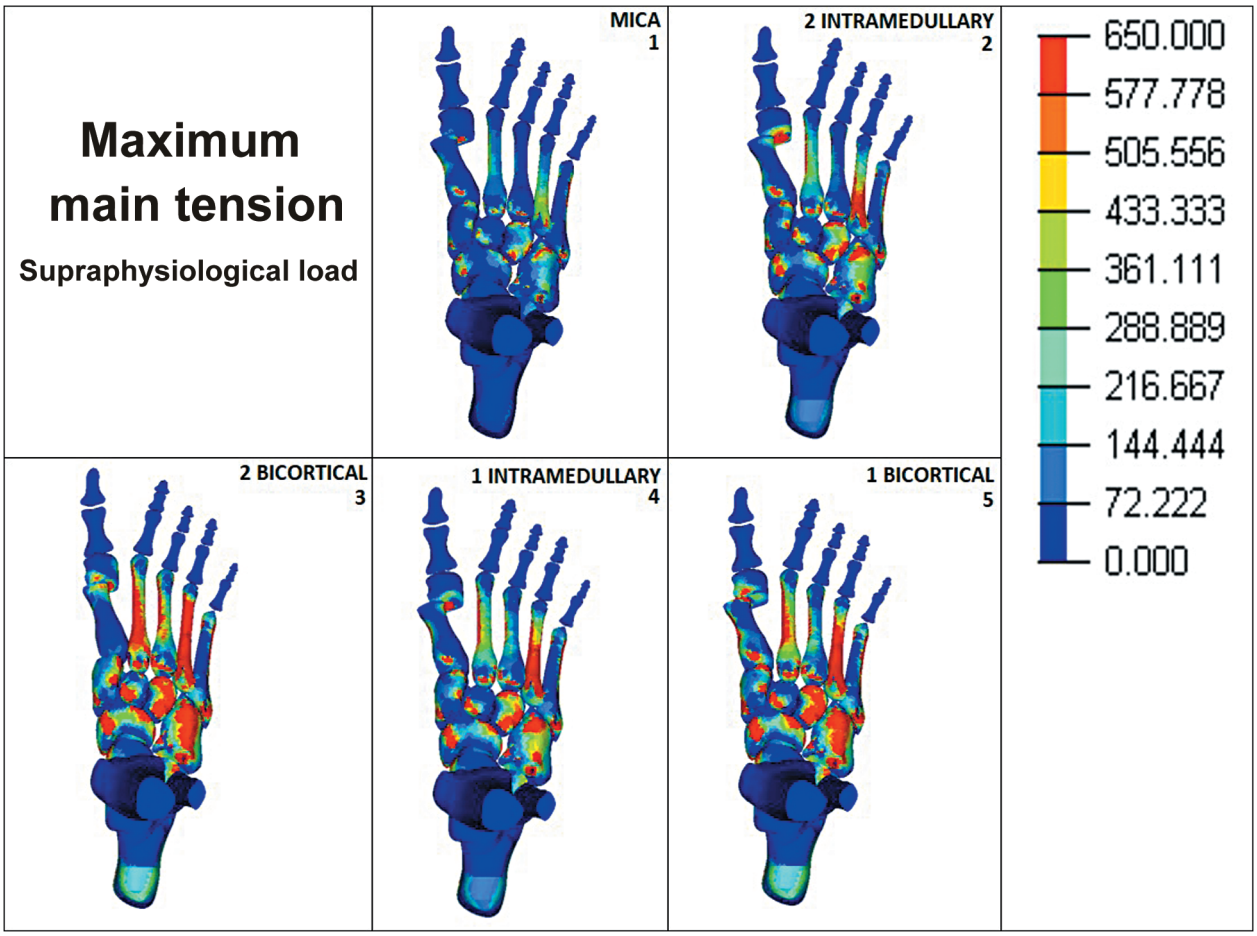


Fig. 4 Maximum main tension in supraphysiological load (300 N) in 5 different fixation techniques.

Conclusion

In the present study, FEM analysis showed that after MICA osteotomy for HV correction, there is an increase in tension forces on the lesser metatarsals, especially the second and fourth. The technique fixing the first metatarsal with one bicortical and one intramedullary screw showed the lowest values in the lesser metatarsals loads. Besides, for physiological and supraphysiological loads, the forces were concentrated mainly in the metatarsal shaft independent of the technique.

Authors' Contributions

Each author contributed individually and significantly to the development of this article: HM and GN: software and formal analysis. HM and BA: writing – original draft. HM and GN: conceptualization and project administration. All authors discussed the results and contributed to the final manuscript.

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Underweight Patients with Low Bone Density are at Greater Risk of Intraoperative Fracture during Hemiarthroplasty

Pacientes com baixo peso e baixa densidade óssea correm maior risco de fratura intraoperatória durante a hemiartroplastia

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Abstract

Objective To investigate whether body mass index (BMI) modifies the association between bone mineral density (BMD) and intraoperative fracture risk in cementless hemiarthroplasty.

Methods Between April 2020 and March 2025, 588 patients who received cementless stems and underwent dual-energy X-ray absorptiometry scans within one week postoperatively were included. Patients were stratified by BMI ($\geq$ 18.5 kg/m^2 versus $<$ 18.5 kg/m^2) and young adult mean (YAM) (cutoff: 70%). Fracture risk was compared across groups. Subgroup analyses based on YAM levels and operative parameters were performed in 577 patients with complete data.

Results In underweight patients (BMI $<$ 18.5 kg/m^2), lower YAM was associated with higher intraoperative fracture risk ($p = 0.128$), whereas no significant association was observed in patients with BMI $\geq$ 18.5 kg/m^2 ($p = 0.80$). Fracture rates increased with lower YAM: 3.97% ($\geq$ 70%), 5.24% (60–69%), 5.88% (50–59%), 6.58% ($<$ 50%), though not statistically significant. Higher BMI was associated with longer operative time and greater blood loss.

Conclusion Body mass index modifies the association between BMD and intraoperative fracture risk. Preoperative YAM assessment may help identify underweight patients at higher risk during cementless hemiarthroplasty. Level of Evidence III, therapeutic study

Keywords
- body mass index
- bone mineral density
- femoral fractures
- femoral neck fractures
- risk factors

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Resumo

Objetivo Investigar se o índice de massa corporal (IMC) modifica a associação entre densidade mineral óssea (DMO) e risco de fratura intraoperatória em hemiartroplastia não cimentada.

Métodos Entre abril de 2020 e março de 2025, foram incluídos 588 pacientes que receberam hastes não cimentadas e foram submetidos a exames de raios X de dupla energia em até uma semana de pós-operatório. Os pacientes foram estratificados por IMC ($\geq$ 18,5 kg/m^2 versus $<$ 18,5 kg/m^2) e porcentagem média de adultos jovens (YAM, do inglês *young adult mean*) (ponto de corte: 70%). O risco de fratura foi comparado entre os grupos. Análises de subgrupos, com base nos níveis de YAM e nos parâmetros operatórios, foram realizadas em 577 pacientes com dados completos.

Resultados Em pacientes com baixo peso (IMC $<$ 18,5 kg/m^2), menor YAM associou-se a maior risco de fratura intraoperatória ($p = 0{,}128$), enquanto nenhuma associação significativa foi observada em pacientes com IMC $\geq$ 18,5 kg/m^2 ($p = 0{,}80$). As taxas de fratura aumentaram com menor YAM: 3,97% ($\geq$ 70%), 5,24% (60–69%), 5,88% (50–59%), 6,58% ($<$ 50%), embora esse aumento não tenha sido estatisticamente significativo. O IMC mais alto foi associado a maior tempo operatório e maior perda de sangue.

Conclusão O IMC modifica a associação entre DMO e risco de fratura intraoperatória. A avaliação pré-operatória do YAM pode ajudar a identificar pacientes com baixo peso e com maior risco durante a hemiartroplastia não cimentada. Nível de evidência III, estudo terapêutico.

Palavras-chave

- densidade mineral óssea
- fatores de risco
- fraturas do colo femoral
- fraturas do fêmur
- índice de massa corporal

Introduction

Proximal femoral fractures are common injuries in elderly populations, representing a major public health burden worldwide due to the aging society. Hip arthroplasty is frequently performed for displaced femoral neck fractures, providing favorable functional outcomes and pain relief. However, intraoperative periprosthetic fractures remain one of the major complications during arthroplasty procedures, particularly in elderly and osteoporotic patients.

Bone mineral density (BMD) is considered a key factor influencing the risk of intraoperative fracture. Preoperative assessment of BMD, often expressed as a young adult mean (YAM) percentage, has been proposed as a useful parameter for evaluating bone quality in surgical candidates. In addition, body mass index (BMI), reflecting nutritional status and sarcopenic tendencies, may also play an important role in bone fragility and fracture susceptibility.

Although both BMD and BMI are recognized as important contributors to bone strength, limited studies have explored the potential interaction between these factors in the context of intraoperative periprosthetic fractures. Understanding how BMI modifies the association between BMD and intraoperative fracture risk may offer useful insights for surgical risk stratification and preoperative optimization.

The purpose of the present study was to investigate whether BMI modifies the predictive value of BMD for intraoperative periprosthetic fractures in patients undergoing hip arthroplasty for femoral neck fractures.

Materials and Methods

Study Design and Patient Selection

The present retrospective study was conducted at our institution between April 1, 2020, and March 31, 2025. During this period, 1,119 patients underwent hip arthroplasty for femoral neck fractures. Among them, 588 patients who received cementless femoral stems and underwent bone mineral density (BMD) assessment using dual-energy X-ray absorptiometry (DEXA) within 1 week postoperatively on the contralateral hip were included in the analysis. Patients with missing BMD data or incomplete clinical information were excluded.

Data Collection

Bone mineral density was measured using DEXA with a Lunar Prodigy scanner (GE Healthcare). The regions of interest included the femoral neck, greater trochanter, and proximal shaft. Values were expressed as a percentage of the young adult mean (YAM), based on Japanese reference data for individuals aged 20 to 39 years.

The following demographic and clinical variables were collected from medical records: sex, age, laterality (right or left), body mass index (BMI), and BMD. Bone mineral density was expressed as a percentage of the young adult mean (YAM), which is commonly used in Japan as an indicator of bone quality.

Group Classification

Patients were stratified into 4 groups according to international BMI classification (cutoff at 18.5 kg/m^2) and YAM

threshold (cutoff at 70%). This created the following categories:

YAM $\geq$ 70% and BMI $\geq$ 18.5 kg/m^2;
YAM $\geq$ 70% and BMI $<$ 18.5 kg/m^2;
YAM $<$ 70% and BMI $\geq$ 18.5 kg/m^2; and
YAM $<$ 70% and BMI $<$ 18.5 kg/m^2.

Additionally, patients were further categorized into 4 groups based on YAM levels alone:

YAM $\geq$ 70%;
YAM 60–69%;
YAM 50–59%; and
YAM $<$ 50%.

Outcome Assessment

The primary outcome was the occurrence of intraoperative periprosthetic fracture, which was assessed intraoperatively and confirmed by intraoperative findings and postoperative imaging.

Statistical Analysis

In addition, subgroup analyses were performed in 577 patients with complete data for operative time and blood loss, to compare these operative parameters between patients with BMI $\geq$ 18.5 kg/m^2 and those with BMI $<$ 18.5 kg/m^2. Mann-Whitney U tests were used to assess statistical significance.

Descriptive statistics were used to summarize the patients' characteristics. Intraoperative fracture rates were compared among groups. Stratified analysis was performed to assess whether BMI modified the association between YAM and fracture risk. Fisher's exact test was used to calculate odds ratios (ORs) and p-values. A p-value of < 0.05 was considered statistically significant. Statistical analyses were conducted using standard software.

Results

A total of 588 patients were included in the present study (►**Table 1**). The mean age was 83.8 $\pm$ 8.1 years, and there were 160 males and 428 females. The mean BMI was 20.19 $\pm$ 4.20 kg/m^2, and the mean YAM was 62.4 $\pm$ 11.8%.

Table 1 Baseline characteristics stratified by YAM

Variable	YAM $<$ 70%	YAM $\geq$ 70%
n	264	83
Mean age (years)	84.6 $\pm$ 7.7	81.7 $\pm$ 8.0
Female sex: n (%)	204 (77.3%)	54 (65.1%)
Mean BMI (kg/m^2)	19.50 $\pm$ 3.36	21.55 $\pm$ 3.57
Mean YAM (%)	57.4 $\pm$ 8.0	76.0 $\pm$ 7.4
Mean operative time (minutes)	55.5 $\pm$ 18.1	58.7 $\pm$ 19.8
Mean blood loss (mL)	134.7 $\pm$ 110.2	124.1 $\pm$ 72.5
Fracture: n (%)	5 (1.9%)	3 (3.6%)

Abbreviation: YAM, young adult mean.

Baseline characteristics stratified by YAM are shown in ►**Table 1**, and those stratified by combined YAM $\times$ BMI categories are presented in ►**Table 2**. These tables provide the detailed distribution of demographic and operative variables across the analytical groups.

Patients were initially classified into 4 groups based on the combination of BMI ($\geq$ 18.5 or $<$ 18.5 kg/m^2) and YAM ($\geq$ 70% or $<$ 70%) (►**Table 3**). Intraoperative periprosthetic fractures occurred in 5.36% of patients with YAM $\geq$ 70% and BMI $\geq$ 18.5 kg/m^2, 0.00% in those with YAM $\geq$ 70% and BMI $<$ 18.5 kg/m^2, 4.85% in patients with YAM $<$ 70% and BMI $\geq$ 18.5 kg/m^2, and 7.10% in those with YAM $<$ 70% and BMI $<$ 18.5 kg/m^2.

Stratified analysis according to BMI showed that in patients with BMI $\geq$ 18.5 kg/m^2, no significant association was observed between YAM and intraoperative fracture (OR: 1.11, $p = 0.80$). In contrast, in patients with BMI $<$ 18.5 kg/m^2, no fractures were observed in those with YAM $\geq$ 70%, whereas fractures occurred exclusively in those with YAM $<$ 70% (OR: 0.0, $p = 0.128$) (►**Table 4**).

Additionally, when patients were categorized into 4 groups based on YAM levels alone ($\geq$ 70%, 60–69%, 50–59%, and $<$ 50%), the fracture rates demonstrated a gradual increasing trend: 3.97%, 5.24%, 5.88%, and 6.58%, respectively. Although these differences did not reach statistical

Table 2 Baseline characteristics stratified by YAM and BMI

Variable	YAM $<$ 70% and BMI $<$ 18.5 kg/m^2	YAM $<$ 70% and BMI $\geq$ 18.5 kg/m^2	YAM $\geq$ 70% and BMI $<$ 18.5 kg/m^2	YAM $\geq$ 70% and BMI $\geq$ 18.5 kg/m^2
n	107	157	18	65
Mean age (years)	85.5 $\pm$ 7.8	84.0 $\pm$ 7.6	79.5 $\pm$ 9.7	82.3 $\pm$ 7.5
Female sex: n (%)	83 (77.6)	121 (77.1)	11 (61.1)	43 (66.2)
Mean BMI (kg/m^2)	16.66 $\pm$ 1.36	21.44 $\pm$ 2.91	16.37 $\pm$ 1.31	22.98 $\pm$ 2.49
Mean YAM (%)	55.0 $\pm$ 8.1	59.0 $\pm$ 7.6	73.8 $\pm$ 4.1	76.7 $\pm$ 8.0
Mean operative time (minutes)	52.6 $\pm$ 15.8	57.5 $\pm$ 19.4	54.4 $\pm$ 15.9	59.8 $\pm$ 20.8
Mean blood loss (mL)	111.8 $\pm$ 85.7	150.7 $\pm$ 122.3	120.2 $\pm$ 60.9	125.2 $\pm$ 75.8
Fracture: n (%)	1 (0.9)	4 (2.5)	0 (0.0)	3 (4.6)

Abbreviations: BMI, body mass index; YAM, young adult mean.

Table 3 Intraoperative fracture rate by YAM and BMI

Group	N	Fractures (n)	Fracture rate (%)
YAM $\geq$ 70% and BMI $\geq$ 18.5 kg/m^2	112	6	5.36
YAM $\geq$ 70% and BMI $<$ 18.5 kg/m^2	39	0	0.00
YAM $<$ 70% and BMI $\geq$ 18.5 kg/m^2	268	13	4.85
YAM $<$ 70% and BMI $<$ 18.5 kg/m^2	169	12	7.10

Abbreviations: BMI, body mass index; YAM, young adult mean.

Table 4 Stratified analysis according to the body Mass index (BMI)

BMI category	Odds ratio	*p*-value
$\geq$ 18.5 kg/m^2	1.11	0.80
$<$ 18.5 kg/m^2	0.0	0.128

Table 5 Intraoperative fracture rate by detailed YAM categories

YAM group	N	Fractures (n)	Fracture rate (%)
$\geq$ 70%	151	6	3.97
60–69%	191	10	5.24
50–59%	170	10	5.88
$<$ 50%	76	5	6.58

Abbreviation: YAM, young adult mean.

significance, a dose-dependent tendency was observed (►**Table 5**). Furthermore, among the 577 patients for whom operative time and blood loss data were available, patients with BMI $\geq$ 18.5 kg/m^2 demonstrated significantly longer operative time (60.5 $\pm$ 20.9 minutes versus 55.3 $\pm$ 16.8 minutes; $p = 0.006$) and greater blood loss (133.5 $\pm$ 100.4 mL versus 109.5 $\pm$ 76.4 mL; $p = 0.004$) compared with those with BMI $<$ 18.5 kg/m^2 (►**Table 6**).

In addition, multivariable logistic regression analysis adjusting for age, sex, operative time, and blood loss did not identify any independent predictors of intraoperative fracture; adjusted odds ratios for low BMI and low YAM were not statistically significant, likely due to the small number of events. Interaction testing (BMI $<$ 18.5 kg/m^2 $\times$ YAM $<$ 70%) also did not reach statistical significance. Post-hoc power analysis indicated that the observed difference ($\approx$ 1% versus 0% fracture rate in the underweight group) provided only $\sim$ 12% power, whereas a clinically meaningful difference (6% versus 0%) would have yielded $\sim$ 49% power. Therefore, the lack of statistical significance likely reflects limited power rather than absence of association. Operative parameters differed significantly between BMI groups: patients with BMI $\geq$ 18.5 kg/m^2 had longer operative time (59.2 $\pm$ 19.3 versus 54.4 $\pm$ 15.5 minutes; $p = 0.009$) and greater blood loss (144.3 $\pm$ 116.2 vs 125.0 $\pm$ 93.1 mL; $p = 0.024$).

Discussion

In contemporary management of proximal femoral fractures, early surgical intervention within 48 hours has consistently been associated with improved outcomes. Moja et al.[1] reported a pooled OR of 0.74 (95%CI: 0.67–0.81) for mortality when surgery was performed within 48 hours compared to delays, based on $>$ 190 thousand patients. Similarly, another systematic review confirmed reduced 30-day and in-hospital mortality with early surgery.[2]

Choice of implant also influences intraoperative fracture risk. Meta-analyses have found that cemented stems are associated with significantly fewer intra- and postoperative periprosthetic fractures compared to cementless options.[3] Registry data support a 59% relative risk reduction with cemented stems.[4]

In our study, we observed a clear inverse trend between preoperative YAM and intraoperative fracture risk, especially in underweight patients (BMI $<$ 18.5 kg/m^2), with a suggestive trend despite not reaching statistical significance. This indicates that YAM assessment may provide valuable risk stratification among low-BMI patients.

Body mass index is routinely available in clinical practice, and preoperative YAM evaluation in underweight patients could guide both surgical planning and prehabilitation, involving early osteoporosis treatment.

In contrast, among patients with BMI $\geq$ 18.5 kg/m^2, fracture rates did not differ by YAM. Notably, our sub-analysis of 577 patients showed that patients with higher BMI had significantly longer operative times (60.5 $\pm$ 20.9 versus 55.3 $\pm$ 16.8

Table 6 Comparison of operative time and blood loss according to the body Mass index (BMI)

BMI category	n (N = 577)	Mean operative (minutes)	Mean blood loss (mL)	*p*-value (operative time)	*p*-value (blood loss)
$\geq$ 18.5 kg/m^2	372	60.5 $\pm$ 20.9	133.5 $\pm$ 100.4	0.006	0.004
$<$ 18.5 kg/m^2	205	55.3 $\pm$ 16.8	109.5 $\pm$ 76.4		

minutes; $p = 0.006$) and greater blood loss (133.5 ± 100.4 versus 109.5 ± 76.4 mL; $p = 0.004$) (►**Table 5**). This indicates procedural complexity, rather than bone quality, drives risk in this group. Conversely, streamlined exposure in lean patients may lead to quicker—but riskier—stem insertion in the context of low bone quality.

Given that plain radiographs and BMI are universally available, there is potential for artificial intelligence (AI)-driven prediction models to estimate YAM and forecast fracture risk, enhancing preoperative planning in frail patients.

Although the key comparison between patients with BMI < 18.5 kg/m^2 and YAM $< 70\%$ did not reach statistical significance ($p = 0.128$), the divergent trend observed between low– and high–BMI groups in relation to bone mineral density is clinically meaningful. The lack of significance is most likely attributable to limited statistical power, particularly because the subgroup of patients with BMI < 18.5 kg/m^2 and YAM $\geq 70\%$ was very small in our cohort. This highlights the need for larger multi–center studies or pooled analyses to confirm and strengthen these preliminary findings.

Moreover, a recent large cohort study demonstrated that the association of total hip BMD with incident hip fractures may be weaker among underweight individuals than among those with higher BMI, supporting our findings regarding increased fracture vulnerability in low–BMI, low–YAM patients.[5] A prospective analysis in diabetic patients similarly confirmed low BMI as an independent and powerful risk factor for fractures.[6] Systematic reviews have also challenged the protective notion of obesity in low trauma fractures, emphasizing the complexity of BMI–fracture relationships.[7] Finally, recent data suggest that suboptimal bone health—including low BMD and osteoporosis—is significantly associated with periprosthetic fractures and poor hip arthroplasty outcomes.[8,9]

Limitations

- This was a retrospective, single-center study conducted at our institution.
- Despite observing consistent trends, sample size limitations may have reduced statistical power. Larger, multicenter validation is necessary.
- Although our institution predominantly uses cementless hemiarthroplasty, a shift toward cemented stems is possible. Cementless fixation remains necessary in select patients, and external validation in varied cohorts is needed.

Conclusion

In cementless hemiarthroplasty for femoral neck fractures among patients with BMI < 18.5 kg/m^2, preoperative YAM evaluation can help reduce intraoperative periprosthetic fracture risk, highlighting the importance of bone quality assessment in surgical planning for underweight patients.

Data Availability

Data will be available upon request to the corresponding author.

Ethical Committee Approval Statement

This retrospective study was conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study protocol was approved by the institutional review board of our hospital on June 25, 2025. All patient data were anonymized and de-identified prior to analysis to ensure confidentiality and privacy. Informed consent was waived due to the retrospective nature of the study and the use of de-identified data, as approved by the committee.

ICMJE Form Summary Statement for CORR Submission

The corresponding author, Dr. Jun Takeuchi, declares that there are no conflicts of interest relevant to this work. Specifically:

- No financial support was received from any third party for the work under consideration for publication (section 2).
- No relevant financial activities outside the submitted work over the past 36 months (section 3).
- No patents, whether planned, pending, or issued, broadly relevant to the work (section 4).
- No other relationships or activities that readers could perceive to have influenced, or that give the appearance of potentially influencing, what was written in the submitted work (section 5).

This disclosure is made in accordance with the requirements of the International Committee of Medical Journal Editors (ICMJE).

The present research was conducted solely by Jun Takeuchi; no other individuals were involved.

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Conflict of Interests

The author has no conflict of interests to declare.

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The Pencil Fulcrum Technique: A Simple Method for Closed Reduction of Extra-Octave Fractures in Children

Técnica do fulcro com lápis: Um método simples para redução fechada de fraturas da falange proximal por mecanismo de hiperabdução, o "mecanismo do pianista", em crianças

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Abstract

Extra-octave fractures of the fifth proximal phalanx are Salter-Harris type II physeal injuries resulting in ulnar deviation and dorsal angulation. If inadequately reduced, these fractures may result in cosmetic deformity, malalignment, and functional impairment. Traditional reduction methods, such as the Jahss maneuver, can be technically demanding, forceful, and often require sedation or surgical assistance, which limits their use in younger children and in resource-constrained environments.

We report our experience with the fulcrum-assisted "pencil technique" for closed reduction in four children, aged 4 to 11 years, under digital nerve block without sedation or traction. The method employs a simple pencil placed at the base of the fourth web space near the metacarpophalangeal joint, serving as a fulcrum. Gentle adduction and flexion pressure is applied to the proximal phalanx, correcting both ulnar deviation and dorsal angulation by biomechanical leverage. Reduction was confirmed clinically and radiographically, and immobilization was achieved with buddy strapping or tin splinting for 3 weeks.

All patients achieved stable reduction and demonstrated uneventful healing, pain-free full range of motion, and return to baseline activities at follow-up ranging from 6 to 12 weeks. Functional outcomes assessed by the quick disabilities of the arm, shoulder, and hand (QuickDASH) scores were excellent: two patients scored 0, one 2.27, and another 4.55. No complications or redisplacements were observed.

The pencil fulcrum technique is simple, safe, reproducible, and cost-effective. It represents a valuable addition to the armamentarium of physicians managing pediatric extra-octave fractures, particularly in outpatient, emergency, and low-resource settings.

Keywords

- closed fracture reduction
- finger phalanges
- fractures, bone
- pediatrics

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Resumo

As fraturas extra-oitavas da quinta falange proximal são lesões fisárias do tipo II de Salter-Harris e provocam desvio ulnar e angulação dorsal. A redução inadequada dessas fraturas pode causar deformidade estética, perda de alinhamento e comprometimento funcional. Métodos tradicionais de redução, como a manobra de Jahss, podem ser tecnicamente complexas, agressiva e frequentemente exigem sedação ou cirurgia, o que limita seu uso em crianças pequenas e ambientes com recursos limitados.

Relatamos nossa experiência com a "técnica do lápis" assistida por fulcro para redução fechada em quatro crianças, com idades entre 4 e 11 anos, sob bloqueio nervoso digital sem sedação ou tração. O método emprega um lápis simples, que atua como fulcro, posicionado na base do quarto espaço interdigital próximo à articulação metacarpofalangiana. Uma leve pressão de adução e flexão é aplicada à falange proximal, o que corrige o desvio ulnar e a angulação dorsal por alavancagem biomecânica. A redução foi confirmada clínica e radiograficamente, realizando-se imobilização solidária com a técnica de "buddy strapping" ou tala de estanho, mantida por 3 semanas.

Na consulta de acompanhamento, realizada 6 a 12 semanas após o procedimento, todos os pacientes apresentaram redução estável, cicatrização sem intercorrências, amplitude de movimento completa e indolor, e retorno às atividades básicas. Os resultados funcionais avaliados pelo escore Quick Disabilities of the Arm, Shoulder and Hand (QuickDASH) foram excelentes: dois pacientes com pontuação 0, um com 2,27 e o último com 4,55. Não foram observadas complicações ou novas luxações.

A técnica do fulcro com lápis é simples, segura, reprodutível e econômica. Representa uma valiosa adição ao arsenal de médicos para tratamento de fraturas extra-oitavas pediátricas, particularmente em ambulatórios, emergências e instituições com poucos recursos.

Palavras-chave

- falanges dos dedos da mão
- fraturas ósseas
- pediatria
- redução fechada

Introduction

Pediatric hand fractures are among the most common injuries seen in emergency and orthopedic settings, often resulting from sports, falls, or direct trauma. Within this spectrum, fractures involving the base and neck of the fifth proximal phalanx are frequently encountered, particularly due to axial loading or impact to the ulnar border of the hand. One specific variant, known as the "extra-octave fracture", is a Salter-Harris type II injury of the fifth proximal phalanx's base.[1]

The term "extra-octave fracture" was given to the increased ulnar deviation and dorsal angulation of the little finger that allows a theoretical extension of hand span similar to a pianist reaching an extra octave, at the cost of function and alignment (►**Fig. 1**).[1,2]

Historically, these injuries were often misclassified or grouped with other juxtaepiphyseal fractures until the unique angulation and anatomical implications of the extra-octave variant were better recognized. Early literature noted that, although these fractures might appear innocuous, improper reduction could lead to cosmetic deformity, rotational malalignment, and loss of fine motor control, particularly in tasks requiring a strong ulnar grip.[1,2]

Conventional management of these fractures involves closed reduction using traction-based methods such as the Jahss maneuver (90-90 flexion-pressure technique), which was first described for metacarpal neck fractures, and later adapted for phalangeal base injuries, including extra-octave ones.[3] This maneuver involves flexing the metacarpophalangeal joint (MCPJ) and applying force in a volar direction on the metacarpal shaft and a dorsal direction on the proximal interphalangeal (PIP) joint, along with immobilization to ensure the finger is not in extension. Forceful reduction with this technique can worsen the soft tissue injury. Al-Qattan recommends immobilization with an ulnar gutter splint or cast with the MCPJ flexed at 90°.[1]

Given these challenges, there is an increasing shift towards simple, reproducible, and less invasive techniques that can be safely performed in outpatient settings or emergency departments. In this context, we used a novel fulcrum-assisted method described as "the pencil method," which was introduced by Beatty et al.[4] It employs a standard pencil or a similar solid cylindrical object to achieve closed reduction through biomechanical leverage, reaching anatomical reduction of these fractures.[4]

Hereby, we present a series of four children with extra-octave fractures treated with fulcrum-based reduction under digital block, using a pencil or a similar solid cylindrical object without any surgical tools.

Methods

The Institutional Review Board (IRB) approved this retrospective study and an informed consent was taken from the

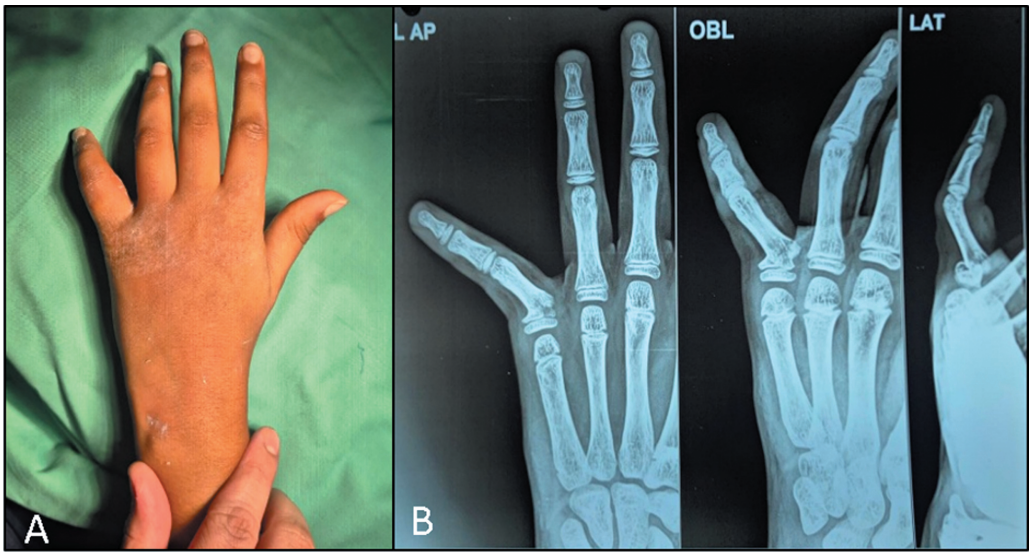


Fig. 1 (A) Clinical image showing the ulnar deviation and dorsal angulation in a "extra-octave fracture". (B) Radiograph showing Salter-Harris type II injury on the fifth proximal phalanx.

guardians of all patients for data and image representation. We conducted a retrospective case series of 4 pediatric patients, aged 4 to 11 years, who presented with extra-octave fractures of the 5th proximal phalanx, between 2023 and 2024.

All fractures were classified as Salter–Harris type II at the base of the proximal phalanx. Patients were treated in the outpatient clinic or emergency department using a fulcrum-assisted closed reduction technique, performed under digital nerve block with 2% lidocaine. All patients were assessed for radiological healing and the Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH) questionnaire for functional recovery.

Technique Description

1. Position the patient supine with the affected hand pronated on a hand table.
2. Administer a digital nerve block using 2% lidocaine to the finger involved.
3. Clinical deformity of the fifth digit and the fracture was visualized.
4. Place a pencil or a similar solid cylindrical object perpendicular to the table at the base of the fourth web space, near the MCPJ (►**Fig. 2A**).
5. Using the pencil as a fulcrum, gentle pressure was applied to adduct and flex the proximal phalanx. This coordinated

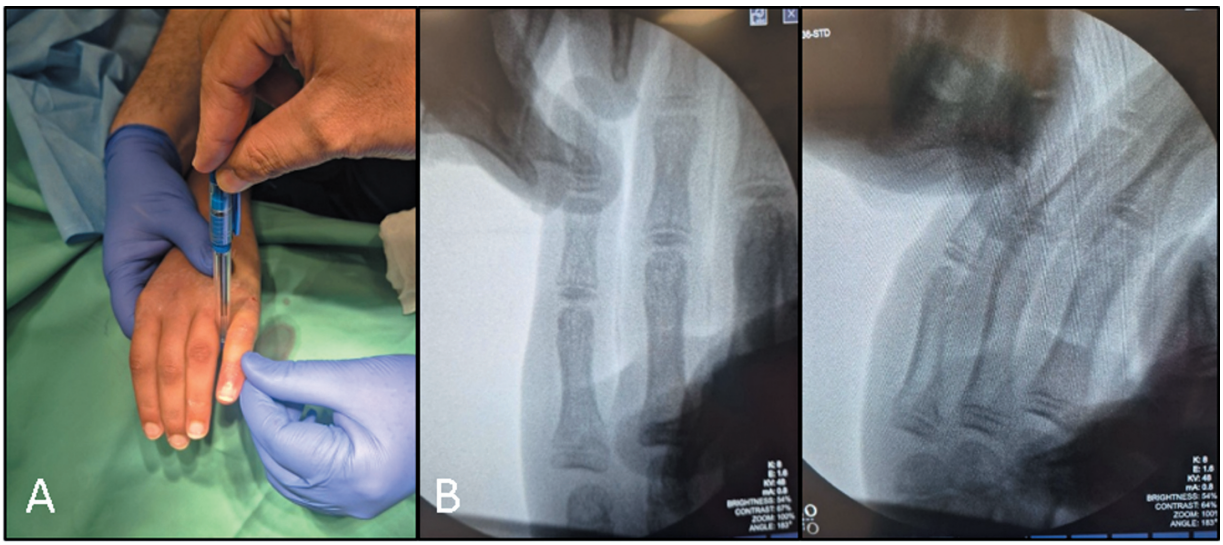


Fig. 2 (A) Demonstration of the fulcrum-assisted reduction with pencil in the fourth web space near the MCPJ. (B) Intraoperative fluoroscopy image showing anatomical reduction.

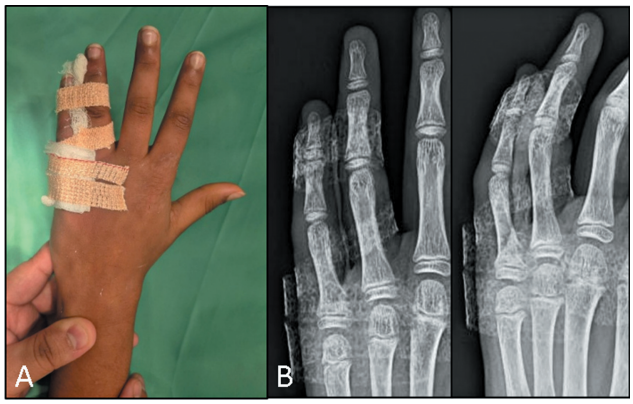


Fig. 3 (A) Postoperative immobilization with buddy strapping. (B) Postoperative radiograph showing a stable fracture reduction.

movement facilitated fracture reduction through biomechanical leverage, correcting both the ulnar deviation and the dorsal angulation.

6. The reduction was confirmed clinically and radiographically using fluoroscopy in anteroposterior, oblique, and lateral views (►**Fig. 2B**).
7. The finger was immobilized using buddy strapping with or without a tin splint for a duration of 3 weeks (►**Fig. 3A**). Radiographic imaging was taken in the immediate postoperative period (►**Fig. 3B**).
8. Range-of-motion exercises were initiated at the end of 3 weeks, followed by grip-strengthening exercises.

Results

All fractures in our cohort occurred in the dominant right hand. All four patients underwent successful closed reduction with the pencil fulcrum technique without the need for traction, sedation, or surgical instrumentation. Radiographic assessment confirmed anatomical alignment in each case, which was maintained until bone union. Immobilization was well tolerated.

Fracture healing was achieved uneventfully in all cases, with no instances of redisplacement, infection, or neurovascular compromise. At final follow-up, which ranged from 3 to 6 months, every patient demonstrated full, pain-free range of motion of the affected finger and returned to preinjury levels of activity. Functional outcomes assessed using the QuickDASH questionnaire showed excellent recovery, with scores of 0 in 2 cases, 2.27 in one, and 4.55 in another (►**Table 1**).

Discussion

Although relatively uncommon, extra-octave fractures represent a distinct subset of pediatric proximal phalangeal injuries that demand careful management to prevent long-term deformity and dysfunction. The characteristic ulnar deviation and dorsal angulation can result in significant functional impairment if inadequately reduced, especially in activities requiring strong ulnar grip and fine motor control.[1,2] Traditional closed reduction methods, such as the Jahss maneuver,[3] have been adapted for these injuries but remain technically challenging and uncomfortable for children.

The Jahss maneuver, originally described for metacarpal neck fractures, involves 90° flexion of the MCP joint and opposing dorsal-volar pressure across the fracture site. While effective in experienced hands, the technique is inherently forceful, often painful, and frequently necessitates sedation or even general anesthesia in younger patients. Furthermore, reduction attempts using traction-based maneuvers can exacerbate soft tissue injury and may have a predisposition to redisplacement. These interventions also carry procedural risks and increase healthcare utilization, including potential operating room time and resource allocation. There has been a growing emphasis on developing alternative reduction strategies that are both minimally invasive and feasible even in remote nursing homes or clinics.

In contrast, the pencil fulcrum technique offers a biomechanically elegant and patient-friendly alternative. This technique was originally described by Beatty et al.[4] By using a simple cylindrical object, such as a pencil, as a fulcrum at the base of the fourth web space, the surgeon can apply gentle adduction and flexion forces that leverage the proximal phalanx into anatomical alignment. This technique minimizes traction and avoids excessive manipulation, thereby reducing discomfort and eliminating the need for sedation in most cases. Our results demonstrated that the maneuver is both effective and well tolerated under digital block alone.

Table 1 Patient characteristics, injury details, follow-up, and functional outcomes (QuickDASH)

Patient	Age, years	Injured hand	Dominant hand	Mechanism	Type of injury	Follow-up	QuickDASH score
1	4	Left	Right	Fell on an outstretched hand	Salter-Harris II – base of proximal phalanx	3 months	4.55
2	11	Left	Right	Direct trauma	Salter-Harris II – base of proximal phalanx	6 months	0
3	9	Left	Right	Injury while catching a cricket ball	Salter-Harris II – base of proximal phalanx	4 months	2.27
4	10	Left	Right	Direct trauma by a football	Salter-Harris II – base of proximal phalanx	6 months	0

Abbreviations: QuickDASH, quick Disability of the arm, shoulder, and hand questionnaire).

Other reduction methods, such as percutaneous pin-assisted reduction or mini-open approaches, are reserved for irreducible or unstable patterns. While these techniques provide reliable outcomes, they increase procedural complexity and resource utilization. They also carry risks of infection, physeal injury, and anesthesia-related complications. In contrast, the pencil fulcrum method requires no specialized equipment, can be performed rapidly in outpatient or emergency settings, and avoids the morbidity associated with operative intervention.

Our small series supports the reproducibility and safety of this maneuver. All patients achieved stable reductions with no complications, and functional outcomes were excellent at follow-up. It is important to highlight that the absence of redisplacement underscores the biomechanical soundness of this fulcrum-assisted approach when applied to stable fracture patterns.

Limitations of our study include the small cohort size, short-term follow-up, and lack of a comparative control group. The shorter follow-up can be attributed to a shorter recovery time in these children. Furthermore, this technique is not appropriate for comminuted, open, grossly unstable fractures, or cases with soft tissue interposition. Its applicability in older adolescents or adults, with stiffer bones and soft tissues, remains to be determined.

Final Considerations

The fulcrum-assisted pencil technique is a simple, safe, reproducible and cost-effective method for closed reduction of extra-octave fractures in children. Its minimal reliance on specialized tools or sedation makes it an excellent option for outpatient clinics, emergency departments, and resource-limited setups. Given its reproducibility and cost-effectiveness, this technique offers a valuable addition to the orthopedic clinician's armamentarium. Future studies involving larger, multi-center cohorts and longer-term follow-up are warranted to further validate its efficacy and optimize clinical guidelines for management.

Data Availability

Data will be available upon request to the corresponding author.

Authors' Contributions

VS: conceptualization; methodology; validation; visualization; writing – review & editing. DM: data curation; formal analysis; writing – original draft. RJ: data curation; formal analysis; writing – original draft. SP: conceptualization, supervision.

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Conflict of Interests

The authors have no conflict of interests to declare.

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CONTENTS

Peer Reviewing Process 3
MANUSCRIPT FORMAT **3-6**
- Article Types 3
- General Guidelines 3
- Files/Information Checklist 3
- Language 4
- Title Page 4
- Abstract and Keywords 4
- Main Document 4
- Acknowledgments 5
- Formatting of Funding Sources 5
- Conflict of Interest Statement 5
- Informed Consent 5
- Conflicts arising from papers authored by Editorial Board Members 6
- References 6
- Figure Captions 6
- Tables 6
- Videos 6
- Supplementary Material 6

DIGITAL ARTWORK PREPARATION **6-7**
- General Guidelines 6
- Black and White Art 7
- Color Art 7
- Art Labels 7

SUBMISSION PROCEDURE **7**
- Article Processing Charge (APC) and Open Access 7
- Submission Procedure 7
- Revision Procedure 7

PRODUCTION PROCEDURE **7**
- Page Proofs 7

POLICY STATEMENTS **8-9**
- Privacy Statement 8
- Preprint Server Statement 8
- Ethics standards 8
- Authorization Letter 8
- Conflict of Interest Statement (if any): 8
- Informed Consent 8
- Copyright Statement 8
- Definition of Authorship 8
- Contributors 9
- Changes to authorship 9

EDITORIAL CONTACTS **9**

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