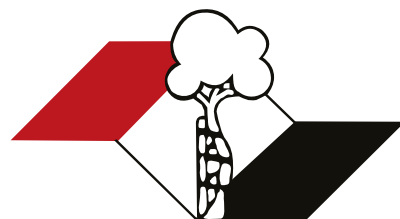


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ULTRASONOGRAPHIC EVALUATION OF BONE HEALING IN METACARPAL AND PHALANGEAL FRACTURES

AVALIAÇÃO ULTRASSONOGRÁFICA DA CONSOLIDAÇÃO ÓSSEA NAS FRATURAS DOS METACARPAIS E DAS FALANGES

ANTONIO CARLOS DA COSTA¹ , THIAGO BARROS PINHEIRO² , ANEES SALIM SAAD NETO³ , FABIO HIDEKI NISHI ETO² , YUSSEF ALI ABDOUNI² , DIEGO FIGUEIRA FALCOCHIO² 

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ABSTRACT

Objective: This study aimed to evaluate the use of ultrasonography (USG) compared to radiography in identifying callus formation and fracture healing in hand bones (metacarpals and phalanges). **Methods:** A prospective observational study was conducted with patients who sustained metacarpal and phalangeal fractures and were followed in the hand and microsurgery clinic of a philanthropic hospital in São Paulo between July 2023 and April 2024. Fractures were treated either conservatively or surgically with Kirschner wire fixation. Callus formation was monitored using serial weekly USG and radiographic examinations. Follow-up ended when bone healing was confirmed by both methods. **Results:** There was a difference in the mean time of callus appearance between ultrasonographic and radiographic evaluations for all analyzed variables. **Conclusion:** Ultrasonographic callus formation preceded radiographic callus appearance by approximately 18.2 days across all variables studied, suggesting that USG is a useful and alternative tool for the early diagnosis of bone healing in phalangeal and metacarpal fractures. **Level of Evidence II; Prospective Observational Study.**

Keywords: Ultrasonography; Fracture Healing; Fracture; Metacarpals; Finger Phalanges.

RESUMO

Objetivo: Esse trabalho teve como objetivo avaliar o uso da ultrassonografia (USG), comparativamente à radiografia, na identificação do calo ósseo e consolidação de fraturas da mão (ossos metacarvais e falanges). **Método:** Estudo observacional prospectivo dos pacientes com fratura dos metacarvais e falanges que foram acompanhados no ambulatório de cirurgia da mão e microcirurgia de um hospital filantrópico de São Paulo, no período entre julho de 2023 e abril de 2024, que foram tratados de forma clínica ou cirúrgica com fixação com fios de Kirschner. A formação do calo ósseo foi analisada através de exames de USG e radiografias seriadas semanalmente. O término do acompanhamento foi definido a partir da evidência de consolidação da fratura por ambos os exames. **Resultados:** Houve diferença entre o tempo médio do surgimento do calo ultrassonográfico em relação ao tempo médio de surgimento do calo radiográfico em todas as variáveis analisadas. **Conclusão:** O calo ultrassonográfico precedeu o calo radiográfico em aproximadamente 18,2 dias em todas as variáveis estudadas, elencando, dessa forma, a USG como uma ferramenta alternativa e útil para o diagnóstico precoce da consolidação óssea das fraturas das falanges e metacarvais. **Nível de evidência II; Estudo Prospectivo Observacional.**

Descritores: Ultrassonografia; Consolidação da Fratura; Fratura; Metacarvais; Falanges dos Dedos da Mão.

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INTRODUCTION

Hand fractures are among the most frequent in the human skeleton, with metacarpal and phalangeal fractures accounting for approximately 35% and 45% of all such injuries, respectively, predominantly affecting young adults.¹ Early bone healing and functional recovery are the main objectives of treatment for these fractures.²

It is known that healing of these fractures occurs within three to four weeks,^{3,4} while clinical stability of the fracture occurs well before radiographic evidence of consolidation.⁵ Uncertainty and excessive reliance on an objective parameter, such as callus formation detected by radiography, for authorizing mobilization may lead to permanent stiffness of the joints around the fracture. This is because

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The study was conducted at Grupo da Mão e Microcirurgia do Departamento de Ortopedia e Traumatologia da Irmandade Santa Casa de Misericórdia de São Paulo, R. Dr. Cesário Mota Junior, 112, Vila Buarque, São Paulo, SP, Brazil. 01221-010.

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fractures with more than eight weeks of evolution, even without pain or mobility at the fracture site, may still not show unequivocal signs of consolidation on plain radiographs.⁶

Ultrasonography (USG) is capable of detecting callus formation and its progression earlier than radiography. Over the past decades, some studies have highlighted the importance of USG in the diagnosis of bone healing.^{2,7,8} This method is based on its ability to distinguish tissues with different densities. During the healing process, the periosteal soft callus grows, increases in density, and fills the fracture gap. This callus appears in various shades of gray depending on its density and can be distinguished from adjacent soft tissues.⁹ Despite this, we did not find studies in the literature that employed this method in the treatment of phalangeal and metacarpal fractures. Therefore, given the importance of early hand rehabilitation, the aim of this study was to evaluate the presence of bone callus by USG compared with radiography and to assess differences between phalangeal and metacarpal fractures, between closed and open fractures, and between conservative and surgical treatment.

PATIENTS AND METHODS

We conducted a prospective observational study of patients with metacarpal and phalangeal fractures who were followed at our outpatient clinic between July 2023 and April 2024. Patients were treated either conservatively or surgically with Kirschner wire fixation. The study was approved by the Institutional Research Ethics Committee, in accordance with Resolution 196/96 (CAAE: 47826721.6.0000.5479).

A total of 32 patients were evaluated weekly until bone healing was confirmed by both methods.

The selected sample (Table 1) included patients over 18 years of age, of any sex, with acute fractures, open or closed, of any of the metacarpal or phalangeal bones of the hands. All patients were assessed by a single orthopedic surgeon experienced in USG, always using the same device.

Callus formation was analyzed through weekly USG and radiographic examinations, starting seven days after trauma in conservatively treated cases and, for those who underwent surgery, starting seven days after the surgical procedure. Follow-up ended when fracture consolidation was confirmed by both imaging methods.

The cutoff point for defining consolidation by USG was determined at the moment of identifying callus formation bridging at least two cortices of the studied bone. From the evidence of fracture consolidation on USG, patients were released from immobilization and, in operated cases, Kirschner wires were removed and rehabilitation was initiated. However, weekly follow-up was maintained until radiographic consolidation was identified.

Table 1. Description of all parameters evaluated in the patients.

Variable	Description
Age (years), mean SD	44.6 ± 14.6
Sex, n (%)	
Female	5 (26.3)
Male	14 (73.7)
Fracture location, n (%)	
Metacarpal (MC)	14 (73.7)
Phalanx	5 (26.3)
Type of fracture, n (%)	
Closed	15 (78.9)
Open	4 (21.1)
Treatment, n (%)	
Conservative	9 (47.4)
Surgical	10 (52.6)

For statistical analysis, qualitative characteristics of all patients were described using absolute and relative frequencies, and quantitative characteristics were described using summary measures (mean and standard deviation). Normality of distribution of callus formation times and the interval between methods was assessed using the Kolmogorov-Smirnov test, which did not indicate lack of normality in the data distribution.¹⁰

Times to callus formation with each assessment method were described and compared using the paired Student's t-test, with the interval between methods also presented.¹⁰ Both the times assessed with each method and the interval between methods were described according to the qualitative characteristics evaluated and compared across methods and categories of each characteristic using two-factor analysis of variance (ANOVA), with repeated measures between methods, followed by Bonferroni multiple comparisons to assess differences. Pearson correlations between age and times/interval were calculated to verify possible associations between callus formation times and patient age. Changes in correlations between methods and age were assessed using two-factor ANOVA.¹¹

All analyses were performed using IBM SPSS for Windows, version 22.0, and data tabulation was performed using Microsoft Excel 2013. Tests were conducted with a significance level of 5%.

RESULTS

Evaluation of the 32 patients demonstrated that bone callus formation on USG appeared earlier than on radiography.

Table 2 shows that the mean time to callus formation assessed by USG was 18.2 days shorter than the time assessed by radiography ($p < 0.001$).

There was a difference between the mean time of ultrasonographic callus appearance compared with the mean time of radiographic callus appearance across all analyzed variables. No statistical influence was observed for characteristics such as sex, type of fracture, and treatment on the times or on the interval between times ($p > 0.05$). (Table 3)

Table 2. Description of bone callus formation times with each assessment method, comparison between methods, and the time interval between methods.

Variable	Mean ± SD	p
Callus USG	31.6 ± 9.5	<0.001
Callus X-ray	49.7 ± 11.2	
Δt	18.1 ± 6.2	

Paired Student's t-test.

Table 3. Description of bone callus formation times and the interval between methods according to the evaluated characteristics and the results of comparisons between categories.

Variable	Callus USG	Callus RX	Δt
Fracture location			
Metacarpal	34.8 ± 8.6	52.1 ± 10.9	17.3 ± 6.3
Phalange	22.8 ± 5.8	43 ± 10.4	20.2 ± 6.2
p	0.011	0.124	0.385
Type of fracture			
Closed	31.7 ± 10.5	48.5 ± 12.2	16.8 ± 5.7
Open	31.3 ± 5	54 ± 5.6	22.8 ± 6.7
p	0.931	0.403	0.090
Treatment			
Conservative	32.6 ± 12.3	51.3 ± 13.8	18.8 ± 6.1
Surgical	30.8 ± 6.7	48.2 ± 8.9	17.4 ± 6.6
p	0.699	0.559	0.644

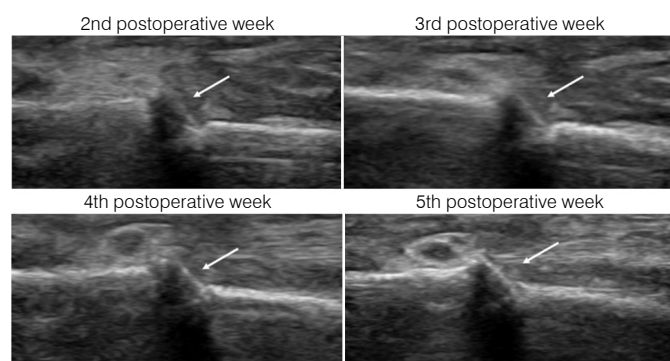
Data expressed as mean ± SD; r: Pearson correlation; unpaired Student's t-test.

Figures 1 and 2 illustrate a patient included in this study, with an open fracture of the third metacarpal that was surgically treated. After five postoperative weeks, when ultrasonographic callus was visualized, the Kirschner wires were removed. However, radiographic callus appeared only at the ninth postoperative week.



Source: Authors.

Figure 1. Postoperative follow-up radiographs of a metacarpal fracture. Kirschner wires were removed at the 5th postoperative week after evidence of ultrasonographic consolidation. Radiographic callus formation was observed only starting at the 9th postoperative week.



Source: Authors.

Figure 2. Serial postoperative ultrasonographic images demonstrating bone callus formation. At the 5th postoperative week, Kirschner wires were removed after visualization of the bone bridge at the fracture site.

DISCUSSION

Over the past three decades, several studies have attempted to demonstrate the importance of USG as a more accurate tool than conventional radiography for the early diagnosis of bone healing.^{6,8,12-18} This study was based on this prior knowledge, with the consideration that most of those series focused on long bones of the lower limbs, and no studies were found in the literature specifically addressing bone healing of hand fractures.

With the increasing use of USG by orthopedic surgeons and the advent of portable devices, examinations can be performed on an outpatient basis, providing more parameters for the management of hand fractures. USG has the advantages of being radiation-free, having lower operational costs, and enabling a more objective assessment of bone healing. This, in turn, helps to determine the ideal and safe time to begin patient rehabilitation,¹³ thereby reducing the uncertainties generated by radiographs as well as the risk of unfavorable outcomes secondary to imprudent treatment. Furthermore, the importance of early hand rehabilitation must be emphasized, since its joints are highly predisposed to stiffness following trauma and/or prolonged immobilization.¹⁹

Considering the results obtained in our case series, the time to callus formation detected by USG was on average 18.2 days earlier than that detected by radiography ($p < 0.001$), regardless of the variable analyzed, supporting the concept that ultrasonographic visualization of bone callus precedes radiographic detection. The standard deviation (SD) for both USG and radiographic callus diagnosis was relatively high because both phalanges and metacarpals were included in each group. As shown in Table 3, bone healing time for phalanges tends to be relatively shorter than for metacarpals.

Although factors such as fracture location (metacarpal or phalanx), fracture type (open or closed), and treatment method (conservative or surgical) did not demonstrate statistically significant differences due to an insufficient sample size, the differences observed in this study are consistent with those described in the literature when considering fracture location. However, when evaluating fracture type (open or closed), a discrepancy was noted.²⁰ The mean healing time observed was approximately 4 weeks for metacarpals and 3 weeks for phalanges, which is consistent with expectations in the literature. In contrast, closed fractures in our series showed a longer mean healing time compared with open fractures, which likely reflects the still limited number of cases analyzed.

In our series, USG proved to be an alternative and useful tool for the early diagnosis of bone healing in phalangeal and metacarpal fractures.

CONCLUSION

We conclude that ultrasonographic callus preceded radiographic callus by approximately 18 days across all studied variables, and that no differences were observed regarding fracture location, fracture type, or treatment modality.

AUTHOR'S CONTRIBUTION: Each author contributed individually and significantly to the development of the manuscript. ACC: study design, review, and final approval; TBP, ASSN, and FHNE: data collection, patient follow-up, and manuscript drafting; YAA and DFF: assisted in patient follow-up, actively participated in result discussions, and contributed to manuscript drafting.

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WHERE ARE THE ORTHOPEDIC ONCOLOGY CENTERS IN THE BRAZILIAN UNIFIED HEALTH SYSTEM (SUS)?

ONDE ESTÃO OS CENTROS DE ONCOLOGIA ORTOPÉDICA NO SUS?

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ABSTRACT

Objective: To identify and analyze the geographical distribution, surgical volume, and population adequacy of Orthopedic Oncology Centers (OOCs) within the Brazilian Unified Health System (SUS). **Methods:** We evaluated 11,139 procedures recorded in Hospitalization Authorizations (AIHs) between 2008 and 2019, including “hemipelvectomy in oncology” and “resection of bone tumors with replacement or reconstruction.” Hospitals performing both procedures and at least three hemipelvectomies during this period were classified as OOCs. **Results:** A total of 58 OOCs were identified in 18 states, accounting for 79.5% of all procedures. Most patients (93.7%) were treated in their home state. High-Volume Centers (HVCs) performed 95% of the surgeries, while Low-Volume Centers (LVCs) were responsible for only 5%. The Northeast region concentrated 39.1% of procedures, while the South had the highest number of OOCs per population. **Conclusion:** The geographical distribution of OOCs in Brazil is relatively adequate; however, procedures are highly concentrated in a few high-volume centers. This centralization may be associated with better clinical outcomes, reinforcing the need for policies that encourage specialized treatment in reference units. **Level of Evidence III; Cross-Sectional Observational Study.**

Keywords: Health Services Accessibility; Cancer Care Facilities; Bone Neoplasms; Orthopedics.

RESUMO

Objetivo: Identificar e analisar a distribuição geográfica, o volume cirúrgico e a adequação populacional dos Centros de Oncologia Ortopédica (COOs) no Sistema Único de Saúde (SUS). **Métodos:** Foram avaliados 11.139 procedimentos registrados em Autorizações de Internação Hospitalar (AIHs) entre 2008 e 2019, correspondentes a “hemipelvectomia em oncologia” e “ressecção de tumor ósseo com substituição ou reconstrução”. **Consideraram-se COOs os hospitais que realizaram ambos os procedimentos e pelo menos três hemipelvectomias no período.** **Resultados:** Foram identificados 58 COOs em 18 estados, responsáveis por 79,5% dos procedimentos. A maioria dos pacientes (93,7%) foi tratada em seu estado de origem. Centros de Alto Volume (CAV) realizaram 95% das cirurgias, enquanto Centros de Baixo Volume (CBV) responderam por apenas 5%. O Nordeste concentrou 39,1% dos procedimentos, e o Sul apresentou o maior número de COOs por habitante. **Conclusão:** Existe distribuição geográfica relativamente adequada dos COOs no Brasil, mas com grande concentração de procedimentos em poucos centros de alto volume. Essa centralização pode estar associada a melhores desfechos clínicos, reforçando a necessidade de políticas que incentivem a consolidação do tratamento em unidades especializadas. **Nível de Evidência III; Estudo Observacional Transversal.**

Descritores: Acesso aos Serviços de Saúde; Institutos de Câncer; Neoplasias Ósseas; Ortopedia.

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INTRODUCTION

In Brazil's Unified Health System (SUS), the healthcare network is stratified and divided into Health Regions, whose purpose is to ensure medical care at all levels of complexity for the entire population.¹ The rarer the disease, the fewer the number of referral centers available within the network, and the greater the distance patients must travel to receive specialized care.

Musculoskeletal malignancies are rare, accounting for less than 1% of neoplasms in adults and 15% in children.² Delays in diagnosis profoundly impact patient prognosis, often resulting in mutilating surgeries or low survival rates. In developed countries, the average time between the first symptom and diagnosis is six weeks; for pelvic bone tumors, this interval increases to 16 weeks. In Brazil, it is estimated that the time is twice as long.³ In a study conducted in

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The study was conducted at Universidade de São Paulo, Faculdade de Medicina de Ribeirão Preto, Av. Bandeirantes, 3900, Monte Alegre, Ribeirão Preto, São Paulo, SP, Brazil. 14.049-900.

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India, difficulty accessing orthopedic oncology centers—defined as delayed diagnosis or treatment—was observed in 72.2% of cases.⁴ The literature does not provide a clear definition of an Orthopedic Oncology Center (OOC), but it is well established that such centers should have a multidisciplinary team with specialized physicians, infrastructure with advanced diagnostic and treatment resources, and preferably a high patient flow that ensures extensive experience in the field.^{5,6}

In Brazil, both physicians and patients face significant challenges in identifying such centers. The National Cancer Institute (INCA) lists 317 hospital units accredited for cancer treatment, in which the participation of an orthopedic specialist on the medical team is required.^{1,7,8} However, there is no requirement that this orthopedic surgeon have specific training in orthopedic oncology.

These institutions are divided into two main models: UNACON (High-Complexity Oncology Units), which must provide care for the most prevalent cancers, and CACON (High-Complexity Oncology Centers), which must treat all cancer types and provide in-house radiotherapy services.^{1,8} According to recent studies, the number of such hospitals is insufficient, and their geographic distribution is inadequate.⁹

Therefore, the aim of this study was to identify Orthopedic Oncology Centers within the Brazilian Unified Health System and to assess their geographic distribution, surgical volume, and population adequacy.

METHODOLOGY

This study was approved by the local ethics and research committee under certificate number 125276/2023. Data from Hospital Admission Authorizations (AIHs), contained in the Hospital Information System of the Unified Health System (SIHSUS), were analyzed between January 2008 and December 2019. These data originate from the files of the Brazilian Ministry of Health, managed by the Department of Informatics of the Unified Health System (DATASUS), and are used for accountability between hospitals and the Ministry of Health.

The tools Dbsaúde® (Numb3rs Analytics®, 2017, Barueri, Brazil) and Tableau Software® (Salesforce Brasil®, 2019, São Paulo, Brazil) were used to process the data by the Executive Agreement Group of the Hospital das Clínicas, Ribeirão Preto Medical School, University of São Paulo (HC FMRP-USP). From the AIHs, the following data were extracted: (1) CNES – National Registry of Health Establishments, corresponding to the hospital name recorded in the DATASUS database; (2) municipality and (3) state of the establishments that issued the AIH; (4) municipality and (5) state of residence of the patient who underwent the procedure; (6) the date, including month and year, of the procedure; and (7) the AIH number. The only procedures available in the AIHs that are exclusively related to the orthopedic oncology specialist and performed in high-complexity hospitals are “hemipelvectomy in oncology” and “resection of bone tumor with substitution (endoprosthesis) or with reconstruction and fixation in oncology,” coded in the Sigtap (Management System of the Table of Procedures, Medications, and OPM of the SUS).¹⁰ This field was used as a filter to identify Orthopedic Oncology Centers (OOCs) in Brazil.

The 11,139 procedures identified (745 hemipelvectomies and 10,394 oncologic resections) were carried out in 205 facilities across 27 states in 121 municipalities. These procedures were performed on patients from 2,446 municipalities across the 27 states. Since many of these facilities performed the procedures randomly or sporadically, a subjective eligibility criterion was created to define OOCs. Hospitals that, between 2008 and 2019, performed at least three hemipelvectomies and one bone resection with substitution or reconstruction in oncology were selected.

After applying this selection criterion, a total of 8,861 procedures performed in 58 hospitals were obtained, corresponding to 79.5% and 28.2% of the initial dataset, respectively. These hospitals, classified as OOCs, were cross-referenced with their respective SUS accreditations,⁷ regarding certification as CACON (High-Complexity Oncology Centers) or UNACON (High-Complexity Oncology Units, with or without pediatric oncology care), and with national, macroregional, and state population estimates from the Brazilian Institute of Geography and Statistics (IBGE) for 2019.¹¹

RESULTS

Identification of Orthopedic Oncology Centers

The survey enabled the development of a catalog containing the names of the establishments according to CNES, their accreditation for oncology care within the SUS,⁷ location, and provision of pediatric oncology and radiotherapy services. These parameters allowed for both qualitative and quantitative assessments of the centers, analyzed collectively and individually. Of the 58 identified OOCs, 26 were CACONs, 18 of which provided pediatric care. The remaining 32 corresponded to UNACONs, of which 15 offered pediatric care, including two centers dedicated exclusively to pediatric care: Boldrini Campinas and Hospital GRAACC Instituto de Oncologia Pediátrica (IOP).

Geographic Distribution

The OOCs are distributed across 18 states and 37 municipalities. These centers served patients from 2,001 cities covering all 27 Brazilian states. The state of São Paulo accounted for 29.3% of these centers, followed by Minas Gerais and Paraná, with 10.3% each, and Rio Grande do Sul, Santa Catarina, and Pernambuco, with 6.9% each (Table 1). On the other hand, 9 states did not have OOCs according to the criteria applied in this study, which resulted in greater patient migration in search of specialized care in other states or regions. Five of these states are located in the North region, two in the Northeast, and two in the Center-West.

All five Brazilian macro-regions are covered by OOCs, with the following distribution: 43.1% in the Southeast, 24.1% in the South, 22.4% in the Northeast, 6.9% in the Center-West, and 3.4% in the North. (Table 2)

Geographic Reach of the Centers

The survey of the municipalities of origin of the patients treated at each center allowed the creation of maps showing the catchment areas of each OOC. Some centers receive patients from up to 16 different states. Conversely, the vast majority serve patients from their own state. Three distinct profiles were identified: National reach centers, which serve a large region beyond state boundaries, such as Fundação Pio XII in the city of Barretos; Regional reach centers, which cover a macro-region, with few long-distance cases and a high volume of procedures; Local reach centers, which serve patients from a small region, with shorter distances and reduced patient flow. (Figure 1)

Surgical Volume Analysis of Orthopedic Oncology Centers

When dividing the OOCs into quartiles, it was observed that the 15 hospitals in the first quartile were responsible for 63.8% of the procedures included in the study, and the first two quartiles together accounted for 86.9% of the procedures (or 75.6% of the initial total). The lowest-volume quartile, consisting of 14 hospitals, performed only 2.6% of the procedures analyzed.

A significant discrepancy in the number of surgeries performed was identified, allowing the classification of OOCs into High-Volume Centers (HVCs), which include the first quartile, and Low-Volume Centers (LVCs), corresponding to the quartile with the lowest number of procedures.

Table 1. Distribution of Orthopedic Oncology Procedures by State and Population Density.

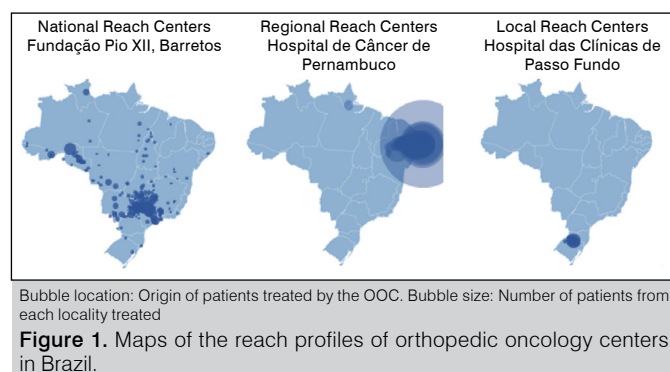
State	Population	%	Centers	%	Procedures	%	OOC/M. inhab.	Procedures/M. inhab.
SP	45,919,049	21.9	17	29.3	2207	24.9	0.37	48
MG	21,168,791	10.1	6	10.3	812	9.2	0.28	38
RJ	17,264,943	8.2	1	1.7	169	1.9	0.06	10
BA	14,873,064	7.1	2	3.4	1055	11.9	0.13	71
PR	11,433,957	5.4	6	10.3	811	9.2	0.52	71
RS	11,377,239	5.4	4	6.9	479	5.4	0.35	42
PE	9,557,071	4.5	4	6.9	1039	11.7	0.42	109
CE	9,132,078	4.3	3	5.2	779	8.8	0.33	85
PA	8,602,865	4.1	2	3.4	138	1.6	0.23	16
SC	7,164,788	3.4	4	6.9	122	1.4	0.56	17
GO	7,018,354	3.3	1	1.7	333	3.8	0.14	47
AM	4,144,597	2.0	1	1.7	141	1.6	0.24	34
ES	4,018,650	1.9	1	1.7	57	0.6	0.25	14
PB	4,018,127	1.9	1	1.7	246	2.8	0.25	61
RN	3,506,853	1.7	1	1.7	159	1.8	0.29	45
PI	3,273,227	1.6	1	1.7	172	1.9	0.31	53
DF	3,015,268	1.4	2	3.4	128	1.4	0.66	42
SE	2,298,696	1.1	1	1.7	14	0.2	0.44	6
BRAZIL	210.147.125	100	58	100.0	8861	100.0	0.28	42
SD							0.15	27

OOC: Orthopedic Oncology Center according to this study's criteria. M. inhab.: million inhabitants. SD: standard deviation. States without OOC: Acre; Alagoas; Amapá; Maranhão; Mato Grosso; Mato Grosso do Sul; Rondônia; Roraima; Tocantins.

Table 2. Distribution of Orthopedic Oncology Procedures by Macro-Regions and Population Density.

Region	Population	%	Centers	%	Procedures	%	OOC/M. de inhab.	Procedures/M. de inhab.
Southeast	88,371,433	42.1	25	43.1	3,245	36.6	0.28	37
Northeast	57,071,654	27.2	13	22.4	3,464	39.1	0.23	61
South	29,975,984	14.3	14	24.1	1,412	15.9	0.47	47
North	18,430,980	8.8	2	3.4	279	3.1	0.11	15
Center-West	16,297,074	7.8	4	6.9	461	5.2	0.25	28
Brazil	210,147,125	100	58		8,861		0.28	42
SD							0.12	16

OOC: Orthopedic Oncology Center according to this study's criteria. M. inhab.: million inhabitants. SD: standard deviation.



There was a trend for HVCs to be accredited as CACONs and LVCs as UNACONs. However, this was not an absolute rule, as the second highest volume identified was from the Hospital de Câncer de Pernambuco, a UNACON. Conversely, among the 51 CACONs registered in the SUS, 25 were not classified as OOCs in this study. Over the 12 years analyzed, 95% of the procedures were performed in 42 OOCs, while the remaining 16 centers accounted for only 5% of the total. The macro-regions with the highest concentration of procedures were the Northeast (39.1%), followed by the Southeast (36.6%), South (15.9%), Midwest (5.2%), and North (3.1%). (Table 2)

Adequacy of Orthopedic Oncology Centers to the Population

Macro-regions

Table 2 presents a summary of the correlation between population density, the number of OOCs, and the procedures performed. In the Southeast and Midwest regions, the proportions of these variables are similar to the national average and considered balanced. In the Northeast, a disproportionately high number of procedures (39.1%) was observed relative to its population (27.2%) and number of centers (22.4%). In contrast, in the South, a high number of OOCs (24.1%) was identified compared to its population (14.3%) and the number of surgeries performed (15.9%). Finally, in the North, both the number of OOCs (3.4%) and procedures (3.1%) were relatively low compared to the population (8.8%). (Figure 2)

These findings are confirmed when using the coefficients of centers and procedures per million inhabitants. The Northeast showed a high coefficient of procedures per inhabitant, while the South presented elevated coefficients for both centers and procedures. The North had below-average coefficients, and the Southeast and Midwest demonstrated values close to the Brazilian average.

Federative Units

In the state-level analysis (Table 1), the low number of centers (1.7%) and procedures (1.9%) in the state of Rio de Janeiro stands out when compared to its population (8.2%). On the other hand,

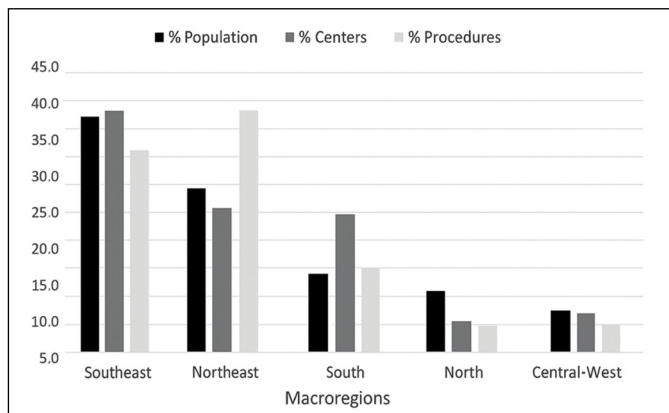


Figure 2. Relationship between the proportions of population, number of COOs, and procedures in the macro-regions.

Pernambuco, Bahia, and Ceará presented a high surgical volume relative to their local demographic proportion. Pernambuco accounts for 4.5% of the population, yet concentrates 6.9% of the COOs and 11.7% of the procedures. Bahia, with 7.1% of the population and 3.4% of the COOs, performed 11.9% of the surgeries analyzed. Ceará, with 4.3% of the population, accounted for 5.2% of the COOs and 8.8% of the surgeries. São Paulo, Paraná, and Paraíba are also states in which the proportion of procedures is greater than the share of the population.

Regarding the coefficient of COO concentration (Figure 3), the Federal District and the states of Santa Catarina and Paraná presented the highest values. In Paraná, this coefficient was accompanied by a high coefficient of procedures. At the other extreme, Rio de Janeiro, Bahia, and Goiás had fewer COOs relative to their populations than the Brazilian average.

Pernambuco and Ceará showed the highest coefficients of procedures, remaining above one standard deviation from the national average (42 procedures per million inhabitants). Conversely, Santa Catarina, Pará, Espírito Santo, Rio de Janeiro, and Sergipe were below one standard deviation (Table 1). The chart in Figure 3 shows that there is no correlation between the coefficient of centers and procedures, and that there is wide variation in relation to the national average.

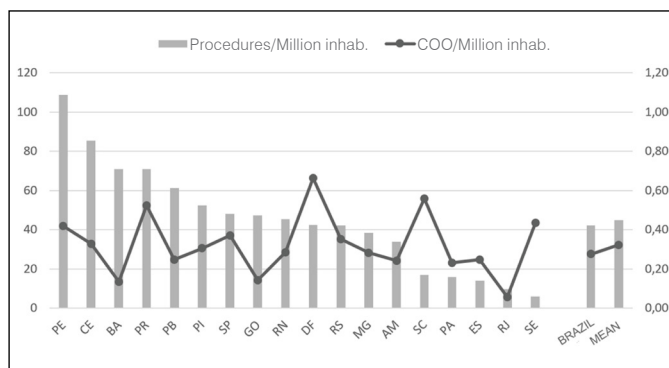


Figure 3. Relationship between the coefficients of Centers and Procedures per million inhabitants in the Federative Units.

Analysis of Migrations

The correlation between the patient's state of origin and the state where treatment was performed allowed us to evaluate the migrations that occurred and the capacity of each state to treat its own patients. In 9 states, patient migration is mandatory, or procedures are carried out in hospitals not classified as COOs.

Patients from the Southeast, South, and Northeast remain within their macroregions, with resolution rates close to 100%. In the Midwest and North regions, migratory flows correspond to 20.4% and 30.1% of patients, respectively. However, these rates represent only a small portion of patients at the national level. Thus, the percentage of patients who migrated to another macroregion was only 3.3%. States without COOs, which correspond to 10.6% of the population, accounted for 39.4% of interstate migrations. In contrast, among states with COOs, only Sergipe did not show a resolution rate higher than 80% within its own state. Overall, the rate of treatment resolution within the patient's home state was above 90%.

Qualitative analysis revealed preferential migration flows. In states without COOs, São Paulo was the main destination, receiving most patients from Acre, Roraima, Rondônia, Tocantins, Mato Grosso do Sul, and Mato Grosso. Patients from Amapá migrated preferentially to Pará, those from Maranhão to Piauí, and those from Alagoas to Pernambuco.

DISCUSSION

The national scientific literature lacks information on patient flow within the Brazilian Unified Health System (SUS). The development of healthcare strategies and the rational distribution of resources across the country are only possible with a deep understanding of the installed infrastructure and the availability of human resources. In the case of orthopedic oncology, as in other high-complexity areas, infrastructure requires high investment in technology, and human resources demand prolonged training.

The quality of data analysis from a database is closely linked to the quality of the database itself. In the case of DataSUS, the following factors may have impacted the results:

- Hospital Admission Authorizations (AIHs) may not have been completed in some hospitals because they exceeded the SUS budget cap, were denied reimbursement, or received funding from another payer other than SUS.
- Codes may have been incorrectly recorded, either by the physician or by administration.
- The residence address may have been altered by the patient, with some frequency, to allow treatment in the hospital of choice. Among these, two factors appear most significant: 1) the migration index may be higher than that presented in this study, and 2) the volume of care in hospitals in Rio de Janeiro may be underestimated, possibly due to the financing model.

Since there is no formal definition of an Orthopedic Oncology Center (COO), an arbitrary criterion was used. Hemipelvectomies are uncommon procedures but have high specificity for orthopedic oncology.⁷ The procedure "resection of bone tumors and reconstruction" is also specific, though more common. With the exception of small resections of the iliac wing, both procedures require a professional trained in orthopedic oncology. Although three hemipelvectomies and one bone reconstruction in 12 years represent a low surgical volume, these numbers do not reflect the total number of procedures performed in orthopedic oncology and should therefore be considered as a sample of procedures performed in each COO.

With this less restrictive criterion, a greater number of hospitals were included, accounting for nearly 90% of the procedures selected during the study period, thereby allowing a broader and more detailed analysis.

Despite the limitations introduced by these factors, the analysis of 11,139 surgical procedures typical of orthopedic oncology, over a 12-year period, certainly provides consistent results and reflects the reality of public care for musculoskeletal cancer in Brazil.

Several authors confirm that specialized high-volume centers achieve the best outcomes in the treatment of sarcomas.^{5,6,12-15}

Well-structured orthopedic oncology groups, which sometimes act as regional references and operate in more than one hospital, may have been excluded, while other less specialized hospitals may have been included. On the other hand, the definition of a COO is not based solely on surgical volume. The care of malignant musculoskeletal tumors is multidisciplinary and requires several additional components that were not addressed in this study.¹⁵ Although oncology care hospitals accredited by SUS are clearly identified as CACON (51) and UNACON (263), the study demonstrated that not all of them provide care for musculoskeletal tumors. Even the regulations requiring the inclusion of orthopedic surgeons in High-Complexity Oncology Centers and Units do not mandate that these professionals be trained in orthopedic oncology. This is compounded by the fact that orthopedic oncology is not formally recognized as a specialty or subspecialty by SUS. Conversely, if all these centers and units provided orthopedic oncology care, services would be dispersed across 314 centers, when it is already known that 41 centers are capable of handling 75.6% of the national demand, and high surgical volume is associated with better outcomes. This suggests that a regulatory change would be the most appropriate solution.

The vast majority of surgeries were performed either within the patient's state (93.7%) or within the same macroregion (96.7%), indicating low migration rates. Even considering the potential bias of falsified residence declarations, these values can be considered very high and reflect the quality of the various centers across Brazil, whose geographic distribution correlates reasonably well with the population density of each macroregion.

In summary, the methodology used identified hospitals that provide specialized orthopedic oncology care within SUS. A total of 58 Orthopedic Oncology Centers (COOs) were identified, which accounted for 8,861 of the 11,139 (79.5%) procedures included in the study.

Regarding surgical volume, 95% of the selected procedures were performed in 42 of the 58 COOs studied, while 2,721 procedures (24.4% of the total) were performed in low-volume hospitals on a sporadic basis.

The orthopedic oncologist is a rare professional who treats a rare disease. On the one hand, there should not be an excessive number of bone cancer treatment centers; on the other hand, Brazil's size requires a geographic distribution that ensures patient access. The study also suggests that mechanisms should be created to concentrate musculoskeletal tumor cases in institutions led by trained orthopedic oncologists, avoiding the sporadic performance of highly complex procedures by less experienced professionals. This study provides important data and may serve as a valuable tool for healthcare managers, as well as a basis for discussing adjustments in the public healthcare system for rare diseases, such as orthopedic oncology.

In conclusion, according to the criteria used, 58 Orthopedic Oncology Centers (COOs) were identified, which accounted for 79.5% of the 11,139 procedures analyzed in the study.

The geographic distribution of COOs correlates reasonably well with the distribution of the Brazilian population and ensures a low interstate migration rate (6.3%). On the other hand, the variation across states in the number of procedures per million inhabitants is considerable (ranging from 6 to 109, with an average of 42), and the main cause of this variation is the quality of information recorded in the AIHs.

There is a tendency toward concentration of procedures in high-volume COOs, since 95% of procedures were carried out in 42 of the 58 COOs. This trend aligns with the literature, which associates high-volume centers with better clinical outcomes. However, Brazilian legislation lacks mechanisms to consolidate this trend, which would promote specialized treatment for musculoskeletal tumors, as well as for other rare diseases.

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PRECONDITIONING OF PORCINE FLEXOR TENDONS FOR APPLICATION IN RECONSTRUCTION OF HAND FLEXOR TENDONS

PRÉ-CONDICIONAMENTO DE TENDÕES FLEXORES SUÍNOS PARA APLICAÇÃO NA RECONSTRUÇÃO DE TENDÕES FLEXORES DA MÃO

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ABSTRACT

Objective: In chronic hand flexor tendon reconstruction with tendon grafts, the challenge is to obtain the best resistance and tension of the suture that allows early active mobility. This experimental study of tendon relaxation aims to investigate whether prior preconditioning of the tendon graft could assist to identify the ideal tendon graft tension in these reconstructions. **Methods:** The porcine flexor tendons were subjected to the tension relaxation test, with three test cycles each with up to 50 N of tension and relaxation for 300 seconds. **Measured:** maximum force (N), maximum tension (Mpa) and maximum deformation. **Results:** After the peak tension of 50 N, the following was observed: maximum deformation, with an average tendon elongation of 2.3 mm; average residual tendon elongation of 0.6 mm; demonstrating the viscoelastic spring characteristic of porcine tendons. **Conclusion:** We recommend performing intraoperative preconditioning of the tendon graft with loads close to active grip strength (50 N to 70 N). If it is impossible to perform preconditioning, the suture can be placed 17 degrees of flexion of the proximal interphalangeal joint above the cascade flexion of fingers, compensating for tendon elongation under a load of 50 N. **Level of Evidence III; Experimental.**

Keywords: Active Mobility; Swine; Sutures; Tendons.

RESUMO

Objetivo: Na reconstrução de lesão crônica de tendão flexor da mão, o desafio é a obtenção da melhor resistência e tensão da sutura que possibilite a mobilidade ativa precoce. Este estudo experimental de relaxamento a tensão, tem como objetivo investigar se o pré-condicionamento prévio do enxerto de tendão poderia auxiliar na identificação da tensão ideal do enxerto de tendão nestas reconstruções. **Métodos:** Os tendões flexores suínos foram submetidos ao ensaio de relaxamento à tensão, com três ciclos de testes cada até 50N de tensão e relaxamento por 300 segundos. **Mensurados:** a força máxima (N), a tensão máxima (Mpa) e a deformação máxima. **Resultados:** Após o pico de tensão de 50 N, foi observado: deformação máxima, com alongamento do tendão médio de 2,3 mm; alongamento médio residual de 0,6 mm; demonstrando a característica viscoelástica de mola dos tendões suínos. **Conclusão:** Recomendamos a realização do pré-condicionamento intraoperatório do enxerto de tendão flexor com cargas próximas à força de preensão ativa (50N a 70N). Na impossibilidade da realização do pré-condicionamento, a sutura pode ser realizada com 17 graus de flexão da interfalângica proximal acima da flexão em cascata dos dedos, compensando o alongamento do tendão sob carga de 50 N. **Nível de Evidência III; Experimental.**

Descritores: Mobilidade Ativa; Suínos; Sutures; Tendões.

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INTRODUCTION

Chronic flexor tendon injury of the hand represents a significant reconstructive challenge for hand surgeons. Among the therapeutic options are tendon transfers, arthrodesis, and tendon grafting. In cases of severe mobility limitation and complex lesions, amputation of nonfunctional fingers may be indicated. Flexor tendon reconstruction with tendon grafts¹ is the most common option, but it faces technical challenges such as graft adhesion, inadequate tension, and failure to restore range of motion.

To reduce postoperative complications, early active mobilization is advocated, aiming to promote tendon gliding and reduce adhesions and motion limitations. However, no objective data are available regarding the optimal surgical tension for tendon grafts. Studies on stress-relaxation in autologous tendon grafts for knee ligament reconstruction² suggest that graft preconditioning with 50 Newtons (N)^{3,4} may prevent postoperative laxity. The present study aims to evaluate the viscoelastic properties of porcine flexor tendons through stress-relaxation testing.

All authors declare no potential conflict of interest related to this article.

The study was conducted at Hand Surgery and Reconstructive Microsurgery Group of the Instituto de Ortopedia e Traumatologia do Hospital das Clinicas da Faculdade de Medicina da Universidade de Sao Paulo, Sao Paulo, SP, Brazil.

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The objective is to determine the applicability of these properties in flexor tendon reconstruction using tendon grafts, in order to prevent elongation and laxity, thereby reducing common postoperative complications in flexor tendon reconstruction of the hand, such as increased flexion force due to inadequate graft tension.

MATERIALS AND METHODS

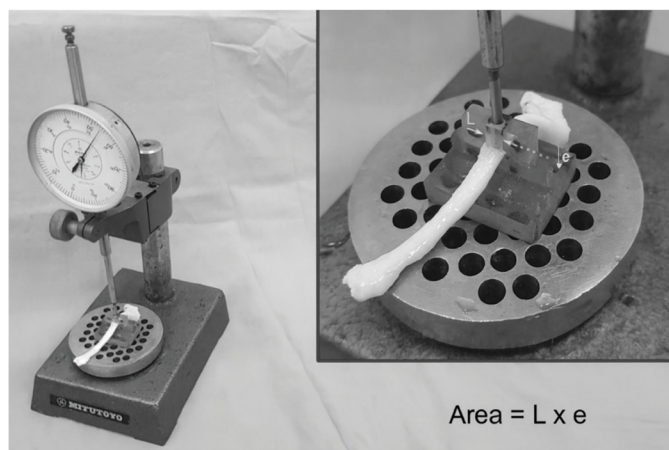
Twenty-one stress-relaxation tests were performed on seven flexor tendons harvested from porcine carcasses used in the surgical technique program of our University. The tendons were collected from the hind limbs of pigs after approval by the institutional animal ethics committee (CEUA No. 1560/2020). The animals were euthanized with intraperitoneal thiopental sodium at a dose of 75 mg/kg, in accordance with the guidelines of the Brazilian College of Animal Experimentation (COBEA, 2007). After use in the surgical technique program, the carcasses designated for disposal were repurposed for this project. Both flexor tendons of the pigs' hind limbs were collected after euthanasia.

Preliminary measurements of the porcine flexor tendon diameter were obtained using a caliper (mm). Three measurements were taken, and their mean was calculated to minimize error, from which the total cross-sectional area (mm^2) was determined.

The tendons were immediately prepared for testing. Both ends of the tendons were positioned in rectangular trapezoidal-profile clamps, previously designed to accommodate the average diameter of porcine flexor tendons.

The tendons were subjected to stress-relaxation testing using a Kratos mechanical testing machine, model 5002, equipped with a 981 N (100 kgf) load cell adjusted to a 98.1 N (10 kgf) scale. A Lynx data acquisition system, model ADS2000, recorded force and displacement data from the machine at a rate of 10 samples per second and transferred them to a personal computer via software that enabled visualization and recording of the acquired data over time (resolution of 100.0 milliseconds).

Before tendon fixation to the testing machine, each specimen was measured at three cross-sectional regions: at the tendon midpoint and 20 mm proximally and distally. Measurements were performed using a device consisting of a dial indicator (Mitutoyo, resolution 0.01 mm), a channel measuring 4.7 mm in width and 8 mm in depth, and a parallelepiped-shaped actuator sliding along the channel, coupled to the dial indicator stem. The cross-sectional area was calculated by multiplying the channel width of 4.7 mm by the thickness measured by the dial indicator. (Figure 1)



Source: Authors.

Figure 1. The area is calculated by multiplying the actuator width ($L = 4.7 \text{ mm}$) by the thickness (e) measured with the dial indicator.

Two rectangular clamps with a sinusoidal profile (6.5 mm pitch) were used. Each clamp had four screws with lock washers to ensure that the clamping force on the tendon remained less variable during the test. One clamp was fixed to the base of the testing machine using a bench vise, and the other clamp was attached to the load cell (mobile part) using a universal joint. The tendon ends were secured in the clamps so that the central portion to be tested was set at a distance of 35 mm between clamps.

With the specimen positioned in the testing machine, a load of 50 N was applied for 10 seconds. After this procedure, the load was released and the clamp screws were retightened. The tendon was rehydrated with 0.9% sodium chloride solution for 20 minutes to ensure recovery of its initial length. Then, the movable clamp was repositioned until the load returned to zero, and the distance between the clamps, corresponding to the initial tendon length, was measured using a Mitutoyo caliper with a resolution of 0.05 mm. The test consisted of pulling the tendon at a speed of 5 mm/min until reaching a load of 50 N, at which point the testing machine immediately stopped its upward motion, producing elongation of the material within its elastic zone. After 300 seconds, the machine reversed its motion, returning to the point where the recorded load was equal to zero, at which point it immediately stopped again. After an additional 300 seconds, the test was completed. Throughout the procedure, the tendon was hydrated with 0.9% sodium chloride solution.

Due to the viscoelastic behavior of the material, during the first 300 seconds there was a loss of tension evidenced by the decrease in load, and in the final 300 seconds a slight increase in load was recorded, corresponding to the material's attempt to recover its initial length. At the end of the test, the machine recorded a load and displacement value, which was reset once the crosshead returned to the tendon's initial length. Figure 2 illustrates a hypothetical stress-relaxation curve of the tendon test, showing the main phases of the procedure: peak, relaxation at 300 s, return to zero load, and recovery.

Each tendon underwent three repetitions of stress-relaxation tests with a 50 N load, always maintaining a 30-minute interval between repetitions.

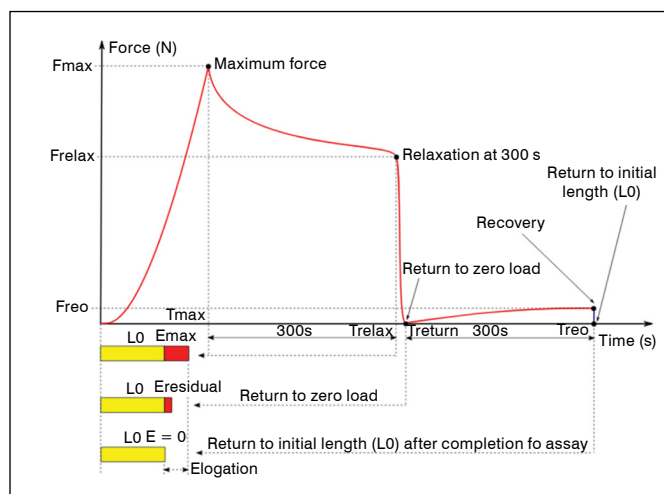


Figure 2. Hypothetical graph of force as a function of time during a stress-relaxation test, highlighting the phases of 50 N load application (Peak), stress relaxation after 300 s, tendon return to zero load, and recovery after 300 seconds. Where: F_{pico} and T_{pico} : force and time at peak; F_{relax} and T_{relax} : force and time at 300 s relaxation; T_{retorno} : time at the moment of return to zero load; F_{rec} and T_{rec} : force and time after 300 s of recovery; L_0 : initial tendon length; D_{pico} : deformation at the load peak; D_{residual} : deformation after return to zero load.

The calculated parameters were relaxation force (Frelax) and stress (srelax), relative deformation at peak ($\epsilon\%$ pico), absolute residual deformation (Dres) relative residual deformation (D%res), and recovery force (Frec) and stress (srec).

Stresses were calculated as the ratio of force (N) to the mean cross-sectional area (mm^2) of the three tendon regions, expressed in MPa. Relative deformation at peak ($\epsilon\%$ pico) was calculated as the ratio of absolute residual deformation (Dres) to the initial tendon length, multiplied by 100.

At the moment of peak stress of the flexor tendon, four measurements were performed:

1. Maximum force reached (N)
2. Maximum stress (MPa)
3. Maximum tendon deformation (mm)
4. Percentage deformation, based on comparison with the mean of the initial unstressed measurements (mm)

Following the stress-relaxation test, the four measurements described at the 50 N peak load were repeated at the following time points:

1. Tendon relaxation after 300 seconds (5 minutes) from peak stress
2. Return to zero load (N)
3. Characteristics after return, including residual tendon deformation

A descriptive study was conducted using SPSS. Statistical analysis was performed with SPSS software version 20.0 (SPSS Inc®, Chicago, IL, USA), employing descriptive statistics and inferential statistical analysis.

RESULTS

The mean cross-sectional area of the porcine tendons used in the stress-relaxation tests was 11.4 mm^2 (standard deviation [SD] 2.7), with a mean diameter of 29.7 mm (SD 2.5 mm). The mean tendon length, calculated from the average of three different measurements, was 36.5 mm (SD 2.6).

During the peak stress of the test, the force achieved was 49.3 N (SD 0.80 N), with the target load of approximately 50 N reached in the trial. At this moment, the peak stress averaged 4.7 MPa (SD 1.3 MPa); peak deformation with tendon elongation averaged 2.3 mm (SD 0.4 mm), with a deformation percentage—based on the mean of initial unstressed measurements—of 6.2% (SD 0.9%); and peak stiffness of the porcine tendon graft was 57.5 N/mm (SD 15.0 N/mm). After the 50 N peak load, the following values were obtained after relaxation to zero load in Newtons for the porcine flexor tendon, compiled from all test cycles: the mean time to return to zero stress was 360.8 seconds (SD 10.3 seconds); mean residual elongation was 0.6 mm (SD 0.18 mm); and the mean residual deformation percentage was 1.6% (SD 0.5).

The values for peak deformation and residual deformation were described separately for the three different cycles of deformation and stress-relaxation of each porcine flexor tendon. (Table 1)

Table 1. General values and after each 50 N tensioning cycle (first, second, and third cycles).

	Mean	SD	Minimum	Maximum
Dpico	2.26	0.38	1.73	2.90
Dresidual	0.59	0.18	1.73	2.91
Dpico (1.o cycle)	2.31	0.42	1.75	2.90
Dresidual (1.o cycle)	0.54	0.17	0.30	0.77
Dpico (2.o cycle)	2.27	0.43	1.76	2.75
Dresidual (2.o cycle)	0.69	0.19	0.42	1.01
Dpico (3.o cycle)	2.31	0.42	1.75	2.90
Dresidual (3.o cycle)	0.54	0.17	0.30	0.77

Legend: Deformation in mm at the 50 N peak load (Dpico); residual deformation after return to zero load (Dresidual); standard deviation (SD).

After statistical evaluation, no statistically significant differences were observed among the three different cycles regarding the mean deformation data at the 50 N peak load ($p = 0.19$) and residual deformation after return to zero load, as assessed by ANOVA in SPSS ($p = 0.14$).

DISCUSSION

The tension of the tendon graft for reconstruction of chronic flexor tendon injuries is empirically determined, with reconstruction usually performed for the flexor digitorum profundus.⁵

Previous experimental studies have demonstrated that porcine flexor tendons are compatible with human flexor tendons and are suitable for comparative experimental models, behaving similarly to tendon grafts.⁶ The most common human flexor tendon graft sources are the palmaris longus, plantaris, flexor digitorum superficialis, semitendinosus, or gracilis tendons⁶ and more recently, allografts.⁷ According to biomechanical evaluations of hand flexor tendons,⁸ we know that for finger flexion with the wrist in neutral position, there is a total displacement of 32 mm (15–43 mm) of the flexor digitorum profundus during its full excursion.⁹ The following tensions are observed:

- Passive flexion: 2–4 N of force
- Active (light) flexion: 10 N of force
- Active (strong) flexion: 50–70 N / pinch: 120 N of force

Preconditioning of porcine flexor tendons at 50 N is based on experimental preconditioning studies of grafts for anterior cruciate ligament reconstruction²⁻⁴ and also on the load corresponding to strong active flexion. The biomechanical properties of the flexor tendon¹⁰ should not be analyzed linearly, but rather in terms of the tendon's viscoelasticity after stress and relaxation, which are time- and load-dependent, leading to constant elongation and relaxation. Previous studies, such as that by Monleon,¹¹ observed that under hydration conditions and after two preconditioning cycles, the viscoelastic characteristics of human flexor tendons resemble spring-like behavior. However, it is important to note that tendon behavior may change with repeated loading, as the tissue absorbs load and energy after each cycle.¹⁰

In the context of flexor tendon reconstruction of the hand, the key question is: what would be the ideal behavior of an avascular tendon graft to simulate the optimal tension of a flexor digitorum profundus tendon?

In this experimental study, for tendon preconditioning we applied a 5 kg (50 N) load. After stress-relaxation, the residual deformation was 1.6% of the initial length. With these preconditioned tendons, the return to zero load and zero deformation took an average of 6 minutes. This residual deformation of 0.6 mm on average cannot be considered plastic deformation, since it may occur in experimental testing due to adverse technical conditions such as dehydration and/or failure of the machine clamps to properly hold the graft. Therefore, porcine tendons ultimately behave like a spring.

During surgery, this spring-like viscoelastic behavior allows the tendon graft to be sutured for flexor tendon reconstruction under optimal tension. With the advent and increasing use of the WALANT technique (Wide Awake Local Anesthesia No Tourniquet),¹² the ideal graft tension can be determined intraoperatively, since elongation of the tendon graft can be directly observed and tested.¹³ In cases of tendon elongation during active flexion, there may be loss of strength and full excursion; conversely, excessive tension may cause a quadrage effect, leading to loss of flexion strength in adjacent fingers.^{14,15}

In porcine flexor tendon grafts, under strong active flexion loads, with the 50 N peak used in this study, a maximum mean deformation of 2.3 mm was observed across the three preconditioning

cycles. Upon return to zero load, the tendons behaved like a spring, with insignificant residual deformation (1.3% of tendon length), likely explained by graft dehydration during experimental testing. Considering biomechanical studies describing ~1.3 mm of tendon excursion per 10° of joint rotation,^{16,17} and comparing with our mean peak deformation values at 50 N, postoperative deformation in flexor tendon reconstruction without preconditioning could lead to elongation under an active 50 N load, altering reconstructed tendon function by up to 17° of proximal interphalangeal joint rotation—solely due to tendon deformation, without even considering the risk of suture site laxity.

Therefore, we recommend surgical reconstruction of chronic or irreparable flexor digitorum profundus tendon injuries with tendon grafting under local anesthesia. The surgical technique should begin with distal graft fixation at the distal phalanx or the remnant flexor digitorum profundus stump, followed by intraoperative graft tensioning through cyclic and active finger flexion movements performed by the patient. After proper tensioning, proximal graft fixation should be completed, with additional active flexion tests to confirm adequate graft tension and detect possible elongation. As a second option, if WALANT surgery is not feasible, we suggest intraoperative preconditioning of the flexor tendon graft

with loads close to active grip strength (50–70 N). As a third alternative, if neither option is possible, graft suturing can be performed with a shortening of approximately 2.3 mm (mean peak deformation value in our study) or with an additional 17° of proximal interphalangeal joint flexion beyond the normal flexion cascade of the finger (based on prior reports of 1.3 mm tendon excursion for every 10° loss of flexion).¹⁶

Study limitations include: preconditioning was limited to three linear cycles (a small number, but chosen to avoid graft degradation since this was an in vivo study using porcine tendon grafts); the sample size; and the fact that the actual conditions of tendon graft reconstruction in humans may not be comparable to our experimental study on porcine flexor tendons using the Kratos® universal testing machine.

CONCLUSION

We recommend intraoperative preconditioning of the flexor tendon graft with loads close to active grip strength (50–70 N). If preconditioning is not feasible, the suture may be performed with 17 degrees of proximal interphalangeal joint flexion beyond the natural flexion cascade of the fingers, thereby compensating for tendon elongation under a 50 N load.

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RISK FACTORS, PREVENTION, AND TREATMENT OF INFECTIONS RELATED TO TOTAL HIP ARTHROPLASTY: SYNTHESIS OF CLINICAL EVIDENCE

FATORES DE RISCO, PREVENÇÃO E TRATAMENTO DAS INFECÇÕES RELACIONADAS À ARTROPLASTIA TOTAL DE QUADRIL: SÍNTESE DE EVIDÊNCIAS CLÍNICAS

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ABSTRACT

Total hip arthroplasty (THA) is a complex surgery and is indicated for the treatment of degenerative diseases such as osteoarthritis, rheumatoid arthritis and osteonecrosis, as well as femoral neck fractures. This procedure aims to restore mobility, relieve pain and improve patients' quality of life. However, infections, especially periprosthetic joint infection (PJI), are serious complications that can compromise the success of the surgery. To identify risk factors, as well as methods of preventing and treating infections in THA. An integrative literature review was carried out, selecting clinical trials published in the last 10 years that addressed the proposed topic, using the following search strategy in the PUBMED database: hip[title] AND arthroplasty[title] AND infec*[title]. The analysis involved reading and discussing 12 articles, which addressed different aspects of infection prevention and management in THA. Although some interventions, such as collagen sponges with gentamicin and triclosan-coated sutures, have not significantly reduced the incidence of infections, others, such as closed incisional negative pressure therapy (ciNPWT) and washing with diluted betadine, have shown promise in certain contexts. Diagnostic accuracy, especially for coagulase-negative staphylococci, still presents challenges, highlighting the need for advances in diagnostic and therapeutic methods. Thus, despite advances, the prevention and management of infections in THA still require improvement, and interventions must be carefully evaluated to ensure the effectiveness and safety of the procedure. **Level of Evidence IV; Evidence from Descriptive (non-experimental) or Qualitative Studies.**

Keywords: Arthroplasty, Replacement, Hip; Prosthesis-Related Infections; Postoperative Complications; Therapeutics.

RESUMO

A artroplastia total de quadril (ATQ) é uma cirurgia complexa, sendo indicada para tratamento de doenças degenerativas como osteoartrite, artrite reumatoide e osteonecrose, além de fraturas do colo do fêmur. Este procedimento visa restaurar a mobilidade, aliviar a dor e melhorar a qualidade de vida dos pacientes. No entanto, as infecções, especialmente a infecção articular periprotética (IAP), são complicações graves que podem comprometer o sucesso da cirurgia. Identificar fatores de risco, assim como métodos de prevenção e tratamento das infecções em ATQ. Foi realizada uma revisão integrativa da literatura, selecionando ensaios clínicos publicados nos últimos 10 anos que abordavam o tema proposto, utilizando a seguinte estratégia de busca na base de dados PUBMED: hip[title] AND arthroplasty[title] AND infec*[title]. A análise envolveu a leitura e discussão de 12 artigos, que abordaram diferentes aspectos da prevenção e manejo das infecções em ATQ. Embora algumas intervenções, como as esponjas de colágeno com gentamicina e suturas revestidas com triclosan, não tenham reduzido significativamente a incidência de infecções, outras, como a terapia de pressão negativa incisional fechada (ciNPWT) e a lavagem com betadine diluído, mostraram-se promissoras em determinados contextos. A precisão diagnóstica, especialmente para estafilococos coagulase-negativos, ainda apresenta desafios, destacando a necessidade de avanços nos métodos diagnósticos e terapêuticos. Sendo assim, apesar dos avanços, a prevenção e o manejo das infecções em ATQ ainda requerem aprimoramento, e as intervenções devem ser cuidadosamente avaliadas para garantir a eficácia e segurança do procedimento. **Nível de Evidência IV; Evidências de Estudos Descritivos (não experimentais) ou com Abordagem Qualitativa.**

Descritores: Artroplastia Total de Quadril; Infecções Relacionadas à Prótese; Complicações Pós-Operatórias; Terapêutica.

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INTRODUCTION

Total hip arthroplasty (THA) is a highly complex surgical procedure designed to replace the damaged hip joint with artificial prosthetic components. The procedure aims to restore mobility, relieve pain, and improve the quality of life of patients suffering from advanced joint pathologies. The surgical technique involves removing the compromised articular surfaces and replacing them with a prosthesis consisting of a femoral stem, a femoral head, and an acetabular component, which together reconstitute joint functionality.¹

The indications for total hip arthroplasty are varied and include primarily degenerative diseases such as osteoarthritis, rheumatoid arthritis, and osteonecrosis, as well as femoral neck fractures that cannot be adequately managed by other methods. In addition, congenital deformities and sequelae of dislocations or trauma may also require hip joint replacement. THA is often considered when conservative therapeutic options no longer provide sufficient pain relief or when there is significant functional limitation.²

Among the complications associated with total hip arthroplasty, infection is one of the most severe and challenging. Periprosthetic infection may occur at different postoperative periods, ranging from early infections, shortly after surgery, to late infections, years after prosthesis implantation. This complication is particularly concerning because it may compromise surgical success, require additional interventions, and in severe cases, lead to prosthesis removal. Effective management of this complication requires a multidisciplinary approach, including early diagnosis, preventive strategies, and specific treatments, which may range from antibiotic therapy to complex surgical revisions.³

Given the severity of potential complications and the complexity of the procedure, it is imperative that risk factors be carefully evaluated and preventive measures rigorously implemented.⁴ Furthermore, the establishment of effective treatment protocols in cases of infection is essential to optimize THA outcomes.

MATERIALS AND METHODS

This study was designed as an integrative literature review. Study selection was performed in the PUBMED database using the following search strategy: hip[title] AND arthroplasty[title] AND infec*[title]. Only clinical trials published in the last 10 years were included. The research question that guided this review was: "What are the risk factors associated with infections in THA, as well as their diagnostic and treatment methods?"

The review process was conducted in six sequential stages: formulation of the research question, identification of relevant studies in the literature, data collection from the specified database, critical and detailed analysis of the selected studies, discussion of the findings, and finally, preparation and presentation of the integrative review, as proposed by Souza et al.⁵

RESULTS

The initial search retrieved 12 articles that met the search strategy defined for this review. After screening titles and abstracts, all identified articles were selected. Subsequently, the studies were read in full, summarized, and discussed, following a chronological order based on their year of publication.

DISCUSSION

Surgical site infection (SSI) has been widely recognized as one of the most feared complications in surgery, particularly in hip arthroplasty, as highlighted by Westberg et al.⁶ Their study, conducted between February 2011 and July 2013, investigated the effectiveness of collagen sponges containing gentamicin in preventing SSI in elderly

patients undergoing hemiarthroplasty after femoral neck fracture. The results did not reveal a statistically significant difference in SSI incidence between the gentamicin-collagen group and the control group, indicating that the use of such sponges did not reduce infection rates.

Similarly, González-Vélez et al.⁷ emphasized the severity of SSIs, especially in hip arthroplasty, by analyzing the excessive direct costs associated with these infections. In a case-control study conducted at Hospital Universitario Ramon y Cajal, Spain, they identified that infections related to methicillin-resistant *Staphylococcus aureus* increased costs by 134%, reinforcing the need for preventive interventions to minimize both financial and clinical impacts of such infections.

Ibrahim et al.,⁸ addressed another critical aspect of post-arthroplasty complications: periprosthetic joint infection (PJI). In a study comparing the treatment of patients with negative and positive cultures, they found that culture-negative PJIs presented particular challenges, but adherence to strict protocols allowed reinfection rates similar to those observed in culture-positive patients, underscoring the importance of adherence to well-defined therapeutic strategies. Sprowson et al.⁹ investigated whether triclosan-coated sutures could reduce SSI incidence in patients undergoing total hip and knee arthroplasty. The study, involving 2,546 patients, found no significant evidence that these antimicrobial sutures reduced infection rates, suggesting that the introduction of such technologies must be carefully evaluated before routine implementation.

Closed incisional negative pressure wound therapy (ciNPWT) was assessed by Newman et al.¹⁰ in a study comparing its effectiveness with traditional dressings in patients undergoing revision arthroplasty. The results demonstrated a significant reduction in wound complications and reoperations in the ciNPWT group, indicating that this technique may be beneficial for high-risk patients.

Keeney et al.¹¹ also explored the use of negative pressure wound therapy (iNPWT), but focused on patients undergoing total lower extremity arthroplasty. They observed that although iNPWT could increase initial wound drainage, the devices were effective in reducing complications in patients with elevated body mass index, particularly after total knee arthroplasty.

In the diagnostic field, Kleiss et al.¹² evaluated the accuracy of the synovial alpha-defensin enzyme immunoassay for diagnosing PJI. Despite high specificity rates, the test failed to correctly detect some infections caused by coagulase-negative staphylococci, revealing that additional diagnostic methods are still needed to ensure accurate detection in all cases.

Calkins et al.¹³ investigated whether diluted betadine lavage could reduce postoperative PJI rates compared with saline lavage. The results indicated a significant reduction in infections in the betadine group, suggesting that this practice may serve as a simple and effective preventive measure in aseptic revisions.

Yang et al.¹⁴ conducted a study analyzing the impact of a three-month course of targeted oral antibiotics in patients undergoing revision for chronic prosthetic joint infections. Their findings showed a significant reduction in reinfection rates among patients who received antibiotics, highlighting the effectiveness of prolonged treatment in preventing relapse.

In the study by et al.¹⁵ outcomes of static versus articulating spacers were compared in patients with PJI undergoing two-stage revision arthroplasty. The authors concluded that although hospital stays were longer for patients with static spacers, there was no significant difference in operative time during the second-stage reimplantation, indicating that both methods are comparable in terms of effectiveness for PJI treatment.

Finally, Amini et al.¹⁶ reported that in their research on the use of antibiotic-loaded cement spacers, antibiotic concentrations in

the joints were not significantly affected by the use of drainage devices. This suggests that such devices do not compromise the effectiveness of spacers in preventing infection during two-stage revision arthroplasty.

CONCLUSION

The studies evaluated demonstrate consensus regarding the severity of infections related to hip arthroplasty; however, they diverge on the effectiveness of the preventive interventions tested.

While some methods, such as gentamicin-loaded collagen sponges and triclosan-coated sutures, did not show significant impact in reducing infections, other approaches, such as closed incisional negative pressure wound therapy (ciNPWT) and diluted betadine lavage, yielded promising results in specific contexts. Diagnostic analyses, although advancing in accuracy, still reveal limitations—particularly in the detection of infections caused by coagulase-negative staphylococci—highlighting the ongoing need for improvement in diagnostic and therapeutic methods.

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COMPARATIVE ANALYSIS OF TREATMENTS FOR FOREARM FRACTURES IN CHILDREN: A SYSTEMATIC REVIEW AND META-ANALYSIS

ANÁLISE COMPARATIVA ENTRE OS TRATAMENTOS PARA AS FRATURAS DO ANTEBRAÇO EM CRIANÇAS: UMA REVISÃO SISTEMÁTICA E META-ANÁLISE

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ABSTRACT

To compare the clinical outcomes of children with forearm bone fractures undergoing surgical treatment with intramedullary fixation with TEN rods and Kirschner wires. A systematic review of the literature was carried out, conducting a search for data in the Pubmed/Medline, Science Direct and Scielo databases. The quality of the trials was assessed by the MINORS tool and the meta-analysis of the studies was performed using the R software (version 4.4.0). 16 studies were selected, representing 1,075 patients, with a predominance of males, where the mean age range varied from 8.32 to 14.2 years. Applying the MINORS Scale, the quality of the studies was good (≥ 11). The meta-analysis of the studies revealed a statistically significant increase in the risk of adverse events in the experimental group compared to the control group, with a risk ratio (RR) of 1.35 (95% CI: 1.03 to 1.76). The combined mean difference (raw mean) between the experimental group and the control group was -12.42 minutes (95% CI: -13.75 to -11.10) in the fixed-effect model, indicating a significant reduction in surgical time for the experimental group. In the random-effect model, the mean difference was -21.62 minutes (95% CI: -33.30 to -9.94). Regarding fracture consolidation time, the fixed-effect model indicated a raw mean difference of 0.99 (95% CI: 0.61 to 1.36). Furthermore, heterogeneity was moderate to high, with an I^2 of 73% ($p < 0.01$). Intramedullary fixation with TEN nails and Kirschner wires presents a diversity of clinical outcomes and complications. The systematic review highlighted the importance of choosing the appropriate treatment method, considering the patient characteristics and the nature of the fracture. **Level of Evidence II; Systematic Review.**

Keywords: Fractures, bone; Forearm; Child; Orthopedic Procedures; Therapeutics; Postoperative Complications.

RESUMO

Comparar os desfechos clínicos de crianças com fraturas dos ossos do antebraço submetidas ao tratamento cirúrgico fixação intramedular com hastes de TEN e fios de Kirschner. Realizou-se uma revisão sistemática da literatura, conduzindo a busca de dados nas bases Pubmed/Medline, Science Direct e Scielo. A qualidade dos ensaios foi avaliada pela ferramenta MINORS e a meta-análise dos estudos foi realizada utilizando o software R (versão 4.4.0). 16 estudos foram selecionados, representando 1.075 pacientes, com predominância do sexo masculino, onde faixa etária média variou de 8,32 a 14,2 anos. Aplicando a Escala MINORS, obteve-se que a qualidade dos estudos foi considerada boa (≥ 11). A meta-análise dos estudos revelou em relação aos efeitos adversos o aumento estatisticamente significativo no risco de eventos adversos no grupo experimental comparado ao controle, com uma razão de risco (RR) de 1,35 (IC 95%: 1,03 a 1,76). O tempo de cirurgia demonstrou que a diferença de média combinada (média crua) entre o grupo experimental e o grupo controle foi de -12,42 minutos (IC 95%: -13,75 a -11,10) no modelo de efeito fixo, indicando uma redução significativa no tempo de cirurgia para o grupo experimental. Já no modelo de efeito aleatório, a diferença de média foi de -21,62 minutos (IC 95%: -33,30 a -9,94). No tempo de consolidação da fratura verificou-se que o modelo de efeito fixo indicou uma diferença de média crua de 0,99 (IC 95%: 0,61 a 1,36). Além disso, a heterogeneidade foi moderada a alta, com um I^2 de 73% ($p < 0,01$). A fixação intramedular com haste TEN e fios de Kirschner, apresenta diferentes desfechos clínicos, incluindo complicações diversas. A revisão sistemática destacou a importância da escolha adequada do método de tratamento, considerando as características do paciente e a natureza da fratura. **Nível de Evidência II; Revisão Sistemática.**

Descritores: Fraturas Ósseas; Antebraço; Criança; Procedimentos Ortopédicos; Terapêutica; Complicações Pós-Operatórias.

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INTRODUCTION

Diaphyseal forearm fractures are frequent in children and adolescents, representing 74% of all immature skeletal injuries of the upper limb.¹ This type of trauma encompasses a variety of injury patterns, including isolated radial shaft fractures, isolated ulnar shaft fractures, fractures of both forearm bones, as well as Galeazzi and Monteggia fracture-dislocations.^{2,3} Although less common than distal radius fractures, diaphyseal forearm fractures still represent a significant challenge for orthopedic surgeons.³⁻⁵ While the distal forearm is the most common fracture site, standardized treatment and follow-up protocols for these injuries are not yet established.^{6,7} While the distal forearm is the most common fracture site, standardized treatment and follow-up protocols for these injuries are not yet established.⁸

In the management of pediatric forearm fractures, closed reduction followed by cast immobilization is considered the gold standard.^{4,7} However, there has been a growing trend toward surgical stabilization of diaphyseal fractures. Overall, the evidence suggests that surgery should be reserved for cases in which satisfactory alignment cannot be achieved through closed reductions.⁹ In certain pediatric fractures, the choice between conservative and surgical treatment has been influenced by several factors, including technological advances, the availability of imaging equipment in operating rooms, safer anesthesia, improved implants specifically designed for the pediatric skeleton, and the surgical training of orthopedic surgeons in minimally invasive techniques.⁹

It is noteworthy that several approaches for treating forearm bone fractures, including intramedullary fixation (IM) using Kirschner wires (K-wires) or Titanium Elastic Nails (TEN rods), have emerged as predominant methods for displaced and unstable diaphyseal forearm injuries in children.^{10,11} Nonetheless, it is well recognized that not all patients are suitable candidates for closed manual reduction followed by intramedullary fixation.¹²

Therefore, considering the diversity of aspects related to this topic in the pediatric population, it is essential to deepen the understanding of the best available treatment options and to determine their clinical effectiveness.¹³ Given the lack of consensus regarding optimal treatment and follow-up protocols for these injuries, we consider it pertinent to conduct a comparative analysis between the most common therapeutic options. This investigation aims to improve clinical practice and provide a scientifically sound basis for decision-making, thereby optimizing clinical and functional outcomes for patients with forearm fractures.

In this context, the present study aims primarily to compare the clinical outcomes of children with forearm fractures who underwent surgical treatment using TEN rods and Kirschner wires.

MATERIALS AND METHODS

This study presents a systematic review conducted in accordance with the protocol established by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).¹⁴

Primary studies were included, such as cross-sectional research, cohort studies, randomized clinical trials, and case reports, which addressed treatments for forearm fractures in the pediatric population. No language restrictions were applied, and studies published in the last five years were considered. Review studies and duplicates were excluded.

The guiding question was structured according to the PICO approach, which includes the following elements: the studied population (P), the intervention performed (I), the comparison made (C), and the outcome assessed (O). The population consisted of pediatric patients with forearm fractures; the interventions included treatments with plaster, intramedullary fixation with TEN rods, or Kirschner wires, compared with various treatment types; and the

outcomes included treatment effectiveness, associated complications, recovery time, and post-treatment functionality. Based on this strategy, the following research question was formulated: "What is the effectiveness and what are the associated complications of different treatments for forearm fractures in children, comparing plaster, intramedullary TEN rods, and Kirschner wires?"

Searches were conducted from June to July 2024. The databases used were: Medical Literature Analysis and Retrieval System Online/ National Library of Medicine (MEDLINE®/PubMed®), Science Direct, and Scientific Electronic Library Online (SciELO). Additional searches were carried out in the bibliographies of the selected studies to improve coverage and incorporate studies not initially identified. In the PubMed database, filters for the last 5 years and full-text articles were applied. No filters were applied in SciELO.

The descriptors were selected from the Health Sciences Descriptors/ Medical Subject Headings (DeCS/MeSH) in Portuguese and English, combined using the Boolean operators AND and OR: "fratura do antebraço em crianças," "hastes elásticas de titânio," "fios de Kirschner," "gesso" OR "forearm fracture in children," "titanium elastic rods," "Kirschner wires," "plaster."

Two researchers independently evaluated all included studies. Potentially relevant articles were examined in full. Divergences were discussed among the reviewers and, when necessary, submitted to a third evaluator.

The assessment of the studies was performed by two independent evaluators. The quality of the trials was assessed using the MINORS tool¹⁵ for observational studies. Screening involved analysis of article titles and abstracts, followed by full-text reading of those deemed relevant (Figure 1). During the search process, data were meticulously recorded in a spreadsheet and organized into tables to facilitate analysis.

Meta-analysis of the studies was conducted using R software (version 4.4.0) with the meta package. A total of five meta-analyses were carried out. The first analysis involved binary outcomes (occurrence or non-occurrence of complications in the treatment and control groups) in order to evaluate adverse events in patients. (Figure 2) In addition, three meta-analyses with continuous variables (meta-analysis of continuous outcome data) were conducted, using the random-effects model. This model allowed us to calculate an overall mean across all studies that reported the mean and standard error of continuous variables, such as surgical time, length of hospital stay, and bone consolidation time, in both the experimental and control groups. The results of the meta-analysis on surgical time are presented in Figure 3.

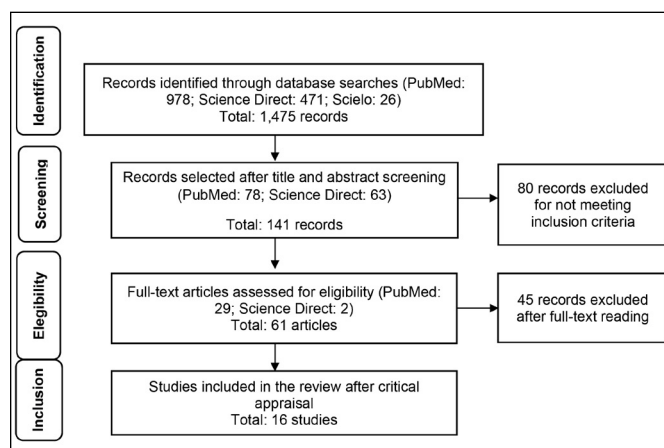


Figure 1. Schematic representation of the methods of identification, screening, eligibility, and inclusion of studies in the review, adapted according to the PRISMA Flow Diagram.

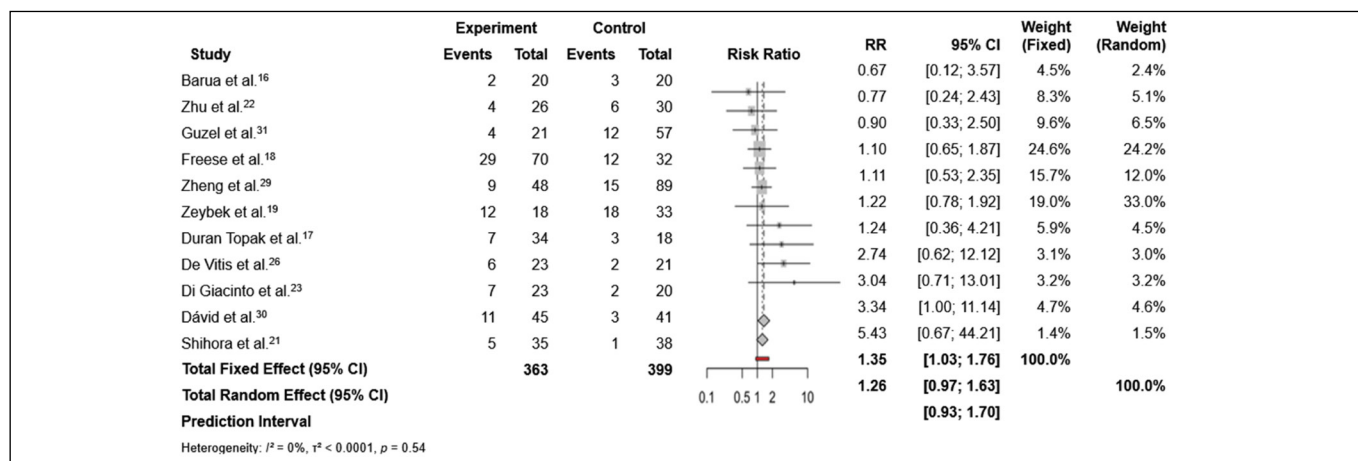


Figure 2. Meta-analysis of the binary outcome (adverse events) in patients treated with TEN rods and/or Kirschner wires versus the control group (other treatments).

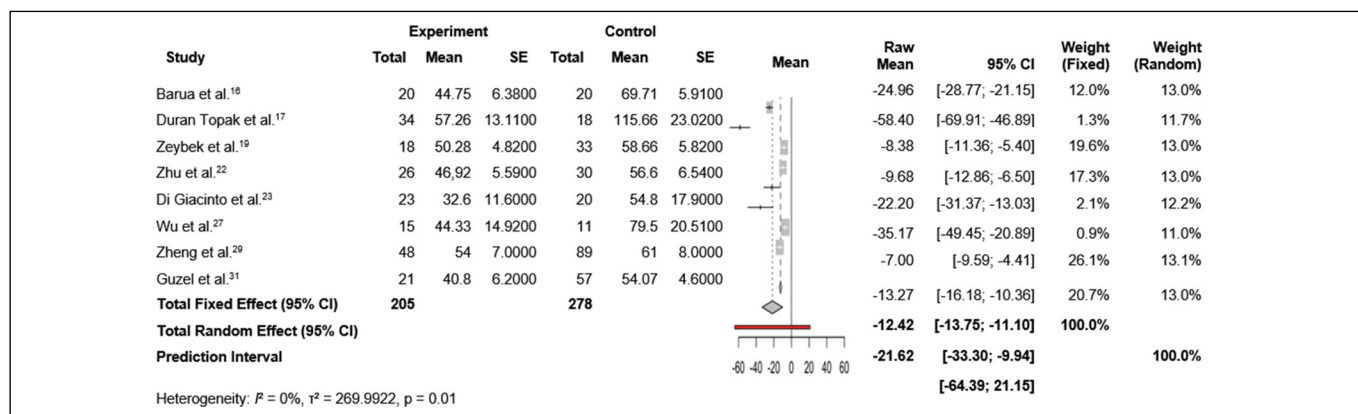


Figure 3. Meta-analysis of continuous outcome (surgical time) in patients treated with TEN rods and/or Kirschner wires versus the control group.

It should be noted that the meta-analysis of hospital stay duration included only a few studies, since it was necessary to exclude those that did not provide data to establish a control group. To address this limitation, an additional meta-analysis was conducted considering hospital stay across all studies, regardless of whether results were reported for the control group. In this case, the procedure followed was a meta-analysis of single means, also using the random-effects model.

RESULTS

A total of 1,475 articles were initially identified in the search. The summary of the article selection process is presented in Figure 1. After evaluation of titles and abstracts, followed by the selection and detailed analysis of the articles, 16 studies were deemed eligible to compose this systematic review.

The systematic review followed the PRISMA recommendations, illustrated in Figure 1.

The studies included in this systematic review consisted of observational research investigating different treatments for forearm fractures, with emphasis on intramedullary (IM) fixation using Kirschner wires (K-wires) or Titanium Elastic Nails (TEN rods).

The overall sample comprised approximately 1,075 patients, with a predominance of male participants across all studies. The mean age range of participants varied from 8.32 to 14.2 years, with a greater proportion of studies focused on children. The methodological characteristics of the selected studies are detailed in Table 1.

The studies investigated different treatment methods, including plate osteosynthesis (PO), Titanium Elastic Nails (TEN rods), a

combination of TEN rods and Kirschner wires (TENK), open reduction and internal fixation with plate and screws (ORIF), plate-screw fixation (FPP), hybrid fixation (FH), conservative treatment with splint and cast (CO), double-plate fixation (FPD), intramedullary fixation with Kirschner wires (FK), and Epibloc system fixation (FES). Follow-up duration varied across studies, providing a comprehensive view of the effectiveness and complications associated with each treatment method. Complications observed in the included studies are summarized in Table 2.

Regarding methodological quality, all studies assessed with the MINORS Scale were rated as good,¹⁶⁻³¹ each scoring 11 points or higher in the overall assessment, as shown in Table 3.

Given this scenario, the meta-analyses focused specifically on changes in the following clinical parameters:

- Adverse events: The analysis of adverse events, based on eleven included studies¹⁶⁻³¹ comparing the risk of adverse events between the experimental group (TEN rods and/or Kirschner wires) and the control group (other treatments), indicated a statistically significant increase in risk in the experimental group, with a risk ratio (RR) of 1.35 (95% CI: 1.03 to 1.76). This suggests that participants in the experimental group had a 35% higher risk of experiencing adverse events than those in the control group. Moreover, there was no evidence of significant heterogeneity across studies ($I^2 = 0\%$, $p = 0.54$), indicating consistent results among the studies. (Figure 2)

- Surgical time: Pooling surgical time reported by eight studies^{16,17,19,22,23,27,29} that compared operative duration between the experimental and control groups showed a combined mean difference (raw mean) of -12.42 minutes (95% CI: -13.75 to -11.10)

Table 1. Summary of demographic data and treatments across all included studies.

Author/Year	Study Type	Intervention Groups	Sex (M/F)	Age (years)	Follow-up (months)
Barua et al. ¹⁶	Retrospective	• PO: 20 • TEN: 20	• PO: 14/6 • TEN: 14/6	• PO: 10.95 ± 2.35 • TEN: 10.40 ± 2.41	• PO: NR • TEN: NR
Duran Topak et al. ¹⁷	Retrospective	• PO: 18 • TEN: 34	• PO: 17/1 • TEN: 28/6	• PO: 13.66 1.45 • TEN: 11.73 1.60	• PO: 29.55 • TEN: 30.85
Freese et al. ¹⁸	Retrospective	• TENK: 70 • ORIF: 32	• TENK: 44/26 • ORIF: 22/10	• TENK: 12.1 • ORIF: 14.2	• TENK: 6 • ORIF: 3.3
Zeybek, Akti et al. ¹⁹	Retrospective	• FPP: 19 • TEN: 18 • FH: 14	• FPP: 8/11 • TEN: 8/10 • FH: 5/9	• FPP: 11.00 2.26 • TEN: 10.11 2.37 • FH: 8.57 2.24	• FPP: 6 • TEN: 6 • FH: 6
Soudy et al. ²⁰	Prospective	• TEN: 18	• TEN: 13/5	• TEN: 8.88	• TEN: 6
Shihora et al. ²¹	Cross-sectional	• TEN: 35 • CO: 38	• TEN + CO: 40/33	• TEN + CO: 8.32	• TEN + CO: 6
Zhu et al. ²²	Prospective	• FPD: 30 • FH: 26	• FPD: 15/15 • FH: 15/11	• FPD: 13.33 1.54 • FH: 13.27 1.64	• FPD: 8 • FH: 8
Di Giacinto et al. ²³	Retrospective	• FK: 23 • ORIF: 20	• FK: 15/8 • ORIF: 13/7	• FK: 12.86 0.64 • ORIF: 13.02 1.77	• FK: 16.86 • ORIF: 16.37
Jain et al. ²⁴	Retrospective	• TEN: 65	• TEN: 40/25	• TEN: 9.13	• TEN: 5.84
Pogorelić et al. ²⁵	Retrospective	• TEN: 173	• TEN: 126/47	• TEN: 11.0	• TEN: 68
De Vitis et al. ²⁶	Retrospective	• FES: 21 • FK: 23	• FES: 16/5 • FK: 18/5	• FES: 8.4 1.6 • FK: 8.5 1.7	• FES: 3.4 • FK: 2.4
Wu et al. ²⁷	Case-control	• TEN: 15 • FK: 11	• TEN: 10/5 • FK: 9/2	• TEN: 7.7 2.0 • FK: 6.4 1.6	• TEN: 14 • FK: 14
Acharya et al. ²⁸	Retrospective	• IM: 31	• IM: 22/9	• IM: 12.90	• IM: 8.51
Zheng et al. ²⁹	Retrospective	• ESIN: 48 • FPD: 44 • Hybrid: 45	• ESIN: 30/18 • FPD: 25/18 • Hybrid: 28/17	• ESIN: 13.5 1.9 • FPD: 13.4 1.9 • Hybrid: 13.2 2.1	• ESIN: 14.8 • FPD: 14.9 • Hybrid: 15.0
Dávid et al. ³⁰	Retrospective	• ESIN: 45 • RESIN: 41	• ESIN: 29/16 • RESIN: 31/10	• ESIN: 10.4 • RESIN: 8.4	• ESIN: NR • RESIN: NR
Guzel et al. ³¹	Retrospective	• TEN: 21 • HF: 19 • I-KW: 20 • FPD: 18	• TEN: 11/10 • HF: 11/8 • I-KW: 9/11 • FPD: 10/8	• TEN: 10.8 2.2 • HF: 11.5 2.1 • I-KW: 10.9 2.1 • FPD: 12.1 1.9	• TEN: 12 • HF: 12 • I-KW: 12 • FPD: 12

Legend: PO: plate osteosynthesis (plating); TEN: Titanium Elastic Nail (TEN rods); TENK: TEN rods + Kirschner wires; ORIF: open reduction and internal fixation with plate and screws; NR: not reported; FPP: plate–screw fixation; FH: hybrid fixation using elastic intramedullary fixation + plate–screw fixation; CO: conservative treatment with splint and cast; FPD: double-plate fixation (dual plating); FK: intramedullary fixation with Kirschner wires (K-wires); FES: Epibloc system fixation; IM: flexible intramedullary rod; ESIN: elastic stable intramedullary nailing (ESIN); Hybrid: ESIN for the radius and plate–screw fixation for the ulna; HIT: titanium intramedullary rod; RESIN: resorbable intramedullary rod; HF: hybrid fixation; I-KW: intramedullary Kirschner wire.

Table 2. Summary of complications/adverse events of the treatments reported in the evaluated studies.

Author/Year	Complications/Adverse Events
Barua et al. ¹⁶	Infections, transient neuropraxia.
Duran Topak et al. ¹⁷	Surgical site infection, refracture, pin entry irritation, hypertrophic scar.
Freese et al. ¹⁸	Wound dehiscence, superficial infection, difficulty removing ulnar rod, finger flexion contracture, transient neuropraxia, implant migration.
Zeybek et al. ¹⁹	Superficial infection, soft-tissue irritation, pseudoarthrosis, delayed union.
Soudy et al. ²⁰	Superficial infection, superficial radial nerve injury, residual nonunion of the radius.
Shihora et al. ²¹	Elbow stiffness, hypertrophic scar, superficial infection, malunion.
Zhu et al. ²²	Refracture, nonunion of the radius, superficial infection.
Di Giacinto et al. ²³	Refracture, malunion, nonunion, superficial infection.
Jain et al. ²⁴	Superficial infection, nonunion, delayed union, refracture.
Pogorelić et al. ²⁵	Skin irritation, refracture, pseudoarthrosis.
De Vitis et al. ²⁶	Skin irritation.
Wu et al. ²⁷	NR (not reported).
Acharya et al. ²⁸	Skin irritation over prominent ulnar nail, superficial infection at nail entry site, ulnar nail backout.
Zheng et al. ²⁹	Superficial infection, superficial radial nerve palsy, soft-tissue irritation, refracture, nonunion.
Dávid et al. ³⁰	Re-displacement, irritation, skin perforation, superficial radial nerve injury.
Guzel et al. ³¹	Superficial infection, soft-tissue irritation, refracture, pseudoarthrosis.

Among the most frequent complications, we observed superficial infections. Other common events included refractures, transient neuropraxia, skin irritation, and hypertrophic scarring, underscoring the variability in patient responses to different treatment methods. More severe complications—such as pseudoarthrosis, malunion, and nonunion—were also reported.

under the fixed-effect model, indicating a significant reduction in surgical time for the experimental group. Under the random-effects model, the mean difference was –21.62 minutes (95% CI: –33.30 to –9.94), likewise indicating a significant reduction but with greater between-study variability. In addition, heterogeneity was high ($I^2 = 95\%$, $p < 0.01$), indicating substantial variability across individual study results. (Figure 3)

These results suggest that, on average, the TEN-rod and/or Kirschner-wire group showed a significant reduction in surgical

time compared with other treatments. However, the high heterogeneity among the studies indicates that these results may vary substantially depending on the specific characteristics of each study, such as differences in surgical protocols, surgeon experience, or patient-related variables.

- Length of Stay: The meta-analysis pooled the results of three studies^{16,17,27} that compared hospital length of stay between the experimental and control groups and showed that the combined mean difference between the experimental and control groups

Table 3. MINORS Scale: 0 (not reported), 1 (reported but inadequate), or 2 (reported and adequate). The quality of each included study was defined based on the total score as poor (<5), fair (6–10), or good (≥11).

Study	Clearly stated aim (a)	Inclusion of consecutive patients (b)	Prospective data collection (c)	Appropriate endpoints (d)	Unbiased assessment of study endpoint (e)	Adequate follow-up period (f)	Loss to follow-up <5% (g)	Prospective calculation of study size (h)	Total score	Study quality
Barua et al. ¹⁶	2	2 / n = 40	1	2	0	2	2	0	11	Good
Duran Topak et al. ¹⁷	2	2 / n = 52	1	2	0	2	2	0	11	Good
Freese et al. ¹⁸	2	2 / n = 102	1	2	0	2	2	0	11	Good
Zeybek, Akti et al. ¹⁹	2	2 / n = 51	1	2	0	2	2	0	11	Good
Soudy et al. ²⁰	2	2 / n = 18	2	2	0	2	2	0	12	Good
Shihora et al. ²¹	2	2 / n = 73	2	2	0	2	2	0	12	Good
Zhu et al. ²²	2	2 / n = 56	2	2	0	2	2	0	12	Good
Di Giacinto et al. ²³	2	2 / n = 43	1	2	0	2	2	0	11	Good
Jain et al. ²⁴	2	2 / n = 65	1	2	0	2	2	0	11	Good
Pogorelić et al. ²⁵	2	2 / n = 173	1	2	0	2	2	0	11	Good
De Vitis et al. ²⁶	2	2 / n = 44	1	2	0	2	2	0	11	Good
Wu et al. ²⁷	2	2 / n = 26	2	2	0	2	2	0	12	Good
Acharya et al. ²⁸	2	2 / n = 31	1	2	0	2	2	0	11	Good
Zheng et al. ²⁹	2	2 / n = 137	1	2	0	2	2	0	11	Good
Dávid et al. ³⁰	2	2 / n = 86	1	2	0	2	2	0	11	Good
Guzel et al. ³¹	2	2 / n = 78	1	2	0	2	2	0	11	Good

was -1.79 days (95% CI: -2.20 to -1.37) in the fixed-effect model, suggesting a significant reduction in length of stay for the experimental group compared with the control.

Furthermore, heterogeneity among the studies was high, with $I^2 = 93\%$ ($p < 0.01$), indicating substantial variability across study results. Overall, the findings indicate that, on average, the experimental group experienced a significant reduction in hospital length of stay compared with the control group. However, the high heterogeneity suggests that the effects may vary significantly between studies, which may be related to differences in clinical context, interventions performed, or patient characteristics.

In the additional analysis performed to evaluate hospital length of stay regardless of the control group, five studies^{16,17,24,25,27} comprising a total of 307 patients were included. The common-effect model indicated a combined mean of 3.46 days (95% CI: 3.36 to 3.56), suggesting a similar average length of stay across the included studies. Heterogeneity was high, with an I^2 of 100% ($p < 0.01$), indicating substantial variability among the studies. The τ^2 value of 2.9467 reflects this high heterogeneity, possibly due to differences in inclusion criteria, interventions, or study populations.

• **Fracture Consolidation (union) Time:** The analysis included six studies^{17-19,22,29,31} that compared the experimental and control groups regarding fracture union time. The fixed-effect model indicated a raw mean difference of 0.99 (95% CI: 0.61 to 1.36), suggesting that the experimental group had a longer recovery/consolidation time compared with the control group, with a statistically significant effect. Moreover, heterogeneity was moderate to high, with an I^2 of 73% ($p < 0.01$), indicating substantial variability among the included studies. These findings suggest that the experimental group, on average, had a longer consolidation time than the control group, particularly when the fixed-effect model is considered. However, the random-effect model, coupled with high heterogeneity, demonstrates considerable uncertainty, meaning that results may vary substantially across studies. The interpretation of these findings should therefore take into account these variations and the possibility that the observed effects may not be consistent across different clinical settings.

DISCUSSION

A comprehensive analysis of the literature indicated that most diaphyseal forearm fractures in children can be managed non-surgically through cast immobilization, a method that has shown excellent outcomes.^{32,33} However, fractures not eligible for conservative treatment generally require surgical intervention. Despite the strong theoretical basis supporting these concepts, there is still no global consensus on the best treatment strategy, particularly for unstable fractures, where surgical fixation is considered indispensable.⁶ From this perspective, the aim of this systematic review was to compare the clinical outcomes of children with forearm fractures who underwent surgical treatment with intramedullary fixation using TEN rods and Kirschner wires.

The analysis of the included studies revealed significant variability in clinical outcomes among the different treatment methods. Some studies highlighted the advantages of TEN, reporting a lower complication rate and faster recovery, while others suggested that K-wires might provide greater stability for certain types of fractures. These discrepancies underscore the need for a careful evaluation of treatment systems, considering the individual characteristics of each patient and the nature of the fracture.

Our data showed a predominance of male participants, a finding consistent across all studies, reflecting a higher incidence of trauma in this population. Furthermore, the mean age of participants ranged from 8.32 to 14.2 years, indicating a wide age distribution within the study groups and, therefore, relevant diversity in treatment responses depending on age.

The evaluated studies demonstrated differences in preferences and treatment outcomes. For instance, Barua et al.¹⁶ reported that TEN fixation significantly reduced surgical time compared to plate osteosynthesis. Similarly, Duran Topak et al.¹⁷ corroborated these findings, observing that TEN rods provided a shorter fracture consolidation time, although no significant differences were noted in functional outcomes or complication rates between TEN and PO. Soudy et al.²⁰ also emphasized that TEN is safe and effective for forearm fractures, with most patients achieving good functional

results. Likewise, Wu et al.²⁷ and Acharya et al.²⁸ found that TEN offers advantages such as shorter operative time and reduced fluoroscopic exposure compared to the use of K-wires.

Despite the benefits of TEN, some comparative studies have reported divergent outcomes. Freese et al.¹⁸ found that intramedullary fixation (IMN), which includes the use of TEN, was associated with a significantly higher complication rate and greater need for reoperations compared to plate osteosynthesis (PO).

Hybrid fixation, which combines TEN rods with plate-screw fixation, demonstrated distinct advantages. Zeybek and Akti¹⁹ observed that hybrid fixation resulted in shorter incision length and reduced operative time compared to PO, while providing an effective combination of the benefits of both techniques. Similarly, Guzel et al.³¹ confirmed that this strategy offered a good balance between surgical duration, blood loss, and immobilization time.

The plate-screw fixation (PO) technique was investigated by De Vitis et al.,²⁶ who found it to be safe and effective for the treatment of distal forearm fractures, providing superior functional outcomes with minimal need for postoperative rehabilitation compared to fixation with K-wires and casting.

Hybrid fixation, according to Zheng et al.,²⁹ also demonstrated advantages over double-plate fixation, including shorter surgical times, reduced blood loss, and faster union rates for the ulna. However, Zhu et al.²² and Dávid et al.³⁰ noted that hybrid fixation and resorbable intramedullary rod techniques, although effective and associated with lower complication rates, still require further studies to validate their long-term efficacy.

Shihora et al.²¹ reported that cast immobilization achieved a higher bone union rate compared to TEN fixation. However, TEN fixation was effective when conservative treatment alone was insufficient. In the study by Di Giacinto et al.²³ although K-wire fixation demonstrated faster bone union, plate-screw fixation (PO) was associated with fewer complications. Regarding complication rates, Jain et al.²⁴ reported an overall complication rate of 41.5% with TEN fixation, emphasizing that cases requiring open reduction showed more complications, despite most patients achieving good to excellent functional outcomes. According to Pogorelić et al.²⁵ intramedullary fixation with titanium elastic rods demonstrated a relatively low complication rate, and most patients achieved complete radiographic healing within an average of 6.8 weeks.

Given this context, the choice of technique for treating double diaphyseal forearm fractures should weigh several factors, including patient age, fracture severity, and surgeon experience. TEN is effective, offering advantages in operative time and recovery, but it may be associated with higher complication rates and reoperation needs when compared with open reduction and internal fixation. Hybrid fixation appears to be a promising alternative, combining the benefits of TEN and plate-screw fixation (PO), with favorable operative characteristics. Further studies are needed to confirm the effectiveness of techniques such as resorbable intramedullary rods and hybrid fixation, particularly with respect to long-term outcomes and complication rates.

Our analysis of complications revealed a wide range of adverse events associated with different surgical treatments for pediatric forearm fractures. Among the most frequently reported, superficial infections stand out as a recurrent issue—cited by Duran Topak et al.¹⁷ Freese et al.¹⁸ Soudy et al.²⁰ and others. Although treatable, such infections can prolong recovery and increase patient discomfort, often requiring additional interventions.

Beyond infections, refractures and transient neurapraxia were also commonly observed. Refractures were reported by Duran Topak et al.¹⁷ Di Giacinto et al.²³ Guzel et al.³¹ e Zhu et al.²² whereas transient neurapraxia was documented by Barua et al.¹⁶ and Freese et al.¹⁸ Even when transient, neurapraxia can impact limb function and warrants continuous monitoring.

Studies by Zeybek e Akti¹⁹ and Pogorelić et al.²⁵ highlighted occurrences of pseudarthrosis and malunion—serious complications that impair bone consolidation and may necessitate further surgery. Pseudarthrosis, in particular, is worrisome because it signals failed bone healing, prolongs recovery, and can require additional treatment.

There was agreement across several studies regarding the prevalence of these complications; however, some discrepancies emerged. While Freese et al.¹⁸ reported issues such as difficult removal of the ulnar rod and implant migration, these were not mentioned by other authors, suggesting that such problems may be linked to technical particulars or surgeon experience. In addition, Acharya et al.²⁸ described a more specific complication—skin irritation over a prominent ulnar nail—not reported elsewhere, possibly reflecting differences in surgical technique or approach. Taken together, these variations underscore the need to individualize treatment and ensure rigorous postoperative follow-up to prevent and manage adverse events effectively. The choice of surgical method should consider not only fracture management efficacy but also each technique's complication profile, with the goal of minimizing risks and optimizing patient recovery.

CONCLUSIONS

Trial quality, assessed with the MINORS tool, was rated good. The meta-analysis for adverse events showed a statistically significant increase in risk in the experimental group compared with controls, indicating that participants in the experimental group were more likely to experience adverse events; no significant heterogeneity was identified across studies.

Regarding operative time, the pooled (raw) mean difference between the experimental and control groups was -12.42 minutes under the fixed-effect model, indicating a significant reduction in surgical time for the experimental group. Under the random-effects model, the mean difference was -21.62 minutes, likewise indicating a significant reduction but with greater between-study variability. For length of stay, there was a significant reduction favoring the experimental group versus controls.

The meta-analysis also showed that, for fracture consolidation, the experimental group had a longer recovery/consolidation time than the control group, with a statistically significant effect. However, the random-effects analysis, together with high heterogeneity, indicates considerable uncertainty—i.e., results may vary markedly across studies. Interpretation should therefore account for this variability and the possibility that effects are not consistent across clinical settings. Conservative cast treatment is broadly effective for stable, simple fractures, yielding excellent outcomes with relatively low complication rates. In unstable or complex fractures, however, surgery becomes indispensable.

Among surgical techniques, elastic intramedullary fixation with TEN rods offers important advantages—faster recovery and shorter operative time—and is particularly effective when conservative treatment fails. Nonetheless, TEN is associated with complications such as reoperations and refractures, and with higher overall complication rates compared with plate-and-screw osteosynthesis. Kirschner wires (K-wires) can achieve rapid union, but they carry higher risks of complications, including infections and transient neurapraxia. Accordingly, the choice between surgical and conservative management should be individualized based on fracture characteristics, patient age, and surgeon experience, carefully weighing each method's risk-benefit and complication profile. Further long-term studies are needed to confirm functional outcomes and complication patterns, especially for emerging techniques such as hybrid fixation and resorbable intramedullary rods.

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BIOABSORBABLE CAGES IN SPINAL FUSION IN AN ANIMAL MODEL: A SYSTEMATIC REVIEW AND META-ANALYSIS

CAGES BIOABSORVÍVEIS NA FUSÃO VERTEBRAL EM UM MODELO ANIMAL: REVISÃO SISTEMÁTICA E METANÁLISE

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ABSTRACT

To evaluate the efficacy of bioabsorbable interbody cages in comparison with conventional techniques in animal models, with emphasis on the impact of follow-up time on developments. A systematic review and meta-analysis was performed including 11 studies on the use of bioabsorbable cages in comparison with conventional techniques. The odds ratio (OR) was calculated for range of motion (ROM), and heterogeneity was assessed by Cochran's Q test. Descriptive statistical analyses and hypothesis tests were performed to evaluate the parameters of fusion rate, intervertebral disc height and ROM. The 11 studies included totaled 244 animals. The analysis revealed a cumulative OR of 1.70 for ROM and fusion rate in the first four months of follow-up. No significant differences were found in height parameters in the study follow-ups. Heterogeneity among studies was low, indicating consistency in the results. The analysis suggests that bioabsorbable cages have advantages in periods of less than four months, and that there is no inferiority in the results in follow-up periods longer than four months in terms of fusion rate, ROM and intervertebral height in long-term experimental studies, and further research is needed to determine their clinical applicability. **Level of Evidence II; Systematic meta-analytical review of non-randomized controlled clinical studies whose results were homogeneous.**

Keywords: Arthrodesis; Spinal Fusion; Absorbable Implants; Meta-Analysis; Models, Animal.

RESUMO

Avaliar a eficácia através do desempenho biomecânico e clínico dos dispositivos intersomáticos bioabsorvíveis na fusão intervertebral em comparação com técnicas convencionais em modelos animais, com ênfase no impacto do tempo de acompanhamento sobre os desfechos. Realizou-se uma revisão sistemática e metanálise com a inclusão de 11 estudos sobre o uso de dispositivos bioabsorvíveis em fusão intersomática vertebral, em comparação com os implantes mais comumente usados na rotina da cirurgia de coluna. A Odds Ratio (OR) foi calculada para a amplitude do movimento (ROM), e a heterogeneidade foi avaliada pelo teste Q de Cochran. Análises estatísticas descritivas e testes de hipóteses foram realizados para avaliar os parâmetros taxa de fusão, altura discal intervertebral e ROM. Os 11 estudos incluídos somaram 244 animais. A análise revelou uma OR acumulada de 1,70 para ROM e taxa de fusão, nos primeiros quatro meses de seguimento. Não foram encontradas diferenças significativas nos parâmetros de altura nos seguimentos dos estudos. A heterogeneidade entre os estudos foi baixa, indicando consistência nos resultados. A análise sugere que os cages bioabsorvíveis apresentam vantagens em períodos de acompanhamento inferiores a quatro meses, e que não há inferioridade nos resultados em períodos de acompanhamento maiores que quatro meses em termos de taxa de fusão, identificadas pela ROM e altura intervertebral. **Nível de Evidência II: Revisão sistemática metanalítica de estudos clínicos controlados não randomizados cujos resultados foram homogêneos.**

Descritores: Artrodese; Fusão Intervertebral; Implantes Absorvíveis; Meta-Análise; Modelo Animal.

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INTRODUCTION

The treatment of spinal pathologies with interbody fusion (arthrodesis), with or without decompression, plays a crucial and well-established role in degenerative, traumatic, infectious, and tumor conditions.¹⁻⁴

The first reports of spinal arthrodesis date back to the early 20th century, in studies by Fred Albee,⁵ in which arthrodesis was achieved after slices of tibia were positioned and sutured between spinous processes, and by Russel Hibbs,⁶ in which fusion was achieved without the use of grafts, through osteotomy and

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subsequent approximation of the spinous process to the vertebral lamina.^{6,7} In 1933, Burns⁸ performed the anterior interbody fusion procedure for the treatment of lumbar spondylolisthesis using a structured tibial graft, and later, in the 1950s, Hodgson⁹ and Stock¹⁰ described interbody arthrodesis via anterior access for the treatment of tuberculosis.

In the cervical spine, anterior arthrodesis with discectomy became the gold standard for the treatment of several pathologies, including degenerative disc disease, myelopathies, and traumatic injuries. This technique has evolved since the descriptions by Cloward¹¹ and Smith and Robinson¹² in the 1950s.

Advances in fixation techniques followed with the development of Luque's sublaminar wiring¹³ and later with Judet¹⁴ and Roy-Camille et al.,¹⁵ who elaborated and disseminated spinal fixation through pedicle screws. The evolution of transpedicular screw fixation continued with more versatile and robust systems applicable to the treatment of deformities, trauma, and degenerative conditions, with historical highlights including Margerl's internal fixation system¹⁶ and Cotrel et al.'s deformity system.¹⁷

In parallel with the development of fixation implants, interbody devices—or “cages”—were also introduced.¹⁸⁻²⁰

The use of these devices has become very common in spinal fusion surgery, consisting of implanting a support in the intervertebral space with an inner cavity to be filled with graft material.²¹

The initial presentation was by Bagby²² in 1988, who, in studies on horses with cervical spondylotic myelopathy, developed a cylindrical steel interbody device with an internal space to be filled with graft material, which was then press-fit into the intervertebral space—known as the “Bagby Bone Basket.” In the early 1990s, the technique was expanded and developed in humans, for both cervical and lumbar spine surgeries.^{22,23}

These devices possess mechanical properties to withstand compressive loads, provide a large surface area for bone graft placement to promote fusion, and improve biomechanical stability. They may also serve as a vehicle for the local delivery of medication to the surgical site.^{2,19,24,25}

Among the available devices, those made of titanium or PEEK (polyether-ether-ketone) are the most commonly used in spinal surgery today.^{26,27}

It is well known that interbody devices made of metal, carbon fiber, or PEEK are non-absorbable materials, which do not allow for complete biological fusion and remain as foreign bodies in the host organism. This can lead to foreign body reactions and, not infrequently, the need for revision surgeries, as well as implant breakage, migration, subsidence, and other complications.^{22,28}

Research on the development of an interbody device capable of overcoming or minimizing the undesirable outcomes of conventional implants has always been a focus.¹⁹

Such a device should provide adequate intervertebral support, demonstrate appropriate biocompatibility and properties as close as possible to host bone, be highly permeable to imaging studies, replace the intervertebral disc or affected area, and promote proper fusion through the concomitant use of bone grafts.^{19,22}

In this context, a potential solution is an interbody device manufactured from bioabsorbable material, which, in addition to the aforementioned properties, would have the advantage of being gradually reabsorbed by the organism in a controlled manner.^{19,22,29}

The most commonly used bioabsorbable materials are polymers such as polylactic acid (PLA), poly-L-lactic acid (PLLA), polyglycolic acid (PGA), and poly-D,L-lactic-co-glycolic acid (PLGA),^{30,31} ceramics such as hydroxyapatite (HA), tricalcium phosphate (TCP), beta-tricalcium phosphate (β -TCP), calcium sulfate, and bioactive glass,³² as well as magnesium (Mg) and its alloys.³³

The primary goal of interbody arthrodesis is to eliminate motion at the operated segment, and its progress can be assessed through imaging studies.⁴ Outcomes may be evaluated by measuring fusion rate, range of motion (ROM) of the segment, and intervertebral disc height.

The present study aims to conduct a systematic review and meta-analysis to assess the performance of bioabsorbable interbody devices in animal models of interbody fusion, evaluating fusion rate, intervertebral disc height, and ROM, in comparison with the most commonly employed implants in routine spine surgery, including PEEK, titanium, and structured tricortical bone grafts.

METHODOLOGY

A systematic review of the literature was conducted as a secondary study, following the Cochrane Handbook for Systematic Reviews of Interventions (version 6.1, 2020) and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Studies were identified through systematic searches in electronic databases and research portals, in addition to reference list analyses, using 10 databases and keywords based on MeSH descriptors and free terms: *Arthrodesis* AND (“*spine*” OR “*spine fusion*” OR “*spinal fusion*”) AND (*cage* OR *interbody device* AND (“*absorbable implants*” OR (*materials* OR *Material* AND (*absorbable* OR *bioabsorbable* OR *biodegradable*) OR “*biodegradable cage*”). Inclusion criteria comprised studies conducted in ovine or caprine animal models, including randomized or non-randomized clinical trials, controlled observational studies, or case series, with no restrictions on year or language. Exclusion criteria included human or in vitro studies, literature reviews, case reports, interviews, commentaries, duplicate articles, and those that did not evaluate arthrodesis outcomes in the cervical or lumbar spine, or were not published in full, even after attempts to contact the authors for data retrieval. Outcomes assessed included fusion rate, segmental range of motion (ROM), and intervertebral disc height.

The systematic search identified 168 articles, distributed across databases as follows: BVS/BIREME ($n = 0$), Cochrane ($n = 4$), EBSCOhost ($n = 1$), EMBASE ($n = 58$), Epistemonikos ($n = 2$), ProQuest ($n = 1$), PubMed PMC ($n = 6$), PubMed ($n = 60$), Scopus ($n = 13$), and Web of Science ($n = 23$). These articles were exported to the reference management programs EndNote and Rayyan, including titles, abstracts, references, and data sources. Duplicate studies were automatically removed, resulting in the exclusion of 60 articles and leaving 108 for eligibility screening. After full-text evaluation, 64 articles were reviewed, and 11 were considered relevant and selected for data extraction, as shown in Figure 1.

Data extraction began with the independent assessment of titles and abstracts from the identified studies by two researchers. Full texts of potentially relevant studies were subsequently retrieved and independently reviewed by the same researchers. Each researcher compiled a list of studies considered to meet the predefined inclusion and exclusion criteria, using a standardized clinical form to record exclusion reasons and document the article selection flow. Lists were compared, and disagreements were resolved by discussion and consensus; if consensus was not reached, the article was assessed by a third independent reviewer for final inclusion. Evidence quality and strength of recommendations were assessed using the Newcastle-Ottawa Scale (NOS) for non-randomized methodology studies, case-control, and cohort designs. This scale evaluates study quality based on a star system, analyzing study group selection, comparability, and assessment of exposure or outcome of interest.

Fusion rate and ROM were evaluated using the approach proposed by Cahill et al.³⁴ while disc height was calculated using the mean of anterior, middle, and posterior intervertebral space measurements.

The main endpoint consisted of data analysis obtained from animal models (ovine or caprine), according to variables observed in case-control studies. The Odds Ratio (OR) was calculated for ROM, based on reported results in the selected articles. In addition to association measures, the Mantel-Haenszel fixed-effect model³⁵ was applied to assess analytic outcomes. These models consider the following calculation: Y_j (desired effect) = $\theta M + \varepsilon_j$ (where ε_j is the random error of the study, and θM is the common effect across all studies).

Heterogeneity was examined using Cochran's Q test, in which the null hypothesis states that studies included in the meta-analysis do not present heterogeneity in relation to randomized analyses and therapeutic interventions. Effectiveness rates of surgeries, obtained from hypothesis tests and association measures reported in the included articles, were analyzed in paired groups of animals treated and untreated with bioabsorbable interbody devices, according to the I^2 index described by Thompson and Higgins.³⁶ According to the authors, $I^2 = (Q - df) / Q \times 100$, where Q is based on Cochran's Q test ($Q = \sum w_i (\theta_i - \theta)^2$), which tests the null hypothesis that the included studies are homogeneous. Descriptive statistical analyses of the selected articles were performed, with hypothesis tests adopting a significance level of 0.05. All statistical analyses were conducted using JASP software, version 0.19.2 (2024).

Each of the 11 selected studies was assessed based on epidemiological methodology, risk of sampling bias, applied statistics, and probabilistic/statistical inference using hypothesis tests (Student's t-test or Mann-Whitney test). The null hypothesis (H_0) of this study was defined as a statistical parameter whereby the studies should be heterogeneous, based on mean values greater than 50% between Mantel-Haenszel and I^2 tests, calculated over the geometric mean and variance of the statistical outcomes of the 11 studies. Analyses related to disc height were assessed using Pearson's correlation coefficient and Student's t-test, based on time variables and the use of bioabsorbable interbody devices. Variables such as ROM and fusion were evaluated together with consolidation time, with mean differences and confidence intervals assessed by hypothesis testing based on data parametricity (Student's t-test), using an alpha level of 0.05.

RESULTS

After applying the exclusion criteria, 11 articles were included in the statistical analyses, considering the description of methodologies applied in paired case-control trials (cases treated with bioabsorbable interbody devices and controls treated with conventional techniques—in these studies, bone grafting, PEEK interbody devices, and titanium interbody devices).

A Figure 1 shows the selection process of the studies that composed the final sample of this review.

The selected studies showed low heterogeneity when pooled, as described in Table 1.

Regarding the analytical factors involving performance, we obtained a pooled OR of 1.70 (CI 1.27–2.04) for biomechanical analyses (ROM) and fusion rate up to 4 months of postoperative follow-up, as presented in Table 2.

In total, the 11 selected studies included 280 animals (mean of 31), ranging from 10 to 45 subjects. A total of 36 animals were excluded from the statistical calculations, leaving 244 animals, due to follow-up periods shorter than 4 months or longer than 12 months, as well as cases in which animals were retested at different time points, in order to minimize sampling bias.

The data collection characteristics of each evaluated study are described in Table 3.

The follow-up time of the groups (mean of eight months) did not show significant differences regarding fusion rates and ROM,

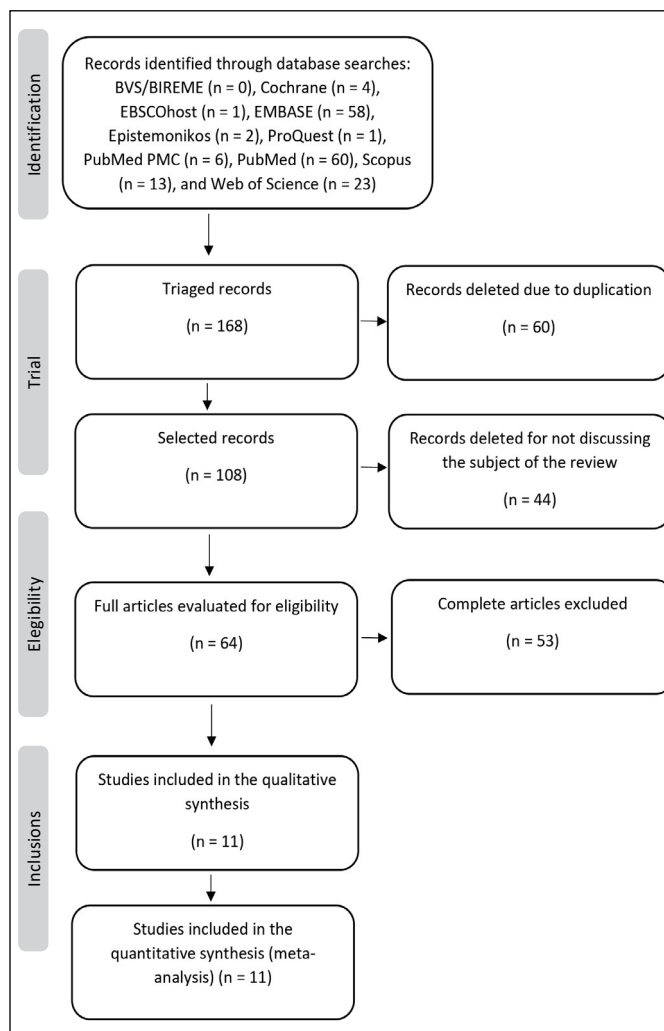


Figure 1. Flowchart of the process of identification and exclusion of articles.

Table 1. Q test and I^2 test values for the analysis of studies that evaluated fusion outcomes, ROM, and disc height, comparing bioabsorbable devices and conventional techniques between 2002 and 2024.

	Q test	Value of p	I^2
Coefficient	< 0.05	< 0.05	28%

Table 2. Measures of association (OR) and respective confidence intervals of the studies analyzed, including sample data for ROM and fusion rate up to 4 months of follow-up.

Parameters	Number of studies	Number of eligible animals in studies	Mean of OR to ROM* and fusion rate (compared with conventional treatment)
Pooled results	11	244	1.70 (1.27-2.04)
Date of analysis			
Between 2002-2004	4 (36.3%)	38 (16.0%)	1.52 (1.01- 2.01)
Between 2004-2024**	7 (64.7%)	206 (84.0%)	1.89 (1.21- 2.43)

CI = Confidence Interval (95%). * Values based on flexion, extension, and rotation. ** Larger sample size and 20-year publication interval between 2004 and 2024.

Table 3. Data collection and results of hypothesis tests for the difference between incidence rates according to follow-up time for fusion rate and ROM.

	n° of animals*	Data source	Bioabsorbable material**	Fusion rate comparison:*** (p)	ROM comparison**** (p)
Toth et al. (2002) ³⁷	10	Milwaukee, EUA	70-30 D, L-PLA	< 0.05	< 0.05
Wuisman et al. (2002) ³⁸	36	Amsterdam, Holanda	PLLA	< 0.05	< 0.05
Cahill et al. (2003) ³⁴	12	Tampa, EUA	PLA-PGA	< 0.05	< 0.05
Kandziora et al. (2004) ³⁹	24	Berlin, Germany	PLLA	< 0.05	< 0.05
Daentzer et al. (2014) ²⁹	24	Hannover, Germany	Mg-PCL	< 0.05	< 0.05
Li et al. (2014) ⁴⁰	24	Xi'an Shaanxi, China	PCL-TCP	< 0.05	< 0.05
Li et al. (2015) ⁴¹	24	Shanghai, China	PDLLA	< 0.05	< 0.05
Cao et al. (2017) ²⁸	18	Shanghai, China	PLA-TCP	< 0.05	< 0.05
Ren et al. (2017) ⁴²	24	Lianyungang, China.	MAACP-TCP	< 0.05	< 0.05
Xu et al. (2018) ⁴³	24	Shanghai, China	Mg-Zn	< 0.05	< 0.05
Yang et al (2024) ⁴⁴	24	Shanghai, China	Mg-Zn-Nd-Zr	< 0.05	< 0.05

* In the studies addressed, animals considered outliers with respect to time, as well as those evaluated at two different time points, were excluded. ** 70-30 D,L-PLA (poly-D-lactic acid), PLLA (poly-L-lactic acid), PLA-PGA (polylactic–polyglycolic acid), Mg-PCL (magnesium–polycaprolactone), PCL-TCP (tricalcium phosphate–polycaprolactone), PDLLA (poly-D,L-lactic acid), PLA-TCP (polylactic acid–tricalcium phosphate), MAACP-TCP (multiamino acid–tricalcium phosphate), Mg-Zn (magnesium–zinc), Mg-Zn-Nd-Zr (magnesium–zinc–neodymium–zirconium). ***Fusion rate comparison: Bioabsorbable devices vs. conventional devices < 4 months of observation (p-values obtained by Student's t-test). ****ROM comparison: Bioabsorbable devices vs. conventional devices < 4 months of observation. p-values obtained by Student's t-test based on flexion, extension, and rotation.

based on Student's t-test results ($p > 0.05$) at time points greater than 4 months. However, at time points shorter than four months, bioabsorbable devices showed better performance in fusion rates and ROM, also based on Student's t-test ($p < 0.05$), as shown in Table 2. Over the total follow-up period, no significant difference was observed in the final intervertebral disc height, as shown in Figure 2.

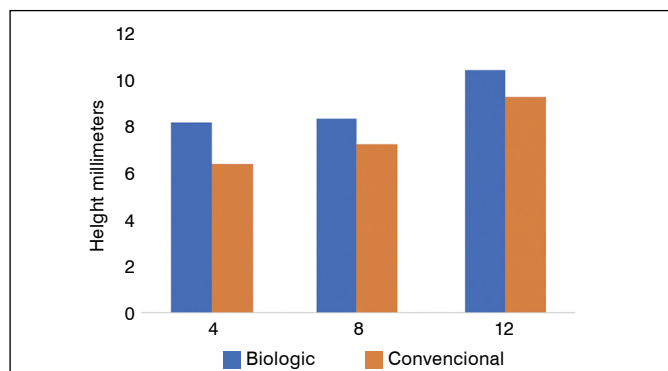


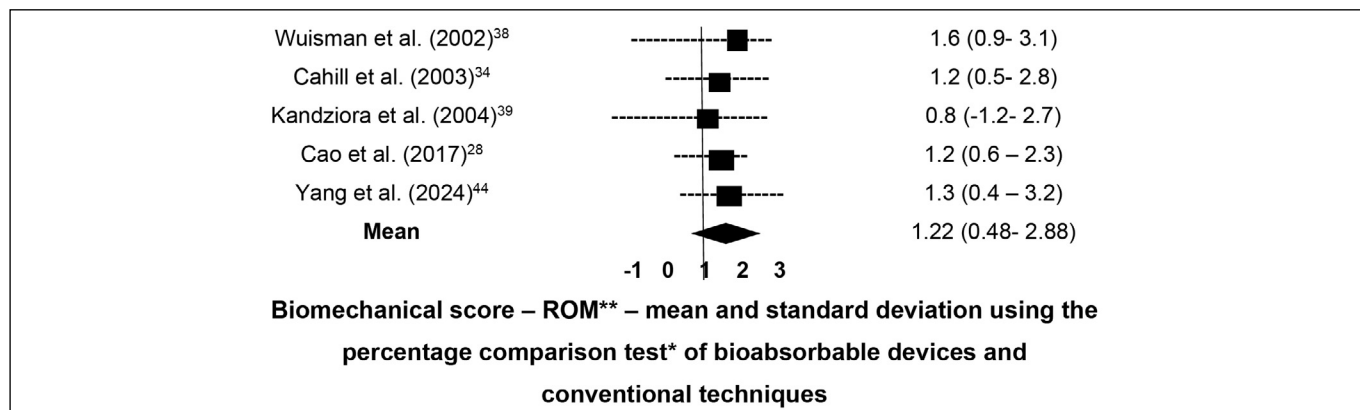
Figure 2. Height in millimeters, compared across 3 time points based on means and 95% CIs, as observed in the 6 studies analyzed using Pearson's regression technique* ($R^2 = 0.96$), $p > 0.05$ (Student's t-test) *Mean of 8.6 mm in cages, with a maximum reach of 10 mm at 12 months.

Figure 3 presents the Forest Plot combining the studies that performed direct comparisons of ORs, means, and standard deviations for ROM, and Figure 4 shows the same for fusion rate, based on studies with paired and controlled groups. These comparisons between bioabsorbable interbody devices and conventional techniques did not demonstrate significant improvement at follow-up longer than 4 months.

Figure 4 shows the assessment of intervertebral disc height, comparing bioabsorbable interbody devices with conventional devices. This parameter showed no significant difference throughout the entire follow-up period, with $p > 0.05$ (Student's t-test) and $R^2 = 0.96$.

DISCUSSION

The present systematic review and meta-analysis aimed to evaluate the efficacy of intervertebral fusion techniques in animals using bioabsorbable devices compared with the cages most commonly employed in spine surgery practice, namely structured autologous bone alone, PEEK, and metals, particularly titanium. Studies conducted in sheep and goats are relevant because the size of the vertebrae and the lamellar bone growth rate in these animals are comparable to humans, which allows human surgical techniques and instrumentation to be applied with ease.^{45,46}



** Score based on flexion–extension movement as proposed by Cahill et al.³⁴

Figure 3. Forest plot comparing ROM between bioabsorbable devices and conventional techniques at follow-up > 4 months.

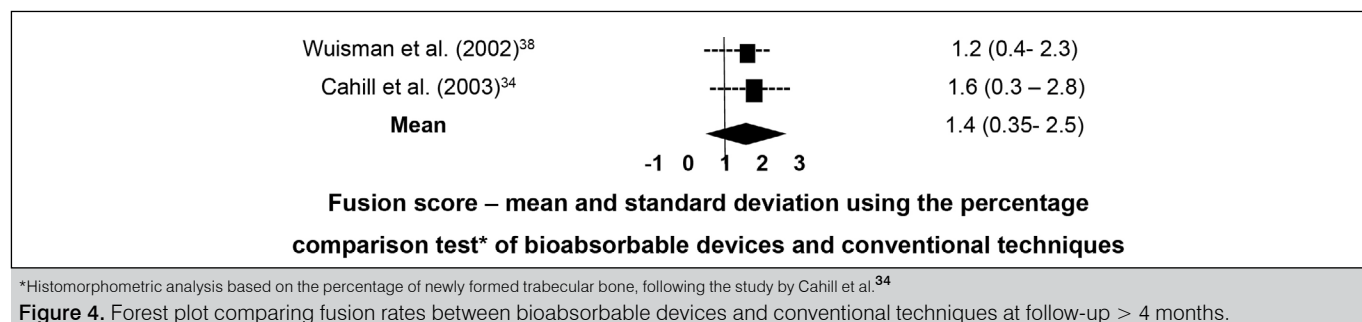


Figure 4. Forest plot comparing fusion rates between bioabsorbable devices and conventional techniques at follow-up > 4 months.

The results of this study demonstrated that bioabsorbable interbody devices performed better with respect to fusion rates during periods shorter than four months of follow-up; after this period, the differences between groups were not significant. In the study by Xu et al.⁴³ it was shown that, for magnesium interbody devices in sheep subjected to cervical arthrodesis, no significant results were found for fusion rates after 6 months of postoperative evaluation. Similar findings were reported by Kandziora et al.²⁰ who also did not demonstrate improved fusion rates with cervical interbody devices at 3 months of follow-up. On the other hand, Lippman et al.³⁰ observed adequate fusion rates at 6 months of cervical arthrodesis with cages made of poly(L-lactide-co-D,L-lactide)/polyglycolic acid (PLDLLA/PGA), with faster results depending on the graft used—in this study, faster with BMP-2. Favorable results for bioabsorbable devices were also found in the study by Cao et al.²⁸ in which, after 3 months of follow-up, fusion rates were higher compared with tricortical bone graft and PEEK devices. Similar results were reported by Ren et al.⁴⁷ with higher fusion rates in cervical arthrodesis using bioabsorbable devices compared with titanium and bone devices at 6 months of follow-up. This study also showed that range of motion (ROM) outcomes were superior when using interbody bioabsorbable devices up to the first 4 months of follow-up compared with traditional techniques, with a pooled OR of 1.70 in biomechanical analyses. In the study by Cao et al.²⁸ at 3 months of follow-up, bioabsorbable devices showed significantly lower ROM compared with controls, indicating greater stability of the fused segment. Conversely, Kandziora et al.²⁰ did not find improvements in this parameter at 3 months of postoperative follow-up for cervical arthrodesis in sheep, compared with tricortical bone.

Regarding intervertebral disc height, Cao et al.²⁸ observed a significant increase in sheep treated with bioabsorbable devices compared with isolated bone grafts, with similar heights to those treated with PEEK devices at 3 months. This result was also found in the study by Ren et al.⁴⁷ in which, at 3 and 6 months of cervical arthrodesis in sheep, bioabsorbable cages showed significantly greater final intervertebral height compared with titanium and bone devices. In our analysis, however, no significant differences in disc height parameters were observed over the follow-up period of the included studies. This suggests that bioabsorbable cages may be effective in promoting bone fusion, as differences in vertebral height are not clinically relevant in the short term, while fulfilling their primary role of providing mechanical support to achieve appropriate segmental fusion in conjunction with graft material. These findings suggest that, in shorter periods, the bone response to fusion may be sufficient to preserve intervertebral height.⁴⁸

There are several nuances regarding the use of bioabsorbable interbody devices. In the study by Toth et al.⁴⁵ it was discussed that the benefits of these devices may be limited by factors such

as material quality and resorption rate, as resorption over time may affect efficacy due to different local and clinical conditions. Similar findings were reported in studies by Bostman et al.^{49,50} and Cahill et al.⁵¹ highlighting that the clinical effectiveness of bioabsorbable cages depends on several factors, including biocompatibility, resorption rate, and the experimental model used.

In this context, the comparison between bioabsorbable cages and conventional techniques, as observed in the study by Wuisman et al.³⁸ indicates that the advantage of biological cages becomes apparent mainly after an adaptation period, which varies depending on the follow-up duration across studies.

A possible explanation for the better outcomes observed with bioabsorbable devices in the early postoperative months lies in the fact that, during this initial period of bone consolidation, implants with properties closer to human bone may carry a lower risk of iatrogenic injuries such as endplate or pedicle fractures—factors that could compromise consolidation. In later stages of fusion, implants with characteristics more similar to host bone reduce the risk of mechanical load deviation caused by more rigid implants (stress shielding), which can result in subsidence and fixation failure.⁵²

Furthermore, the low heterogeneity observed among the selected studies reinforces the consistency of the results, suggesting that the techniques used in the included studies were sufficiently homogeneous to support general conclusions. As Thompson e Higgins³⁵ emphasize, low heterogeneity in meta-analyses increases confidence in the derived conclusions, especially when parameters are well defined and data are consistent across studies.

The results of this meta-analysis suggest that bioabsorbable interbody devices, by not showing inferiority to conventional treatments in interbody spinal arthrodesis in animals, represent a potential material for incorporation into surgical spine care. These devices offer the theoretical appeal of lower complication rates compared with currently used implants, while fulfilling their primary role of mechanical support, gradually degrading over time, enabling high-quality imaging follow-up, and promoting bone fusion when combined with graft material.

Conventional techniques remain the treatment of choice for cervical spine pathologies requiring intervertebral fusion; however, further studies with longer follow-up are needed to more clearly define the advantages of bioabsorbable interbody devices in the clinical context of human pathology.

Study limitations include variability in cage composition, short animal follow-up, and, although animal studies remain a cornerstone of preclinical research, their limitations require careful interpretation of findings. Complementary approaches, including computational modeling, in vitro experiments, and early-phase clinical trials, are essential to bridge the gap between preclinical and clinical contexts.

CONCLUSION

The present review showed that bioabsorbable devices, when compared with traditional techniques, demonstrated slightly superior

performance during observation periods shorter than four months and, in periods longer than four months, did not show inferiority in outcomes regarding intervertebral fusion in animal studies.

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BIOKINETICS IN ACHILLES TENDINOPATHY: ESSENTIAL FINDINGS AND CLINICAL APPLICATIONS

BIOCINÉTICA NA TENDINOPATIA DO AQUILES: PRINCIPAIS ACHADOS E APLICAÇÕES CLÍNICAS

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ABSTRACT

The Achilles tendon, though the strongest in the human body, is the most commonly ruptured and frequently affected by tendinopathy, particularly in athletes. Achilles tendinopathy (AT) impacts approximately 8% of sports participants, with a lifetime incidence of over 50% in runners. Characterized by pain and tenderness, AT significantly compromises quality of life and functional performance. This narrative review explores biomechanical factors contributing to AT, focusing on both kinematic and kinetic parameters and their clinical relevance, providing a review of AT biomechanics literature, nonoperative interventions, and exercises targeting specific biomechanical risks. Studies have linked abnormal motion to AT. Key biomechanical factors include decreased plantar flexion strength, reduced gluteus medius and maximus activity, decreased peak ankle dorsiflexion, altered peak knee flexion, and decreased forward progression of the center of force, which may increase mechanical load and microtrauma, ultimately resulting in tendon damage. The effectiveness of various interventions was examined, emphasizing the integration of specific exercises aimed at addressing distinct biomechanical deficits. Effective management of AT requires addressing strength deficits and biomechanical abnormalities. Traditional rehabilitation protocols focus on strengthening but often neglect critical biomechanical issues. This review highlights the importance of incorporating specific exercises targeting kinematic and kinetic deficiencies. **Level of Evidence V; Expert Opinion.**

Keywords: Tendinopathy; Biomechanics; Kinematics; Motion Analysis; Rehabilitation.

RESUMO

O tendão de Aquiles, embora seja o mais forte do corpo humano, é também o mais comumente rompido e frequentemente acometido por tendinopatia — especialmente em atletas. A tendinopatia do Aquiles (TA) afeta aproximadamente 8% dos participantes de esportes, com uma incidência ao longo da vida superior a 50% entre os corredores. Caracterizada por dor e sensibilidade, a TA compromete significativamente a qualidade de vida e o desempenho funcional. Esta revisão narrativa explora os fatores biomecânicos que contribuem para a TA, com foco em parâmetros cinemáticos e cinéticos e sua relevância clínica, além de apresentar uma revisão da literatura sobre a biomecânica da TA, intervenções não-operatórias e exercícios direcionados aos riscos biomecânicos. Estudos têm relacionado padrões anormais de movimento à TA. Os principais fatores biomecânicos incluem: diminuição da força de flexão plantar, redução da atividade dos músculos glúteo médio e máximo, redução do pico de dorsiflexão do tornozelo, alteração do pico de flexão do joelho e diminuição da progressão anterior do centro de força — fatores que podem aumentar a carga mecânica e a ocorrência de microtraumas, resultando, por fim, em lesão do tendão. A eficácia de várias intervenções foi examinada. O manejo eficaz da TA exige o tratamento de déficits de força e anormalidades biomecânicas. Protocolos de reabilitação tradicionais focam no fortalecimento, mas frequentemente negligenciam questões biomecânicas críticas. Esta revisão destaca a importância de incorporar exercícios específicos que abordem disfunções cinemáticas e cinéticas. **Nível de Evidência V; Opinião de Especialista.**

Descritores: Tendinopatia; Biomecânica; Cinemática; Análise de Movimento; Reabilitação.

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INTRODUCTION

Despite being the strongest and thickest tendon in the human body,¹ capable of enduring substantial stresses and forces, the Achilles tendon is the most commonly ruptured tendon and one of the most frequently affected by tendinopathy.² Achilles tendinopathy (AT) affects approximately 8% of individuals involved in sports and physical activities and is one of the most common overuse injuries among runners³ with a cumulative lifetime incidence of more than 50% in this population.⁴ Characterized by pain, tenderness to palpation, and thickness, AT can persist for years, causing loss of quality of life and functional capacity.^{5,6}

AT has a multifactorial etiology involving diverse intrinsic and extrinsic risk factors. Extrinsic factors associated with AT include the use of quinolones and specific factors related to sports practice such as footwear, training surfaces, changes in training habits, pace, technique and stretching habits^{5,7,8} while intrinsic factors may include vascularity, age, sex, body weight, height, pes cavus deformity, and lateral ankle instability.^{5,7} Several biomechanical aspects have been linked to the genesis and persistence of AT^{5,7,9,10} and understanding each of these biomechanical parameters is essential for effectively treating and rehabilitating patients with AT.

AT mechanism of injury is primarily attributed to overuse.^{11,12} Repetitive microtrauma from mechanical loading leads to tissue damage, which, over multiple loading cycles, impairs tissue function. It has been demonstrated that when the rate of tissue damage surpasses the rate of tissue repair, there is a progressive change in tendon structure. Initially, collagen fibers deform, the interfiber space widens, and ultimately, severe matrix disruption with fiber thinning occurs in fatigue-loaded tendons.¹³ The influence of biomechanical risk factors in AT pathogenesis is due to their contribution to increased mechanical load and microtrauma during motion. When a specific movement pattern increases the mechanical load on the tendon, the likelihood of tissue damage and impaired function increases.¹⁴ In this context, we present a comprehensive review of the biomechanical factors related to AT and provide insights into their clinical implications. We delve into nonoperative interventions and explore the authors' preferred exercises tailored to specific biomechanical risk factors.

Kinematic Parameters

Abnormal kinematic parameters influencing AT, mainly related to rearfoot motion, have been explored by several studies, though with some conflicting results. Many studies have identified specific patterns in patients with AT, such as a greater rearfoot inversion at heel strike, followed by increased peak eversion, a shorter time to maximum eversion, and greater peak eversion velocity through midstance.^{9,15–17} These findings suggest that increased rearfoot eversion could intensify strain on the Achilles tendon, indicating the role of rearfoot motion in AT etiology.

It has been hypothesized that higher rearfoot inversion at initial contact leads to subsequent increased pronation,¹⁶ inducing inevitable internal tibial rotation. This rotation pulls the Achilles tendon medially, generating a whipping or bowstring effect. The enhanced whipping action could contribute to microtears, especially in the tendon's medial aspect.¹⁶ Furthermore, pronounced pronation indicates insufficient foot rigidity during stance, necessitating additional effort from extrinsic and intrinsic musculature to stabilize the foot during gait.⁷ These factors may contribute to the overload of the Achilles tendon.¹⁸

Literature presents controversial results on this parameter. Recently, Mousavi et al. published a meta-analysis reporting that, among kinematic factors, only moderate evidence suggested significant differences between runners with AT and controls for rearfoot eversion at heel strike in shod conditions.¹⁸ Supporting these findings,

Ryan et al., when analyzing barefoot running in AT subjects, detected greater rearfoot eversion during midstance compared to controls, with a trend towards a greater overall range of rearfoot motion.¹⁹ In contrast, Creaby et al. did not find significant differences in rearfoot eversion peak and range of motion (ROM) in AT subjects during running²⁰ and Donoghue et al. also did not find significant differences for a greater rearfoot eversion in AT patients.²¹ However, Donoghue et al. found statistical significance when this parameter was exacerbated in shod trials.²¹ Interestingly, in Becker et al.'s study, AT patients did not present greater excursion or velocity of rearfoot eversion compared to controls, but a longer duration of rearfoot eversion was observed.^{19,22} The discrepancies in findings suggest that rearfoot eversion in AT patients may be influenced by factors such as footwear and running conditions.

In terms of other lower limb joint kinematic parameters, there is evidence showing that proximal and distal joints may play a role in AT pathology.²⁰ Bramah et al. found that runners with AT demonstrated greater contralateral pelvic drop and forward trunk lean at midstance.²³ Greater contralateral pelvic drop has been associated with increased rearfoot eversion in a previous study.²⁴ It was proposed that this proximal motion in the hip could be inducing rearfoot eversion as a compensatory strategy. However, another study found no evidence of the influence of hip kinematics in runners with AT compared with healthy controls showcasing that this relationship may hold true for certain populations only.²⁰

A recent meta-analysis by Mousavi et al. found no significant differences between runners with AT and controls for peak knee flexion in both shod and barefoot conditions, as well as for knee flexion ROM in barefoot conditions, although there was conflicting evidence for shod conditions.¹⁸ Bramah et al. observed a more extended knee and dorsiflexed ankle at initial contact than controls.²³ Azevedo et al. reported that range of knee flexion between heel strike and midstance during running was significantly lower in patients with AT²⁵ similar to findings by Hein et al. and Joachim et al., who observed reduced maximal knee flexion during running in subjects who developed AT.^{17,26} Conversely, Donoghue et al. affirmed that AT patients had greater knee flexion during stance while running.²¹ This variability may be influenced by the fact that insufficient knee flexion is often associated with a protective mechanism to avoid pain, while increased knee flexion can lead to excessive ankle dorsiflexion, increasing tension on the Achilles tendon. These conflicting results underscore the complexity of knee mechanics in AT patients and suggest that further research is needed to better understand the variability and underlying factors influencing knee flexion in this population.

It is important to note that only Hein et al. and Van Ginckel et al. adopted a prospective design^{17,27} making them the only studies whose results allow for inferences of causality. In terms of AT prevention and rehabilitation, it is advised to focus on decreased peak dorsiflexion, decreased peak knee flexion and decreased forward progression of the center of force as these variables are biomechanical risk factors for AT onset and possibly progression. Moreover, the controversial findings on kinematic characteristics in cross-sectional studies may indicate large differences between AT individuals. Subgroup analysis may be beneficial in this population to better understand the role of biomechanics in the AT etiopathogenesis. Different factors may combine to increase the load on the Achilles tendon, and since not all of them will be present in every individual, biokinetic evaluation is essential to identify which factors each patient possesses, allowing for individualized treatment.

Kinetic Parameters

Some studies have reported important findings regarding the kinetic parameters of lower limb joints in subjects with AT, with

direct implications for clinical treatment and rehabilitation. Kim et al. showed that the internal plantar flexion moment (muscle forces to produce plantar flexion) of AT subjects was reduced from the midstance phase to terminal stance compared to controls, and the internal ankle dorsiflexion moment (muscle forces to produce dorsiflexion) was reduced during the terminal swing phase.²⁸ The reduced muscle force production in the ankle during crucial phases of gait means that AT patients may have difficulty pushing off effectively when running, probably leading to compensations in other joints.²⁸

Joachim et al. noticed altered knee moments in individuals with AT.²⁶ They found reduced knee internal extensor moments during stance in patients with AT. Creaby et al. also reported significant findings regarding hip kinetics.²⁰ The authors reported that runners with AT showed an increased peak hip external rotation moment (external joint moment) and impulse compared to controls, as well as a higher hip adduction moment impulse.²⁰ These alterations underscore the importance of assessing the entire kinetic chain in patients with AT, as compensations at the knee or hip could contribute to ongoing tendon stress or other injuries.

Studies have also reported on ankle and tibia kinetics. Azevedo et al. and Creaby et al. did not find differences in ankle kinetic parameters,^{20,25} while Williams et al. reported that patients with AT history had a lower external rotation moment of the tibia.²⁹ This finding may be due to decreased function of the muscles primarily responsible for transverse-plane motion such as posterior tibialis, resulting in greater strain on the Achilles tendon in the transverse-plane.

Regarding ground reaction forces (GRF), Azevedo et al., Joachim et al., McCrory et al. and Andere et al. did not find differences in the vertical GRF during running between runners with AT and healthy controls.^{9,25,26,30} Lalumiere et al. compared GRF between the symptomatic and asymptomatic limbs of AT patients and found limited differences in total GRF symmetries between the lower limbs.³¹ GRF forces may not be an important parameter to differentiate AT subjects and healthy subjects, and more investigation is crucial to assess the role of this variable as a risk factor before the onset of disease symptoms.

Evidence is also limited regarding plantar pressure distribution during running in patients with AT as few studies report data on this parameter and the results are controversial. Baur et al. demonstrated that patients with AT showed a more medial forward roll in the rear and midfoot than controls, suggesting more pronation in these patients during midstance,³² while, Van Ginckel et al. reported an association of AT with a more lateral foot roll-over following heel strike.²⁷ Clinically, this suggests the need for individualized assessments of foot mechanics, as variations in foot strike patterns could influence Achilles tendon load and guide personalized interventions, such as orthotic support or gait retraining.

In summary, the kinetic parameters observed in individuals with AT indicate complex and varied alterations in lower limb joint moments and forces. Reduced internal moments at the ankle, knee, and hip during different phases of gait suggest that AT patients may compensate for the reduced function of the Achilles tendon by redistributing forces across other joints. Strengthening the muscles involved in plantar flexion, as part of a force-sharing strategy, is crucial in treatment. Clinically, these findings emphasize the necessity of targeted rehabilitation programs that not only address Achilles tendon deficits but also optimize the kinetic chain to prevent overloading compensatory structures. By identifying these compensatory patterns through individualized kinetic and kinematic assessments, clinicians can tailor interventions to enhance force-sharing mechanisms, ultimately reducing strain on the Achilles tendon and preventing further injury.

Foot Strike Patterns During Running

Foot strike patterns may impact the magnitude of load on the Achilles tendon during running, potentially influencing the development of injuries. Almonroeder, Willson and Kernozek demonstrated, with weak evidence, that non-rearfoot striker runners exhibited approximately a 15% increase in Achilles tendon loading rate when compared to rearfoot strikers, as well as an 11% higher Achilles tendon impulse in each step.³³ Similarly, Altman and Davis, in a prospective comparison of shod and barefoot runners, showed that barefoot runners experienced more Achilles tendon and calf injuries, likely due to the midfoot/forefoot strike pattern observed in nearly 80% of barefoot runners.³⁴ This strike pattern places greater eccentric demands on the Achilles tendon as the foot dorsiflexes and everts in early stance,³⁴ highlighting the need to appropriately strengthen the gastrocnemius-soleus complex in this population.

Muscle strength

A recent meta-analysis by McAuliffe et al. investigated plantar flexion strength in patients with AT, reporting that subjects with AT demonstrated weaker plantar flexors compared to the uninjured side or healthy controls, showing deficits specifically in maximal, reactive, and explosive strength.³⁵ Conversely, another meta-analysis by Hasani et al. found only moderate evidence of impairments in maximal plantar flexor torque and limited evidence for impairment in concentric endurance on the affected side of AT subjects.³⁶ There was conflicting evidence for other plantar flexor function, such as explosive strength, power, and other endurance measures, between the affected and unaffected sides and for all measures when compared with healthy controls.³⁶

Several studies have identified reduced plantar flexor strength as a prevalent characteristic in individuals with AT and a risk factor for AT, as demonstrated in longitudinal studies. Mahieu et al. demonstrated that male military recruits with weaker plantar flexors developed more injuries during their military training,³⁷ and McCrory et al. also observed insufficiency in the gastrocnemius-soleus complex of AT patients, who were recreational or competitive runners, compared to healthy controls.⁹ Masood et al. showed that maximal plantar flexor force was approximately 14% higher in the contralateral limb compared to the AT limb of recreational athletes.³⁸ Andere et al. found that plantar flexors exhibited lower total work in runners with AT than in healthy runners.³⁰ O'Neill et al. reported that runners with AT had large deficits in plantar flexor torque and endurance with the knees both extended and flexed compared to controls,³⁹ and Crowley et al. demonstrated that active individuals with AT had lower maximal plantar flexor strength and power tested with the knee flexed,⁴⁰ suggesting a greater loss of the soleus force-generating capacity rather than the gastrocnemius in AT patients.

Conversely, Sara et al. found no deficits in plantar flexion strength in AT patients, whether evaluated isometrically, concentrically, or eccentrically.⁴¹ Child et al. and Chimenti et al. did not find differences in plantar flexor strength between AT patients and controls with both the knee flexed⁴² and extended,⁴³ respectively. However, Child et al. reported that runners with AT had higher Achilles tendon aponeurosis strain than healthy subjects.⁴²

Additionally, Hein et al. observed reduced knee flexor strength in runners that developed AT,¹⁷ relating it to the genesis of knee stability deficiencies, which may impact lower limb biomechanics and transfer more stress to the Achilles tendon.

In brief, there is a reasonable quantity of studies demonstrating that reduced plantar flexor strength plays a role in the development of AT and possibly maintenance as evidenced by longitudinal and cross-sectional studies. Corroborating this hypothesis, the most commonly used rehabilitation protocols focus on plantar flexor strengthening and show satisfactory results in over 80% of patients.⁴⁴

Muscle Activity and Neuromuscular Control

Altered muscle activity and neuromuscular control may also play an important role in AT. Smith et al. observed delayed onset and shorter duration of gluteus medius and maximus activation during running in runners with AT compared to healthy individuals, suggesting altered neuromuscular control at the hip level.⁴⁵ This could lead to increased hip adduction and internal rotation, generating greater tibial internal rotation and consequently rearfoot eversion, suggesting a link between hip and ankle biomechanics. Furthermore, a shorter duration of gluteus maximus activation could result in reduced hip extensor power and impaired forward propulsion of the center of mass.⁴⁵ To compensate for the decrease in forward propulsion, the AT could be overloaded in the terminal stance, which is the phase where coordinated contraction between the hip extensors and the plantar flexors is crucial. Additionally, Habets et al. reported that AT individuals demonstrated around 30% less hip isometric abduction strength, less hip isometric external rotation strength, and less hip isometric extension strength in the affected limb, with similar deficits observed in the contralateral healthy limb.⁴⁶ These findings suggest that dysfunction of proximal hip musculature could be associated with increased loading of the distal structures, such as the Achilles tendon, during sport activities.

Azevedo et al. showed a significant decrease in pre-heel strike activity of the tibialis anterior during running in AT runners, as well as post-heel strike activity of the rectus femoris and gluteus medius,²⁵ suggesting that runners with AT had a lower capacity than runners free from injuries for shock absorption due to the reduced muscle activation. Conversely, Baur et al. did not identify differences in tibialis anterior activity during running between patients and controls, but observed lower peroneal muscle activation in AT subjects during the weight acceptance phase, as well as reduced gastrocnemius muscle activity during weight acceptance and push-off phases compared to controls.⁴⁷ It is unclear whether lower gastrocnemius activity in AT patients is a risk factor only or also the result of the injury, but the association of AT with mechanical deficits of the lower limb might impair joint stability during the stance phase.⁴⁷ At the distal level, Wyndow et al. demonstrated that runners with AT presented altered triceps surae neuromotor control during running compared to healthy subjects, showing earlier activation of the soleus.⁴⁸ This imbalance could be related to altered intra-tendinous loads in AT. Furthermore, Crouzier et al. reported a lower contribution of the gastrocnemius lateralis to the overall triceps surae activation in individuals with AT compared to controls during maximal and submaximal isometric plantarflexion tasks, with gastrocnemius lateralis contributing 28% less to the total triceps surae force in AT subjects.⁴⁹ These findings suggest differences in force-sharing strategies within the triceps surae in AT patients compared to controls.

Ankle Flexibility

Limited ankle dorsiflexion passive ROM is another factor associated with AT. Several studies have shown a significant correlation between AT and tightness in the gastrocnemius or soleus muscles.^{16,50–52} However, some authors suggest that this limitation may not be clinically relevant⁵¹ or may be nonexistent during physical examination.¹⁷ Hein et al. and Joachim et al. reported lower peak ankle dorsiflexion during running in AT patients compared to controls.^{17,26} Ryan et al. found a trend toward lower peak ankle dorsiflexion velocity in AT patients.¹⁹ Conversely, Ferreira et al. did not find an association between ankle dorsiflexion and the occurrence of AT,⁵³ and Creaby et al. did not find differences in dorsiflexion parameters during running between patients and controls.²⁰ Donoghue et al. reported greater dorsiflexion during running in AT patients compared to controls,¹⁵ suggesting a complex association between passive and

active dorsiflexion ROM and AT, which may underlie the presence of distinct motion-based subgroups.

Ankle dorsiflexion ROM significantly influences lower limb mechanics, especially during tasks that require a high ROM, such as landing. Limited dorsiflexion ROM can lead to compensatory changes in lower limb kinematics, including increased ankle and foot pronation, knee valgus, and increased landing forces.⁵⁴ Furthermore, restricted ROM has been associated with altered gait patterns, such as increased ankle abductor moments and knee flexor and internal rotator moments during the stance phase,⁵⁵ potentially increasing the risk of injuries in athletes.

Biokinetic Variability

AT is a condition with important biomechanical variability. This is reflected in conflicting evidence concerning kinematic and kinetic parameters, muscle strength, flexibility and neuromuscular activation. Table 1 summarizes the main biomechanical parameters reported across studies, highlighting some of the controversies between them. The presence of substantial heterogeneity identified in this population demonstrates the importance of a personalized approach to treatment.

A biokinetic analysis—an assessment that comprises three-dimensional motion analysis, strength and flexibility test - when employed as a diagnostic clinical tool, is critical in the context of AT. Identifying biomechanical risk factors at an individual level can provide substantial information to personalized treatment regimens. Targeting individual-specific dysfunctions, as opposed to generic interventions, may provide faster, cheaper, and more effective treatment.

There is evidence that gait retraining strategies, which include strength, flexibility, neuromuscular, and biofeedback interventions, can be effective in addressing gait alterations.^{56,57,58} However, no consensus exists regarding the optimal treatment for biomechanical risk factors associated with AT.⁵⁹

Treatment

The management of AT involves minimizing pain, allowing the tendon to repair from repetitive damage, and restoring the tendon's capacity to support load.^{11,60} Interventions for AT are diverse and can involve exercises, injections, shockwave therapy, orthosis, acupuncture, medications, and surgery. The initial treatment is usually nonoperative, with surgical options reserved as a last resort.⁶¹ However, there is no consensus on the best intervention for this condition. A recent systematic review with randomized clinical trials has shown that intervention modalities like exercise therapy, injection therapy, shockwave therapy, acupuncture (and combinations of these modalities) are better than “wait-and-see” approach at reducing pain levels at 3 months.⁶² These results indicate that “wait-and-see” therapy is not clinically recommended and should not be considered ethical for future studies. Exercise combined with shockwave therapy and acupuncture alone was superior to most other treatments at 3 months, including exercise therapy alone. At 12 months, there was no difference between treatment modalities, which included exercise therapy, injection therapy, exercise combined with injection therapy, and exercise combined with night-splint therapy.

Most patients respond well to initial management within one year; however, about 20% do not improve.⁴⁴ For these patients, AT issues may persist for over 10 years, leading to a loss of quality of life and impairing daily activities, heavy work, and sports practice.⁶³ A potential reason for this non-optimal outcome is that biomechanical variables associated with AT, such as the kinematic and kinetic parameters and neuromuscular control reported in this review are not addressed by the current rehabilitation protocols.

Table 1. Main Biokinetic Characteristics of Patients with Achilles Tendinopathy.

Rearfoot Kinematics	- Greater rearfoot inversion at heel strike - Increased peak eversion - Shorter time to maximum eversion - Greater peak eversion velocity during midstance - Controversy in studies, but shod conditions often show increased rearfoot eversion in AT subjects. Some studies find no differences in eversion in barefoot conditions. - Longer duration of rearfoot eversion in some AT patients.
Knee Kinematics	- Conflicting evidence on knee flexion ROM during running - Reduced maximal knee flexion observed in some studies, while others report greater knee flexion during stance. - AT patients often demonstrate altered knee mechanics, potentially linked to pain avoidance or compensatory strategies.
Ankle Kinematics	- Prospective studies report lower peak ankle dorsiflexion in AT patients compared to controls. - Conflicting evidence on whether limited ankle dorsiflexion ROM is associated with AT. - Complex association between passive and active dorsiflexion ROM and AT, suggesting the presence of distinct subgroups.
Hip Kinematics	- Greater contralateral pelvic drop and forward trunk lean in AT patients. - Some studies found no differences in hip kinematics between AT patients and controls.
Kinetic Parameters	- Reduced plantar flexion and dorsiflexion moments at the ankle in AT patients, leading to difficulty in push-off during gait. - Increased knee internal extensor moments during stance. - Altered force distribution across joints as compensatory mechanisms. - Conflicting evidence on ground reaction forces (GRF).
Muscle Strength	- Weaker plantar flexors in AT patients compared to healthy controls. - Reduced maximal, reactive, and explosive strength in the plantar flexors. - Some studies find no significant strength deficits in AT patients. - Reduced knee flexor strength in AT patients, possibly influencing lower limb biomechanics and increasing Achilles tendon stress.
Muscle Activity	- Delayed and reduced gluteus medius and maximus activation during running in AT patients. - Reduced activity of the gastrocnemius and peroneal muscles during running. - Altered triceps surae neuromotor control, with earlier activation of the soleus. - Differences in force-sharing strategies within the triceps surae in AT patients compared to controls.
Foot Strike Patterns	- Midfoot/forefoot strike pattern during running in non-rearfoot strikers is associated with higher Achilles tendon loading. - Barefoot runners (who often use a midfoot strike) experience more Achilles tendon injuries.
Ankle Flexibility	- Limited ankle dorsiflexion passive ROM is associated with AT in some studies. - Other studies report no significant differences in ankle dorsiflexion in AT patients.

The most used and widely studied rehabilitation protocol is the Alfredson protocol.⁶⁴ This protocol consists of eccentric training of the triceps surae that can be performed without supervision and minimal equipment. It consists of two sets of 15 repetitions performed twice a day, 7 days a week, for 12 weeks. The exercises include single-leg plantar flexion with the knee extended and knee flexed, emphasizing the eccentric phase of the exercise. Other protocols such as those described by Silbernagel et al., Beyer et al. and Mafi et al. proposed modifications focusing on concentric protocols, seated position, plyometrics, speed of contraction, and load during each repetition.⁶⁵ However, there is a lack of high-quality comparative studies to prove the superiority of any single program.⁶⁵ Current rehabilitation protocols have slight variations but are fundamentally similar. They focus on the progressive strengthening of the muscle and tendon to meet the demands imposed by the patient's body and activities.⁶⁵ However, this approach has two main problems: (1) adherence tends to vary because pain is expected during rehabilitation,⁶⁶ and (2) in many cases, loss of plantar flexor strength is not present, suggesting that other causal factors contributing to the onset and symptoms of AT are not being addressed.⁶⁷ As demonstrated in the previous section of this review (Table 1), biomechanical risk factors such as reduced peak dorsiflexion, peak knee flexion and decreased forward progression of propulsion are associated with AT, possibly contributing to its onset and persistence of symptoms. If a causal link is better demonstrated in future studies, not addressing these biomechanical risk factors means not addressing important root causes of AT. Ultimately, overlooking biomechanical risk factors may compromise effective management. Effective interventions to address biomechanical risk factors present in gait are scarce in the AT literature. A systematic review that

included 27 studies examined various biomechanical parameters in runners and the effectiveness of gait modifications.⁶⁸ Regarding the rearfoot eversion angle at initial contact, no evidence was found to support that step length manipulation can change this parameter. It was shown that peak rearfoot eversion can be increased with a crossover gait and decreased with a laterally "wide step".⁶⁸ Also, changes in strike pattern can modify peak eversion angle. It was shown that peak eversion decreased with a forefoot strike compared to a rearfoot strike and increased with a toe strike.⁶⁸ No significant differences were observed with a change in step length to modify peak rearfoot eversion.⁶⁸

The systematic review by Napier et al. also assessed gait modifications that could influence knee flexion during running.⁶⁸ There was no evidence to support that modification in stride length affected sagittal knee angle at initial contact in runners. However, the evidence for modification in foot strike was consistent across studies. Changes from rearfoot strike to forefoot strike were shown to decrease the peak rearfoot eversion. This effect was also more pronounced when toe foot strike was adopted.

In summary, there is limited evidence on the best interventions to modify the kinematic, kinetic, and neuromuscular parameters associated with AT. Therefore, we present our exercise suggestions to address the most important biomechanical variables, in case they are identified with biokinetic analysis in a clinical setting.

Authors' Preference of Exercises

Decreased Plantar flexor strength (extended knee)

The gait phase that requires more plantar flexor strength is the push-off, with soleus muscle being the major contributor to power generation.⁶⁹ Weakness in this phase has been demonstrated previously by Kim et al.²⁸ According to the principle of task specificity, we

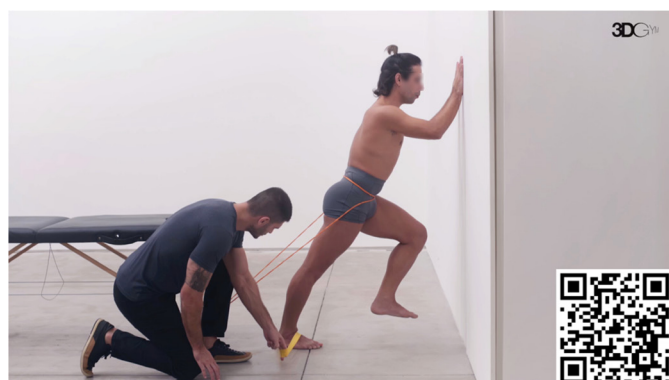
adopted this exercise (Video 1) as the standard approach to target plantar flexor strength, because it reproduces the push-off phase in the running gait cycle. The body's diagonal inclination simulates the position encountered during running, aiming to replicate the force vectors that the plantar flexors must overcome in this activity. In our practice, we train both concentric and eccentric phases with an emphasis on exercise specificity, considering the speed that is required for contraction. Progression to increased speeds on both concentric and eccentric phases is prioritized before adding additional load for the execution of the movement.

In the initial phase, when pain can be a limiting factor for the proper execution of this task, our preferred approach is to increase the force sharing for plantar flexion with fibularis muscles. Fibularis muscles are secondary plantar flexors and contribute to sharing the forces required by triceps surae to produce plantar flexion. The exercise demonstrated in Video 2 depicts an elastic band inducing ankle inversion, that is counterbalanced by the action of fibularis muscles.



Source: Video provided by 3DGym.app S.A.

Video 1. Diagonal Propulsion. Scan the QR code in the figure to view the video (<https://youtu.be/iX9nPvGaCE4>). Video courtesy of 3D Gym App.



Source: Video provided by 3DGym.app S.A.

Video 2. Diagonal Propulsion with Fibularis Stimulation. Scan the QR code in the figure to view the video (<https://youtu.be/QtCGTSaHrcA>). Video courtesy of 3D Gym App.

Decreased maximum ankle dorsiflexion and maximum knee flexion during gait and running

Peak ankle dorsiflexion and peak knee flexion are usually achieved during the loading response phase.⁷⁰ In this exercise (Video 3), the individual is positioned in this phase of gait to increase the specificity of the task. Resistance is applied to the popliteus fossa and induces a concomitant hip flexion, knee flexion, and ankle dorsiflexion. The objective is to gradually prepare the individual to reach higher ankle dorsiflexion and knee flexion, training the individual to resist hip and knee flexion and ankle dorsiflexion forces in this phase of



Source: Video provided by 3DGym.app S.A.

Video 3. Load Response Phase Training. Scan the QR code in the figure to view the video (https://youtu.be/_IN5Airyco). Video courtesy of 3D Gym App.

the gait. The exercise progression is made with gradual increases in applied load, speed, and number of repetitions and series as tolerated by the patient.

Increased rearfoot eversion

Peak rearfoot eversion usually occurs after heel strike, during loading response, and sometimes later in midstance.²⁷ This exercise (Video 4) aims to induce an external eversion torque using an elastic band in the ankle. The expected effect is the development of a specific neuromuscular capacity to resist the external eversion stimulus in the midstance phase. The progression is made with gradual increases, as in the previous exercise.



Source: Video provided by 3DGym.app S.A.

Video 4. Single Leg Squat with Eversion Control with Elastic Band. Scan the QR code in the figure to view the video (<https://youtu.be/1HxihUiL3x8>). Video courtesy of 3D Gym App.

Excessive rear foot eversion may also be counterbalanced by increasing foot stability. The exercise in Video 5 demonstrates an elastic band under the hallux. The objective of the exercise is to induce hallux flexor contraction by preventing the band from slipping. The muscle action generates increased foot rigidity by increasing muscle stiffness and also by depressing the first metatarsus head, which increases the tension of the medial longitudinal arch.^{71,72}

Altered gluteus complex activation

To address proximal deficiencies as demonstrated by Smith et al., who reported delayed onset and shorter duration of gluteus medius and maximus activation in runners with AT,⁴⁵ it is possible to add an elastic band in the pelvis to induce a contralateral pelvic drop and promote the activation of the gluteus complex (Video 6). This exercise promotes the development of neuromuscular control



Source: Video provided by 3DGym.app S.A.

Video 5. Single Leg Balance with Hallux Flexion. Scan the QR code in the figure to view the video (<https://youtu.be/noUQ6dPGiXg>). Video courtesy of 3D Gym App.



Source: Video provided by 3DGym.app S.A.

Video 7. Posterior displacement of the tibia during the terminal stance phase. Scan the QR code in the figure to view the video (<https://youtu.be/zzH6u-oogx8>). Video courtesy of 3D Gym App.



Source: Video provided by 3DGym.app S.A.

Video 6. Single Leg Squat with Rearfoot Eversion Control and Contralateral Pelvic Drop Control. Scan the QR code in the figure to view the video (<https://youtu.be/sM2eFq-oMec>). Video courtesy of 3D Gym App.

and strengthening of the hip in synergy with the distal part of the kinetic chain, while in a position that resembles the midstance phase of gait, adding specificity to the rehabilitation.

Less anterior displacement of the center of pressure (COP) at push-off

Less anterior displacement of COP was interpreted by the authors to occur concomitantly to decreased knee flexion at push-off.¹⁷ In this exercise (Video 7), the patient is positioned in the terminal stance phase and a force is applied inferiorly and anteriorly in the proximal region of the tibia to cause knee flexion. The objective

of the exercise is to develop the capacity to generate full knee extension during this specific phase of the gait cycle. Progression involves gradual increases, as in the previous exercise.

CONCLUSION

AT remains a prevalent and challenging condition, particularly among athletes and those involved in regular physical activities. Despite the strength and resilience of the Achilles tendon, it is highly susceptible to injury and tendinopathy due to various intrinsic and extrinsic factors. The multifactorial etiology of AT, including biomechanical risk factors like altered kinematic and kinetic parameters, highlights the complexity of effectively treating this condition. While current rehabilitation protocols, such as the widely used Alfredson protocol, focus primarily on progressive strengthening, they often overlook critical biomechanical issues contributing to the persistence and onset of AT symptoms. Comprehensive treatment strategies should incorporate targeted exercises that address specific biomechanical deficiencies, such as reduced dorsiflexion, peak knee flexion, and excessive rearfoot eversion, to enhance recovery and prevent recurrence. Integrating these biomechanical considerations into rehabilitation protocols enables clinicians to provide more effective and individualized care for patients suffering from AT, ultimately improving outcomes and quality of life.

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EFFECTS OF CALCIUM SUPPLEMENTATION ON THE RISK OF FRACTURE IN OLDER ADULTS

EFEITOS DA SUPLEMENTAÇÃO DE CÁLCIO NO RISCO DE FRATURA EM ADULTOS IDOSOS

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ABSTRACT

To explore the effect of calcium supplementation on the risk of fractures at various sites in older adults based on randomized controlled trials (RCTs). PubMed, Embase, and the Cochrane Library were systematically searched for eligible RCTs from their inception until May 2023. The included trials investigated the effect of calcium supplementation on the risk of fracture in individuals aged 50 years or above, regardless of the use or nonuse of vitamin D. The primary and secondary outcome measures were total, vertebral, nonvertebral, and hip fractures. Twenty-three RCTs involving 70,837 individuals were enrolled. Calcium supplementation demonstrated a significant reduction in the risk of total (RR: 0.93; 95% CI: 0.88–0.99; $P=0.019$) and nonvertebral (RR: 0.93; 95% CI: 0.87–0.99; $P=0.023$) fractures. No significant differences were observed in vertebral (RR: 0.87; 95% CI: 0.75–1.01; $P=0.074$) and hip (RR: 0.90; 95% CI: 0.73–1.12; $P=0.355$) fractures between calcium and placebo or no treatment. Calcium dose influenced total fracture risk ($P=0.008$), while history of fracture ($P=0.044$), calcium dose ($P=0.041$), and follow-up duration ($P=0.031$) affected nonvertebral fracture risk. Follow-up duration impacted hip fracture risk ($P=0.001$). Calcium supplementation can significantly affect the risk of fracture, particularly nonvertebral fractures, in older adults. **Level of Evidence I; Therapeutic Studies - Investigating the Results of Treatment.**

Keywords: Calcium; Fracture; Older Adults; Meta-Analysis.

RESUMO

Explorar o efeito da suplementação de cálcio no risco de fraturas em vários locais em adultos mais velhos com base em ensaios clínicos randomizados (ECRs). A PubMed, Embase e a Biblioteca Cochrane foram sistematicamente pesquisadas para ensaios clínicos randomizados (ECRs) elegíveis desde a sua criação até maio de 2023. Os ensaios incluídos investigaram o efeito da suplementação de cálcio no risco de fraturas em indivíduos com 50 anos ou mais, independentemente do uso ou não de vitamina D. As medidas de desfecho primárias e secundárias foram fraturas totais, vertebrais, não vertebrais e do quadril. Vinte e três ECRs envolvendo 70.837 indivíduos foram incluídos. A suplementação de cálcio demonstrou uma redução significativa no risco de fraturas totais (RR: 0,93; IC 95%: 0,88–0,99; $P=0,019$) e não vertebrais (RR: 0,93; IC 95%: 0,87–0,99; $P=0,023$). Não foram observadas diferenças significativas nas fraturas vertebrais (RR: 0,87; IC 95%: 0,75–1,01; $P=0,074$) e do quadril (RR: 0,90; IC 95%: 0,73–1,12; $P=0,355$) entre cálcio e placebo ou nenhum tratamento. A dose de cálcio influenciou o risco de fratura total ($P=0,008$), enquanto a história de fratura ($P=0,044$), dose de cálcio ($P=0,041$) e duração do acompanhamento ($P=0,031$) afetaram o risco de fratura não vertebral. A duração do acompanhamento impactou o risco de fratura do quadril ($P=0,001$). A suplementação de cálcio pode afetar significativamente o risco de fratura, particularmente as fraturas não vertebrais, em adultos mais velhos. **Nível de Evidência I; Estudos terapêuticos - Investigação dos resultados do tratamento.**

Descritores: Cálcio; Fratura; Idoso Fragilizado; Metanálise.

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INTRODUCTION

The prevalence of osteoporotic fracture has rapidly increased with the growth of population worldwide.¹ The number of patients with osteoporosis in the European Union was estimated to be 27.5 million, whereas that of patients aged over 50 years in the USA reached 10.2 million.^{2,3} In the Asia-Pacific region, 5%–10% of adults have osteoporosis, with women aged ≥ 50 years exhibiting a higher prevalence.⁴ In Western countries, the lifetime risks of osteoporotic

fracture in both men and women were 13%–22% and 40%–50%, respectively.⁵ Older adults with fractures experience significant harmful effects on their daily routines; even disability or mortality occurs in serious cases.^{6,7} Furthermore, fracture treatment is costly with the demographic trend of aging and the predicted increase in life expectancy.⁸ At present, calcium and vitamin D supplementation is widely recommended to reduce the risk of osteoporosis and progression of

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fractures. However, calcium supplementation may affect the risk of fracture; there is also a growing interest in the assessment of the role of vitamin D in bone health.⁹ In this study, we conducted a meta-analysis of randomized controlled trials (RCTs) to examine the effect of calcium supplementation on the risk of fracture and explored the potential role of the interaction between calcium and vitamin D in reducing the risk of fractures, including total, vertebral, nonvertebral, and hip fractures.

MATERIALS AND METHODS

Data sources, search strategy, and selection criteria

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses was used in this study.¹⁰ Trials that compared the effects of calcium with those of placebo or no treatment on the risk of fractures in older adults were considered eligible, and no restriction on the publication status and languages was imposed. We systematically searched PubMed, Embase, and the Cochrane Library for eligible trials from their inception until May 2023, and the following terms were used: “calcium” [MeSH Terms] OR “calcium” [All Fields] AND (“fractures, bone” [MeSH Terms] OR (“fractures” [All Fields] AND “bone” [All Fields]) OR “bone fractures” [All Fields] OR “fracture” [All Fields]). Ongoing trials or additional eligible trials were also included if they met the abstract requirements, reference lists of relevant articles, and the clinicaltrials.gov website.

To avoid confounding biases, only RCTs were included. The inclusion criteria were as follows: (1) study design: RCT; (2) participants: individuals aged 50 years or above; (3) intervention: calcium supplementation, irrespective of vitamin D use; (4) control: placebo or no treatment; (5) follow-up: follow-up duration of more than 6 months; and (6) outcomes: total, vertebral, nonvertebral, and hip fractures.

Data collection and quality assessment

The author independently extracted the following data: first author's name, publication year, country, sample size, age, male sex (%), history of fracture, vitamin D use, baseline 25 OHD, intervention, control, follow-up, and reported outcomes. Then, the quality of each trial was assessed using the Jadad scale based on the randomization used, data blinding, allocation concealment, withdrawals and dropouts of subjects, and use of intention-to-treat analysis.¹¹ For each trial, the scoring system ranged from 0 to 5, and trials that scored 4 or 5 were considered to be of high quality. Any disagreement between the reviewers regarding data collection and quality assessment was settled by consulting an additional reviewer.

Statistical analysis

The effects of calcium supplementation on the risk of fracture were used as categorical data, and the relative risk (RR) with 95% confidence interval (CI) was calculated before data pooling based on the events that occurred and the sample size of the intervention and control groups. The pooled RRs and 95% CIs for fracture risk were evaluated using the random-effects model, which considers the underlying variability across the included trials and provides conservative results.^{12, 13} Furthermore, heterogeneity across the included trials for each outcome was evaluated using the I^2 and Q statistics, and significant heterogeneity was defined as $I^2 > 50.0\%$ or $P < 0.10$.^{14, 15} Sensitivity analyses were conducted to assess the robustness of the pooled conclusions by sequentially removing individual trials.¹⁶ Subgroup analyses were also conducted based on the mean age, sex, history of fracture, baseline 25 OHD, calcium dose, vitamin D supplementation, follow-up duration, and study quality, and differences between the groups were evaluated using an interaction test, which was based on a *t*-test, and assuming a normal data distribution.¹⁷ Publication bias for each outcome was evaluated using qualitative (funnel plot) and quantitative

(Egger's and Begg's tests) methods.^{18, 19} The inspection level for the pooled outcome was two-sided, and $P < 0.05$ was considered to indicate statistical significance. All statistical analyses were conducted using the STATA software (version 10.0, Stata Corporation, College Station, TX, USA).

RESULTS

Literature search

A total of 1,946 articles were obtained from the electronic search, of which 1,138 were retained after removing duplicate articles. Additional 1,069 studies were excluded due to irrelevant topics. Further full-text review was performed on the remaining 69 studies, which resulted in the removal of 47 articles due to missing sufficient data ($n = 30$), lack of appropriate control subjects ($n = 10$), and review papers ($n = 7$). No new eligible trials were obtained from the review of the reference lists of relevant studies. Ultimately, 22 RCTs were included in the final meta-analysis (Figure 1).²⁰⁻⁴¹

Study characteristics

The characteristics of the selected trials and individuals are presented in Table 1. The number of individuals included was 70,837, and the sample size ranged from 50 to 36,282. Two trials were conducted in China and the remaining 21 in Western countries (the USA, Europe, and Australia). Of the trials, 15 included women and the remaining 8 included both men and women. Furthermore, 14 trials reported the effects of combined calcium and vitamin D supplementation, and the remaining 9 trials reported calcium supplementation alone. The follow-up duration ranged from 9 months to 7 years. The quality assessments in each trial are presented in Table 1.

Total fracture

A total of 15 trials reported the effects of calcium supplementation on the risk of total fracture. The result indicated that the supplementation was associated with reduced risk of total fracture (RR: 0.93; 95% CI: 0.88–0.99; $P = 0.019$; Figure 2A), and there was no evidence of heterogeneity across the included trials ($I^2 = 6.3\%$;

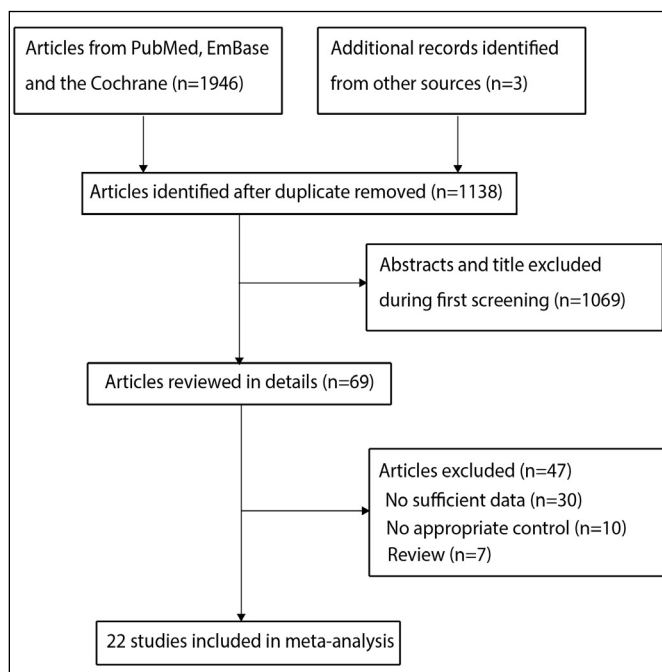


Figure 1. PRISMA flowchart of the processes of literature search and study selection.

Table 1. The characteristics of included trials and involved participants.

Study	Country	Sample size	Age (years)	Male (%)	Prior fracture	Vitamin D	Baseline 25 OHD	Intervention	Control	Follow-up	Jadad
Inkovaar ²⁰	Finland	130 (88/42)	79.8	17.9/18.7	NA	(1000 IU/d)	NA	Calcium (1.2 g/d)	Placebo	9.0 months	3
Hansson ²¹	Sweden	50 (25/25)	65.9	0.0	Yes	No	NA	Calcium (1.0 g/d)	Placebo	3.0 years	2
Chapuy ²²	France	3,270 (1,634/1,636)	84.0	0.0	No	(800 IU/d)	NA	Calcium (1.2 g/d)	Placebo	1.5 years	4
Reid ²³	New Zealand	122 (61/61)	58.0	0.0	No	No	37.5	Calcium (1.0 g/d)	Placebo	4.0 years	4
Recker ²⁴	USA	191 (91/100)	73.5	0.0	Partial	No	25.5	Calcium (1.2 g/d)	Placebo	4.0 years	3
Dawson-Hughes ²⁵	USA	389 (187/202)	71.1	46.0	NA	(700 IU/d)	29.6	Calcium (0.5 g/d)	Placebo	3.0 years	4
Riggs ²⁶	USA	236 (119/117)	66.2	0.0	No	No	30.1	Calcium (1.6 g/d)	Placebo	4.0 years	2
Baron ²⁷	USA	930 (464/466)	61.0	72.3	NA	No	NA	Calcium (1.2 g/d)	Placebo	4.0 years	5
Peacock ²⁸	USA	253 (124/129)	73.8	28.4	Partial	No	25.0	Calcium (0.75 g/d)	Placebo	4.0 years	2
Chapuy ²⁹	France	583 (393/190)	85.2	0.0	No	(800 IU/d)	8.9	Calcium (1.2 g/d)	Placebo	2.0 years	4
Avenell ³⁰	UK	99 (64/35)	78.0	17.0	Yes	(800 IU/d)	NA	Calcium (1.0 g/d)	No treatment	3.8 years	3
Harwood ³¹	UK	112 (75/37)	81.7	0.0	Yes	(800 IU/d)	11.9	Calcium (1.0 g/d)	No treatment	1.0 year	3
Porthouse ³²	UK	3,314 (1,321/1,993)	76.8	0.0	Partial	(800 IU/d)	NA	Calcium (1.0 g/d)	No treatment	2.1 years	3
Grant ³³	UK	3,949 (2,617/1,332)	77.3	15.3	Yes	(800 IU/d)	15.2	Calcium (1.0 g/d)	Placebo	2.0-5.2 years	5
Larsen ³⁴	Denmark	7,073 (4,957/2,116)	74.0	39.8	No	(400 IU/d)	NA	Calcium (1.0 g/d)	No treatment	3.0 years	3
Jackson ³⁵	USA	36,282 (18,176/18,106)	62.4	0.0	Partial	(400 IU/d)	18.9	Calcium (1.0 g/d)	Placebo	7.0 years	4
Prince ³⁶	Australia	1,460 (730/730)	75.2	0.0	Partial	No	31.0	Calcium (0.48 g/d)	Placebo	5.0 years	4
Reid ³⁷	New Zealand	1,471 (732/739)	74.3	0.0	Partial	No	20.7	Calcium (1.0 g/d)	Placebo	5.0 years	3
Bolton-Smith ³⁸	UK	123 (62/61)	68.6	0.0	NA	(400 IU/d)	23.9	Calcium (1.0 g/d)	Placebo	2.0 years	3
Salovaara ³⁹	Finland	3,195 (1,586/1,609)	67.3	0.0	Partial	(800 IU/d)	19.8	Calcium (1.0 g/d)	Placebo	3.0 years	3
Liu ⁴⁰	China	98 (50/48)	62.1	0.0	No	(600 IU/d)	NA	Calcium (1.5 g/d)	Placebo	1.0 year	2
Xue ⁴¹	China	312 (139/173)	63.6	0.0	Partial	(800 IU/d)	30.8	Calcium (0.6 g/d)	Placebo	1.0 year	3

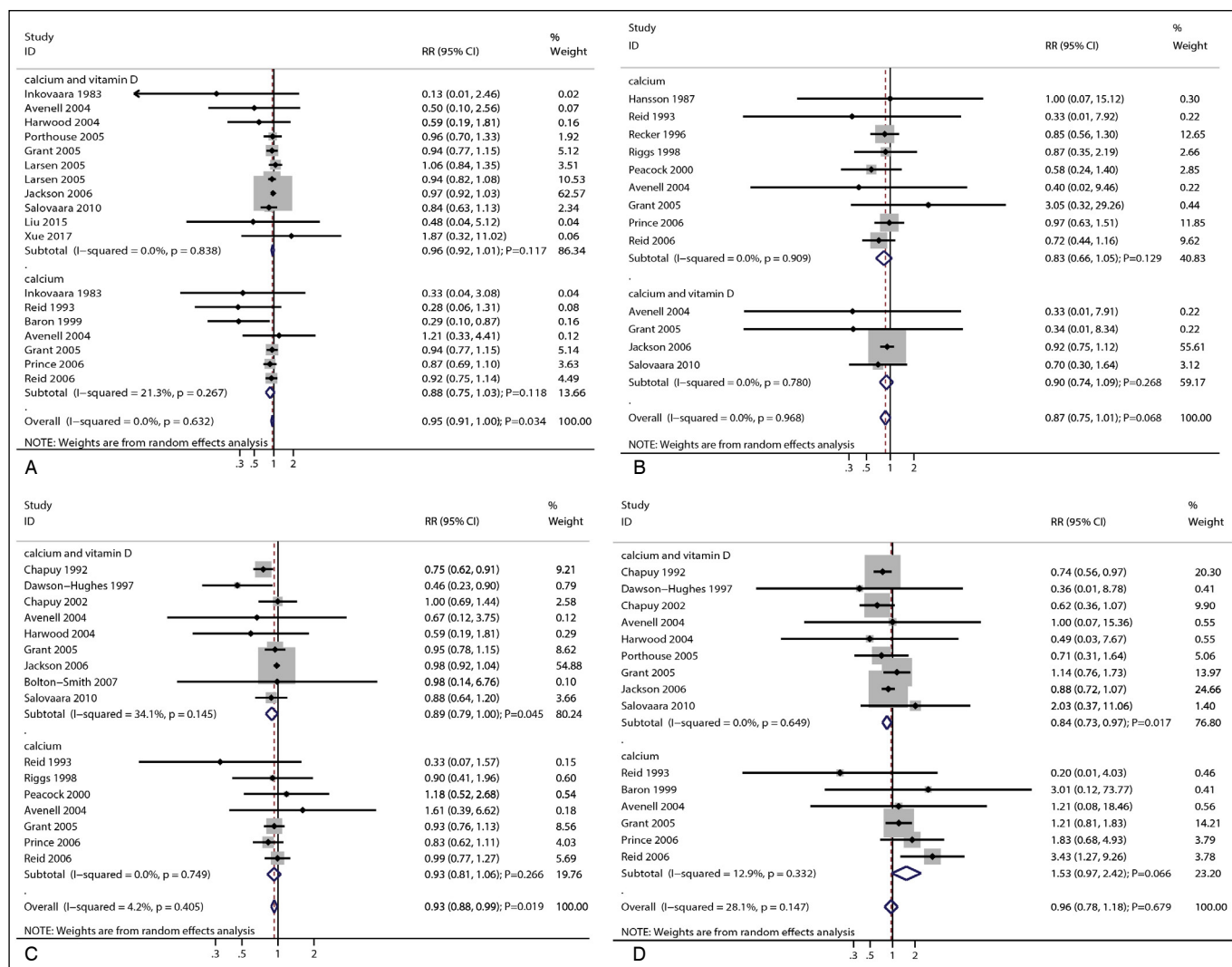


Figure 2. Effect of calcium supplementation on the risk of (A) total fracture, (B) vertebral fracture, (C) nonvertebral fracture, and (D) hip fracture.

$P = 0.380$). Sensitivity analysis revealed that the pooled conclusion was unaltered by the sequential removal of individual trials (Figure 3). On the other hand, subgroup analysis revealed that combined calcium supplementation was associated with reduced risk of total fracture when the mean age of individuals ≥ 70.0 years, history of fracture, irrespective of the calcium dose, did not combine with vitamin D, and irrespective of follow-up duration (Table 2). It was also observed that the reduced risk of total fracture in the subgroup of calcium dose ≥ 1.2 g was greater than that in the subgroup of calcium dose < 1.2 g (RR: 0.31; 95% CI: 0.13–0.73; $P = 0.008$). A potential publication bias was found for total fracture (P -value for Egger's test: 0.004; P -value for Begg's test: 0.074), and the pooled conclusion was unaltered when adjusted using the trim-and-fill method (Figure 4).

Vertebral fracture

A total of 11 trials reported the effects of calcium supplementation on the risk of vertebral fracture. It was found that the supplementation did not exert a significant effect on the risk of vertebral fracture (RR: 0.87; 95% CI: 0.75–1.01; $P = 0.074$; Figure 2B), and there was no evidence of heterogeneity among the included trials ($I^2 = 0.0\%$; $P = 0.970$). The pooled conclusion was solid and unaltered by the sequential removal of individual studies (Figure 3). Subgroup analysis revealed that calcium supplementation was associated with reduced risk of vertebral fracture in pooled trials with moderate quality (Table 2). In addition, no significant publication bias was observed for vertebral fracture (P -value for Egger's test: 0.143; P -value for Begg's test: 0.300; Figure 4).

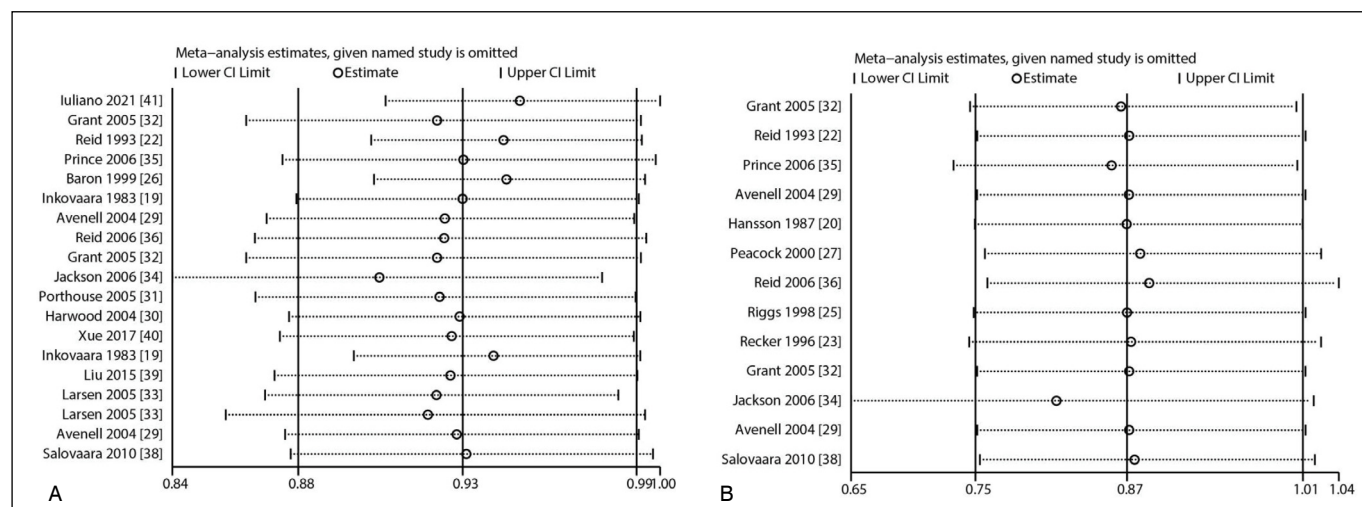


Figure 3. (A) Sensitivity analysis for the risk of total fracture. (B) Sensitivity analysis for the risk of vertebral fracture.

Table 2. Subgroup analyses for fracture at varies sites.

Outcomes	Factors	Subgroup	RR and 95%CI	P value	I ² (%)	P value for I ²	RRR between subgroups	P value between subgroups
Total fracture	Mean age	≥ 70.0	0.92 (0.86-0.99)	0.031	0.0	0.662	1.11 (0.83-1.49)	0.494
		< 70.0	0.83 (0.62-1.10)	0.198	44.1	0.111		
	Sex	Female	0.96 (0.91-1.01)	0.081	0.0	0.673	1.07 (0.93-1.22)	0.359
		Both	0.90 (0.79-1.02)	0.112	30.6	0.164		
	Prior fracture	Yes	0.95 (0.90-0.99)	0.027	0.0	0.703	1.08 (0.81-1.44)	0.600
		No	0.88 (0.66-1.16)	0.357	51.1	0.085		
	Baseline 25 OHD	≥ 20.0	0.89 (0.76-1.04)	0.146	0.0	0.396	0.93 (0.79-1.09)	0.369
		< 20.0	0.96 (0.91-1.01)	0.127	0.0	0.785		
	Dose of calcium	≥ 1.2	0.29 (0.12-0.69)	0.005	0.0	0.918	0.31 (0.13-0.73)	0.008
		< 1.2	0.95 (0.91-0.99)	0.022	0.0	0.656		
	Combined with vitamin D	Yes	0.96 (0.92-1.01)	0.117	0.0	0.820	1.16 (0.98-1.37)	0.089
		No	0.83 (0.71-0.98)	0.030	31.9	0.173		
Vertebral fracture	Follow-up duration	≥ 3.0	0.95 (0.91-1.00)	0.041	0.0	0.491	1.20 (0.96-1.51)	0.110
		< 3.0	0.79 (0.63-0.98)	0.034	0.0	0.426		
	Study quality	High	0.88 (0.78-1.00)	0.058	51.6	0.053	0.94 (0.80-1.10)	0.410
		Low	0.94 (0.85-1.03)	0.171	0.0	0.820		
	Mean age	≥ 70.0	0.83 (0.65-1.05)	0.121	0.0	0.833	0.92 (0.68-1.25)	0.602
		< 70.0	0.90 (0.75-1.09)	0.291	0.0	0.946		
	Sex	Female	0.88 (0.76-1.03)	0.112	0.0	0.975	1.35 (0.62-2.94)	0.443
		Both	0.65 (0.30-1.37)	0.254	0.0	0.688		
	Prior fracture	Yes	0.87 (0.75-1.02)	0.083	0.0	0.935	1.07 (0.4-2.62)	0.875
		No	0.81 (0.34-1.97)	0.646	0.0	0.583		
	Baseline 25 OHD	≥ 20.0	0.82 (0.65-1.04)	0.109	0.0	0.881	0.90 (0.66-1.22)	0.505
		< 20.0	0.91 (0.75-1.11)	0.352	0.0	0.613		
	Dose of calcium	≥ 1.2	0.85 (0.58-1.25)	0.417	0.0	0.964	0.97 (0.64-1.47)	0.871
		< 1.2	0.88 (0.74-1.03)	0.111	0.0	0.918		
	Combined with vitamin D	Yes	0.90 (0.74-1.09)	0.292	0.0	0.789	1.08 (0.80-1.47)	0.600
		No	0.83 (0.66-1.05)	0.127	0.0	0.916		
	Follow-up duration	≥ 3.0	0.87 (0.75-1.01)	0.074	0.0	0.970	-	-
		< 3.0	-	-	-	-		
	Study quality	High	0.93 (0.78-1.11)	0.433	0.0	0.768	1.22 (0.89-1.69)	0.217
		Low	0.76 (0.58-0.99)	0.043	0.0	0.990		

Outcomes	Factors	Subgroup	RR and 95%CI	P value	I ² (%)	P value for I ²	RRR between subgroups	P value between subgroups
Non-vertebral fracture	Mean age	≥ 70.0	0.88 (0.80-0.97)	0.009	2.7	0.417	0.91 (0.81-1.01)	0.087
		< 70.0	0.97 (0.92-1.03)	0.391	0.0	0.674		
	Sex	Female	0.91 (0.84-1.00)	0.046	14.5	0.309	0.99 (0.84-1.17)	0.897
		Both	0.92 (0.80-1.06)	0.253	3.2	0.396		
	Prior fracture	Yes	0.97 (0.92-1.02)	0.203	0.0	0.944	1.21 (1.01-1.46)	0.044
		No	0.80 (0.67-0.96)	0.018	5.4	0.366		
	Baseline 25 OHD	≥ 20.0	0.87 (0.71-1.05)	0.147	7.9	0.368	0.90 (0.73-1.10)	0.292
		< 20.0	0.97 (0.92-1.02)	0.271	0.0	0.917		
	Dose of calcium	≥ 1.2	0.80 (0.68-0.95)	0.009	0.0	0.380	0.83 (0.70-0.99)	0.041
		< 1.2	0.96 (0.91-1.01)	0.137	0.0	0.636		
Hip fracture	Combined with vitamin D	Yes	0.89 (0.79-1.00)	0.052	35.0	0.138	0.96 (0.80-1.14)	0.630
		No	0.93 (0.81-1.06)	0.260	0.0	0.752		
	Follow-up duration	≥ 3.0	0.96 (0.91-1.01)	0.144	0.0	0.614	1.22 (1.02-1.45)	0.031
		< 3.0	0.79 (0.67-0.94)	0.007	0.0	0.540		
	Study quality	High	0.89 (0.79-0.99)	0.040	49.4	0.054	0.94 (0.76-1.16)	0.546
		Low	0.95 (0.79-1.13)	0.551	0.0	0.960		
	Mean age	≥ 70.0	0.92 (0.69-1.22)	0.559	49.7	0.025	1.03 (0.73-1.46)	0.851
		< 70.0	0.89 (0.73-1.08)	0.236	0.0	0.490		
	Sex	Female	0.90 (0.68-1.20)	0.481	44.8	0.070	0.98 (0.61-1.57)	0.928
		Both	0.92 (0.63-1.35)	0.682	36.8	0.148		
Hip fracture	Prior fracture	Yes	1.02 (0.77-1.35)	0.886	46.8	0.043	1.44 (0.99-2.08)	0.056
		No	0.71 (0.56-0.91)	0.007	0.0	0.618		
	Baseline 25 OHD	≥ 20.0	1.76 (0.69-4.48)	0.237	31.9	0.221	1.85 (0.71-4.82)	0.206
		< 20.0	0.95 (0.78-1.16)	0.612	16.4	0.308		
	Dose of calcium	≥ 1.2	0.72 (0.56-0.92)	0.008	0.0	0.580	0.72 (0.50-1.04)	0.081
		< 1.2	1.00 (0.76-1.31)	0.984	40.4	0.065		
	Combined with vitamin D	Yes	0.84 (0.73-0.97)	0.018	0.0	0.655	0.69 (0.36-1.33)	0.270
		No	1.21 (0.64-2.27)	0.554	65.8	0.007		
	Follow-up duration	≥ 3.0	1.14 (0.89-1.47)	0.306	21.4	0.239	1.70 (1.23-2.36)	0.001
		< 3.0	0.67 (0.54-0.82)	< 0.001	0.0	0.808		
	Study quality	High	0.85 (0.69-1.05)	0.139	42.0	0.078	0.62 (0.30-1.30)	0.204
		Low	1.37 (0.68-2.79)	0.381	22.6	0.264		

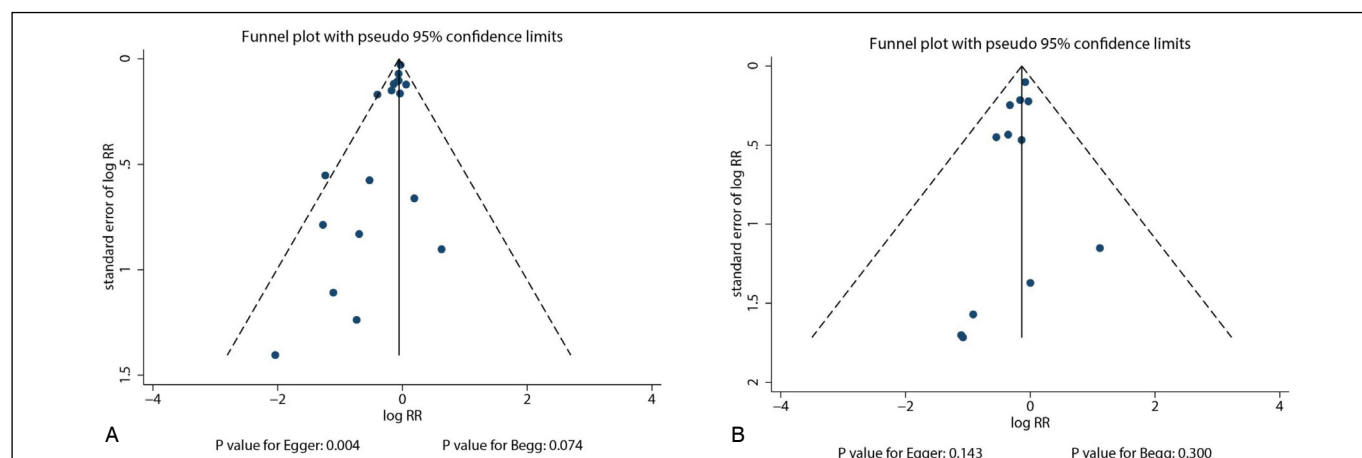


Figure 4. (A) Funnel plot for total fracture. (B) Funnel plot for vertebral fracture.

Nonvertebral fracture

A total of 14 trials reported the effects of calcium supplementation on the risk of nonvertebral fracture. It was observed that the supplementation significantly reduced the risk of nonvertebral fracture (RR: 0.93; 95% CI: 0.87–0.99; $P = 0.023$; Figure 2C). No significant heterogeneity was found for nonvertebral fracture across the included trials ($I^2 = 5.3\%$; $P = 0.393$). The pooled conclusion was variable due to the marginal 95% CI (Figure 3). Subgroup analysis revealed that calcium supplementation was associated with reduced risk of nonvertebral fracture for individuals with a mean age of ≥ 70.0 years, female sex, no history of fracture, calcium dose ≥ 1.2 g, follow-up duration < 3.0 years, and studies with high quality (Table 2). Furthermore, the effects of calcium supplementation on the risk of nonvertebral fracture could be affected by a history of fracture (RR: 1.21; 95% CI: 1.01–1.46; $P = 0.044$), calcium dose

(RR: 0.83; 95% CI: 0.70–0.99; $P = 0.041$), and follow-up duration (RR: 1.22; 95% CI: 1.02–1.45; $P = 0.031$). No significant publication bias for nonvertebral fracture was observed (P -value for Egger's test: 0.081; P -value for Begg's test: 0.964; Figure 4).

Hip fracture

A total of 14 trials reported the effects of calcium supplementation on the risk of hip fracture. The result indicated that the supplementation was not associated with the risk of hip fracture (RR: 0.90; 95% CI: 0.73–1.12; $P = 0.355$; Figure 2D), and significant heterogeneity was observed across the included trials ($I^2 = 38.4\%$; $P = 0.059$). Sensitivity analysis revealed that the pooled conclusion was unaltered by the exclusion of any particular trial (Figure 3). Subgroup analysis revealed that calcium could protect against the risk of hip fracture for patients with no history of fracture, calcium dose ≥ 1.2 g, vitamin D supplementation, and follow-up duration

< 3.0 years (Table 2). No significant publication bias was observed for hip fracture (*P*-value for Egger's test: 0.521; *P*-value for Begg's test: 0.893; Figure 4).

DISCUSSION

In this study, 23 RCTs were analyzed to determine the effect of calcium supplementation on the risk of total, vertebral, nonvertebral, and hip fractures. The results indicated that calcium supplementation can significantly reduce the risk of total and nonvertebral fractures whereas it does not have an effect on the risk of vertebral and hip fractures. The effect of calcium supplementation on the risk of total fracture could be affected by the calcium dose whereas that on the risk of nonvertebral fracture could be affected by a history of fracture, calcium dose, and follow-up duration. On the other hand, the effect of calcium supplementation on the risk of hip fracture could be affected by follow-up duration.

Several systematic reviews and meta-analyses have demonstrated the effect of calcium supplementation on the risk of fracture. Weaver et al. conducted a meta-analysis of eight studies and reported that combined calcium and vitamin D supplementation was associated with reduced risk of total and hip fractures. They suggested that calcium and vitamin D supplementation be given to both community-dwelling and institutionalized middle-aged to older adults.⁴² However, they did not investigate the effects of calcium supplementation alone and those of combined calcium and vitamin D supplementation on the risk of fracture in a specific subpopulation. Zhao et al. conducted a meta-analysis of 33 RCTs to determine the effect of calcium or vitamin D supplementation on the risk of fracture in community-dwelling older adults. They reported that calcium, vitamin D, or the combined use of both did not affect the risk of fracture among these individuals.⁴³ This nonsignificant effect of calcium supplementation alone or the combined calcium and vitamin D supplementation might vary according to the pooled analysis. Therefore, the present meta-analysis was conducted to determine the effect of calcium supplementation on the risk of fracture in older adults.

As reported in previous meta-analyses, calcium supplementation could exert a protective effect against the risk of total fracture. Majority of the included trials did not observe a significant difference between calcium and placebo in the effect on the risk of total fracture, whereas a trial conducted by Baron et al. found that calcium supplementation was associated with reduced risk of total fracture.²⁷ This trial used recurrent colorectal adenomas as the primary endpoint, and this significant effect may have occurred incidentally. Subgroup analysis revealed that calcium supplementation could

exert a protective effect against the risk of total fracture in individuals with a mean age of ≥ 70.0 years, history of fracture, irrespective of calcium dose, did not combine with vitamin D, and irrespective of follow-up duration. Consistent with a previous meta-analysis,⁴² this study found that calcium supplementation had no significant effect on the risk of vertebral fractures, regardless of the use or nonuse of vitamin D. All the trials pooled for this study had similar conclusions; in addition, the number of events that occurred was lower than expected, and broad 95% CI values were obtained.

The results of this study suggest that calcium supplementation significantly reduces the risk of nonvertebral fractures, particularly when used in combination with vitamin D. This is probably because vitamin D promotes calcium absorption in the gut whereas serum calcium maintains normal bone mineralization.⁴² Furthermore, the benefits of calcium supplementation were mainly detected in the subgroups of individuals with a mean age of ≥ 70.0 years, female sex, no history of fracture, calcium dose ≥ 1.2 g, follow-up duration < 3.0 years, and studies with high quality. These results suggested that the beneficial effects of calcium supplementation on the risk of nonvertebral fracture were more evident in individuals with the aforementioned characteristics. Contrary to the previous meta-analysis, the present study did not find evidence to support that calcium supplementation can reduce the risk of hip fractures. This discrepancy could be attributed mainly to the fact that the studies included in the previous meta-analysis used combined calcium and vitamin D supplementation.⁴² Subgroup analysis demonstrated the beneficial effect of calcium supplementation on the risk of hip fracture mainly in individuals with no history of fracture, calcium dose ≥ 1.2 g, combined use of vitamin D, and follow-up duration < 3.0 years. The reason for this could be that these characteristics were associated with a greater requirement for calcium, which could slow the progression of hip fracture.

This study has the following limitations that need to be acknowledged: (1) the inclusion of different population characteristics can lead to variations in the intake of calcium or vitamin D through food, which can influence the occurrence of fractures; (2) most trials did not define fracture as a primary endpoint, and the power was not sufficient to detect the difference between calcium and placebo; and (3) there were inherent limitations for meta-analysis based on published articles, including inevitable publication bias and restricted detailed analyses.

In conclusion, this study demonstrates that calcium supplementation exerts a protective effect against the risk of total and nonvertebral fractures. However, the long-term effects of calcium on the risk of fracture require further investigation, and the dose-response for background vitamin D use should be identified in older adults.

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HAS THE AHLBÄCK CLASSIFICATION BEEN ACCURATELY DESCRIBED AND CITED?

A CLASSIFICAÇÃO DE AHLBÄCK TEM SIDO DESCRITA E CITADA CORRETAMENTE?

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ABSTRACT

The classification of knee osteoarthritis allows assessment of disease severity and may be useful in guiding treatment decisions. One of the most widely used systems for this purpose is the Ahlbäck classification. This study aimed to compare the original description of the Ahlbäck classification with how it has been reported and cited by other authors in subsequent publications. We conducted a search in the PubMed, Embase, and Cochrane databases for articles containing exclusively the terms “knee”, “osteoarthritis”, “osteoarthrosis”, and “Ahlbäck classification”. After applying the inclusion and exclusion criteria, 64 articles remained. These articles were analyzed in two aspects: the description of the Ahlbäck classification (categorized as correct, partially correct, or incorrect) and the accuracy of the reference citation (correctly or incorrectly cited). Only 10 articles (15.6%) correctly described the Ahlbäck classification and cited the original source properly. In contrast, 37 publications (58.4%) contained errors both in the description of the classification and the citation. Conversely, 37 publications (58.4%) contained errors both in the description of the classification and in the bibliographic reference. The proportion of articles that accurately described and cited the Ahlbäck classification was markedly low, comprising only 15.6% of those included in this systematic review. **Level of Evidence III; Systematic Review.**

Keywords: Knee, Osteoarthritis, Ahlbäck Classification.

RESUMO

A classificação da gonartrose permite avaliar a gravidade da doença e pode ser útil na escolha do tratamento. Uma das classificações mais frequentemente usadas para esse propósito é a classificação de Ahlbäck. O objetivo deste estudo foi comparar a descrição original da classificação de Ahlbäck com o que outros autores escreveram sobre essa categorização e como a citaram, em artigos subsequentes. Realizamos uma pesquisa no PubMed, Embase e Cochrane por artigos contendo exclusivamente os conjuntos de palavras “joelho”, “osteoartrite”, “osteoartrose”, “classificação de Ahlbäck”. Após aplicarmos os critérios de exclusão e inclusão restaram 64 artigos. Esses artigos foram classificados em dois aspectos: quanto à descrição da classificação de Ahlbäck (correta, total ou parcial, e incorreta) e quanto às referências bibliográficas (citadas corretamente ou de forma equivocada). Apenas 10 artigos incluídos em nossa revisão sistemática (15,6%) descreveram corretamente a classificação de Ahlbäck e sua respectiva citação. Em contrapartida, 37 publicações (58,4%) apresentaram erros tanto na descrição da classificação quanto na referência bibliográfica. A porcentagem de artigos que descreveram corretamente tanto a escala de Ahlbäck quanto sua citação nas referências foi bastante reduzida, correspondendo a apenas 15,6% das publicações incluídas nesta revisão sistemática. **Nível de Evidência III; Revisão Sistemática.**

Descritores: Joelho; Osteoartrose; Classificação De Ahlbäck; Osteoartrite.

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INTRODUCTION

The classifications of knee osteoarthritis aim primarily to reflect cartilage loss and disease severity, as well as to assist orthopedic surgeons in treatment selection, particularly for patients requiring surgery, such as total knee arthroplasty.¹ In gonarthrosis, radiography is essential for assessing joint involvement and guiding

treatment. Due to the varied presentations of knee osteoarthritis, clinical and radiographic classification is fundamental for defining management strategies and analyzing therapeutic outcomes. In 1968, the Swedish radiologist Sven Olof Ahlbäck (1927–1995; Figure 1), from the Department of Radiology at St. Göran Hospital in Stockholm, published a monograph² emphasizing the importance

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Source: St. Göran Hospital, Stockholm, Sweden.

Figure 1. Portrait of Sven Olof Ahlbäck.

of weight-bearing anteroposterior knee radiographs to identify osteoarthritis in joints that appeared normal when assessed by other methods.

In this publication,² Ahlbäck described the presence of bone defects, possibly caused by friction between the articular surfaces, classifying them into three categories according to size: less than 5 mm, between 5 and 10 mm, and greater than 10 mm. He also mentioned that osteoarthritis could be classified based on the location of cartilage destruction: medial femorotibial, lateral femorotibial, and patellofemoral.

In 1980, Ahlbäck et al.³ described a radiographic classification of knee osteoarthritis based on the measurement of articular cartilage and subchondral bone destruction. This analysis included 359 radiographs of knees with medial osteoarthritis, surgically treated with total arthroplasty. The description of this grading system is presented in Table 1.

The “so-called Ahlbäck classification”¹⁴ was first cited in the scientific literature in 1987 by Lindberg et al.⁵ and continues to be used today. Although some authors have pointed out advantages in using this method,^{1,6,7} others have reported limitations such as low reliability⁸ or reproducibility⁴, as well as moderate interobserver reliability and moderate correlation with arthroscopic findings.⁹ Despite these limitations, the Ahlbäck classification is one of the most frequently cited in the literature^{8,10} and is commonly used to guide therapeutic decisions,^{4,11} including being recommended by the Knee Committee of the International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine (ISAKOS) for surgical indication of knee osteoarthritis.¹²

However, we identified publications that incorrectly described the Ahlbäck classifications and also cited their references inaccurately. Thus, our objective was to compare the classifications described in Ahlbäck’s monograph² and in the publication by Ahlbäck et al.³

Table 1. Ahlbäck & Rydberg Classification (based on articular cartilage and subchondral bone destruction).

Grade 1	Moderate cartilage destruction (joint space narrowing)
Grade 2	Complete cartilage destruction (joint space obliterated or nearly obliterated)
Grade 3	Minor bone attrition (<0.5 cm)
Grade 4	Moderate bone attrition (between 0.5 and 1.5 cm)
Grade 5	Severe bone attrition (>1.5 cm)

with those mentioned in the articles that used them in their bibliography. We also sought to analyze how these classifications were cited, aiming to guide future authors who intend to use and reference them appropriately. Our goal, however, was not to assess the effectiveness of this classification or to compare it with other scales that also serve to categorize knee osteoarthritis.

MATERIALS AND METHODS

This systematic review was conducted in accordance with the PRISMA 2020 statement guidelines.¹³ The search for articles that used the Ahlbäck classification³ was carried out by two independent authors (ISN and LAC) in the PubMed, Embase, and Cochrane databases, covering the period from 1987 — the date of the first publication that applied this grading — up to January 2, 2025. The following keywords were used: “knee,” “osteoarthritis,” “arthrosis,” “Ahlbäck classification.” For practical purposes, we considered both the Ahlbäck² and the Ahlbäck et al.³ classifications as belonging to the “Ahlbäck classification,” as generally described in the literature.⁴ The bibliographic search was manually filtered by the senior author (JCG) to identify eligible and ineligible articles. This selection was performed once and subsequently re-verified on two additional occasions.

Inclusion criteria were: full-text published articles; those in which the Ahlbäck classification was at least partially described in the text; and where the scales were listed in the references, in addition to articles published in English (with the exception of Ahlbäck et al.³, published in Swedish). Exclusion criteria were: publications that could not be fully retrieved from libraries or through requests to the authors by email; articles published in languages other than English; conference proceedings or abstracts; publications addressing subjects other than osteoarthritis; articles in which the Ahlbäck classifications were not found in the references; and publications in which the Ahlbäck categorizations were not presented in whole or in part, or where only a citation was provided.

The included articles were compared with the original descriptions of the classifications found in Ahlbäck’s monograph² and in the publication by Ahlbäck et al.³. We verified how these classifications were described and cited in the analyzed publications. The articles were organized by the senior author (JCG) regarding the description of the Ahlbäck classification into two categories: those that presented the classification correctly (in whole or in part) in the text, and those in which the scale was incorrectly reported. Publications were also divided, with respect to references, into two categories: those in which the classification was correctly cited and those in which it was cited incorrectly.

Finally, we sought to identify how many subsequent publications used as references the articles in which the classification and citation were incorrectly described. This screening, as well as the search for articles citing publications with imprecise grading and references, was initially performed and re-verified on two additional occasions by the senior author (JCG). The review of excluded publications, categorization of included articles, and results of the search for publications referencing articles with inaccurate classification and citation were sent to two independent authors (ISN and LAC) for validation, review, and suggestions for modifications. In case of disagreement, the final decision was made jointly by all three authors (ISN, LAC, and JCG).

RESULTS

Our search identified a total of 267 articles, in addition to the two original publications by Ahlbäck² and Ahlbäck et al.³ The following were excluded: five publications that could not be obtained in full, even after attempts through libraries and by contacting the authors via email; 34 articles published in languages other than English (10 in

Chinese, seven in French, five in German, five in Turkish, two in Polish, two in Spanish, one in Portuguese, one in Croatian, and one in Lithuanian); 40 articles consisting of conference or congress abstracts; eight publications whose topic was not related to osteoarthritis (six on osteonecrosis, one on patella alta, and one on scintigraphy for evaluation of the femoral condyles); 57 articles in which the Ahlbäck classification was not found in the references; and 58 publications that did not present the Ahlbäck classification in whole or in part in the text, or that only mentioned it without adequate description. Thus, 64 articles were included in the analysis, in addition to the two original publications. (Figure 2)

Of the 64 articles analyzed, only 24 (36.9%) presented the Ahlbäck classification correctly. Six publications^{5,14-18} used the 1968 article,² 17 articles¹⁹⁻³⁵ used the 1980³ article and, one article used both scales⁴. On the other hand, 40 articles (62.5%) reported the classification incorrectly. Six of them included grade 0,^{6,11,36-39} four included grade 6,⁴⁰⁻⁴³ both of which do not exist in the original scale; 10 reported the scale in a way very different from the original description⁴⁴⁻⁵³; and 20 described grade 4 as attrition between 5 and 10 mm and grade 5 as attrition greater than 10 mm.^{1, 7-10, 54-68} With regard to citation of the reference, in 13 articles (20.3%) it was done correctly. Six of them^{5,14-18} cited the 1968 publication², five,^{29,30,46,52,63} cited the 1980 publication³ and two,^{4,31} cited both articles. However, only two of the seven articles that adequately mentioned the 1980 publication cited it perfectly, including page 2096.^{30,52} Conversely, 51 (79.6%) publications cited it incorrectly.^{1,6-11,19-28,32-45,47-51,53-62,64-68}

We found 10 articles (15.6%) in which both the classification and citation were correctly reported^{4,5,14-18,29-31} and, in 37 (58.4%), both classification and citation were incorrectly described.^{1,7-11,21,36-45,47-51,53-68} The information contained in the two paragraphs above is summarized in Table 2. Finally, we identified 766 publications that used as references articles in which the classification and citation were inaccurately described.

DISCUSSION

The main finding of this study was that the number of articles that correctly described the Ahlbäck classification and those that

used exact citation in the references, with precise information on the publication journal, is small (36.9% and 20.3%, respectively). On the other hand, only 10 of the articles in our selection (15.6%) correctly described both the classification and citation, whereas in 37 of them (58.4%), both the classification and the citation were incorrect.

Among the 64 articles included in our review, 24 (36.9%) correctly described the classifications. Of these, six publications (25%)^{5,14-18} used the 1968 classification,² articles (70.8%)¹⁹⁻³⁵ used the 1980 classification³ and one publication (4.16%) used both scales.⁴ On the other hand, 40 publications (62.5%) described the classification incorrectly. The inaccuracies identified were: inclusion of grade 0, absent in the original scale, in six articles (15%),^{6,11,36-39} inclusion of grade 6, also absent in the original scale, in four publications (10%),⁴⁰⁻⁴³ description of the classification in a way significantly different from the original in 10 articles (25%),⁴⁴⁻⁵³ and misinterpretation of grades 4 and 5, in which grade 4 was described as attrition between 5 and 10 mm and grade 5 as attrition greater than 10 mm, in 20 publications (50%).^{1,7-10,54-68}

While we did not identify a probable explanation for the first three inaccuracies, the last error likely resulted from confusion between the description of bone defects presented in Ahlbäck's 1968 monograph² and the classification developed by Ahlbäck et al. in 1980.³ In the 1968 monograph², Ahlbäck described bone defects as being smaller than 5 mm, between 5 and 10 mm, and greater than 10 mm. In the 1980 classification,³ however, grade 3 corresponds to minor bone attrition (<0.5 cm), grade 4 to moderate attrition (between 0.5 and 1.5 cm), and grade 5 to severe attrition (>1.5 cm).

Confusing this information may lead to an erroneous assessment of osteoarthritis classification and, consequently, to inappropriate therapeutic decisions if they are based on joint attrition grading. For example, a patient with 12 mm of bone attrition should be classified as grade 4 and not grade 5, according to the 1980 classification.³ The lack of uniformity in osteoarthritis classifications may hinder treatment indication as well as the interpretation and comparison of results across different authors, especially when these are based on gonarthrosis grades assessed by weight-bearing anteroposterior radiographs.

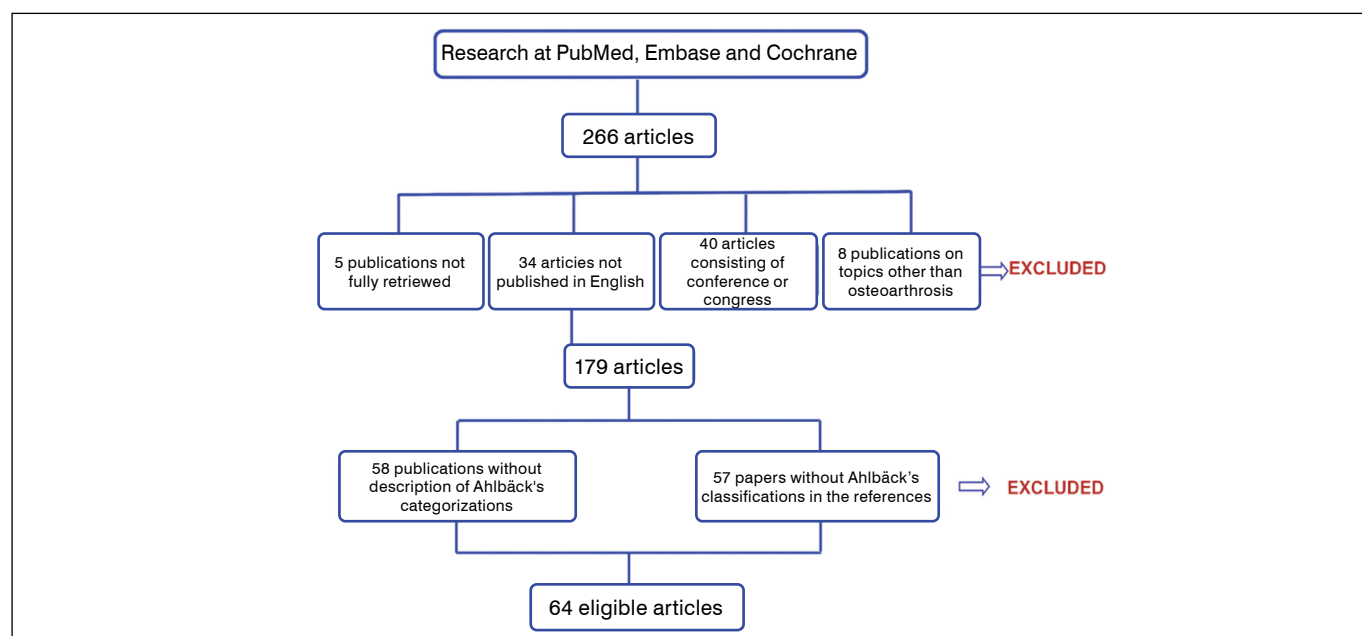


Figure 2. Summary of the systematic review methodology.

Table 2. Comparison of published information on the Ahlbäck classification and its citations in the literature, with respective authors and year of publication.

Authors	Year of publication	Correct classification	Incorrect classification	Correct citation	Incorrect citation
Lindberg & Montgomery ⁵	1987	•		•	
Lysholm et al. ⁴⁰	1987		•		•
Bert et al. ⁴¹	1989		•		•
Barrett et al. ¹⁴	1990	•		•	
Keyes et al. ⁵⁴	1992		•		•
Rockborn et al. ¹⁹	1996	•			•
Petersson et al. ²⁰	1997	•			•
Sahlström et al. ⁶	1997	•			•
Petersson et al. ⁵⁵	1997		•		•
Sahlström et al. ²¹	1997		•		•
Larsson et al. ²²	1998	•			•
Gillquist & Messner ⁴²	1999		•		•
Davies et al. ¹⁵	1999	•		•	
Gidwani et al. ⁴⁴	2003		•		•
Hung et al. ⁴⁵	2003		•		•
Galli et al. ⁸	2003		•		•
Rademakers et al. ⁴⁶	2004		•	•	
Tang et al. ²³	2004	•			•
Tang et al. ²⁴	2005	•			•
Sisto & Mitchell ¹⁶	2005	•		•	
Weidow et al. ⁴	2006	•		•	
Sisto & Sarin ¹⁷	2006	•		•	
Kijowski et al. ³⁶	2006		•		•
Hing et al. ¹⁸	2007	•		•	
Rademakers et al. ⁴⁷	2007		•		•
Beard et al. ⁴⁸	2007		•		•
Becker et al. ⁴⁹	2008		•		•
Lidén et al. ²⁵	2008	•			•
Rademakers et al. ⁵⁰	2009		•		•
Turajane et al. ²⁶	2009	•			•
Ventura et al. ⁵⁶	2010		•		•
Parmaksizoglu et al. ²⁷	2010	•			•
McDonnell et al. ⁵⁷	2011		•		•
Marcacci et al. ⁵¹	2011		•		•
Brucker et al. ⁵²	2011		•	•	
Hernández-Vaquero et al. ¹⁰	2012		•		•
Moon et al. ²⁸	2013	•			•
Staikos et al. ²⁹	2013	•		•	
Wright et al. ⁹	2014		•		•
Waldstein et al. ³⁷	2014		•		•
Li et al. ³⁰	2015	•		•	
Garrido et al. ³¹	2015	•		•	
Ghinelli et al. ³⁸	2016		•		•
Martins et al. ⁵⁸	2016		•		•
Talic-Tanovic et al. ³²	2017	•			•
Skou et al. ³³	2017	•			•
Köse et al. ¹¹	2018		•		•
Belk et al. ⁵⁹	2018		•		•
Elveos et al. ⁶⁰	2018		•		•
Kinsey et al. ⁴³	2018		•		•
Lim et al. ⁶¹	2019		•		•
Keenan et al. ¹	2020		•		•
Identeg et al. ⁵³	2020		•		•
Albergo et al. ³⁹	2020		•		•
Wing et al. ⁶²	2021		•		•
Pedersen et al. ⁶³	2021		•	•	
Jarecki et al. ⁶⁴	2021		•		•
Eckersley et al. ⁶⁵	2021		•		•
Zambianchi et al. ⁶⁶	2021		•		•
Jarecki et al. ⁶⁷	2022		•		•
Nakayama et al. ⁷	2023		•		•
Obara et al. ³⁴	2023	•			•
Törnblom et al. ³⁵	2024	•			•
Schippers et al. ⁶⁸	2024		•		•
		1	2	3	4
		24	40	13	51
		37.50%	62.50%	20.31%	79.69%

Regarding bibliographic references, only 13 publications cited the original sources correctly. Among them, six articles^{5,14-18} correctly mentioned the 1968 publication², five^{29,30,46,52,63} appropriately cited the 1980 publication³ and, in two publications both references were cited.^{4,31} However, only two of these seven articles (28.5%) in which the Ahlbäck classification was correctly used inserted the reference to the specific page (page 2096).^{30,52}

This failure can be explained by a detail in the Ahlbäck et al. publication.³ The original article, published in *Läkartidningen*, begins on page 2091 and appears to end on page 2093. After that page, there is an intercalated publication, which may give the impression that the article had ended. However, the publication resumes on page 2096, where the complete classification is described. This layout of the journal may have induced citation errors.

In 51 articles, the bibliographic references did not correspond to the classification described in the text.^{1,6-11,19-28,32-45,47-51,53-62,64} Among these, nine^{11,23,24,26,28,34,36,38,39} accurately reported the 1980 classification³ in the text of the publication but inexplicably cited the 1968 classification.² Surprisingly, classification and citation were both correctly reported in only 10 articles (15.6%)^{4,5,14-18,29-31} whereas in 37 publications (58.4%), both classification and citation were incorrectly described.^{1,7-11,21,36-45,47-51,53-68}

We identified 766 publications that used as references the 37 articles in which the classification and citation were inaccurately described. This represents an average of more than 20.7 citations per erroneous article, demonstrating a significant multiplier effect. Such propagation of errors may contribute to the dissemination of bias and generate methodological inconsistencies in the literature, compromising standardization, reproducibility, and comparability of results in subsequent studies.

In summary, for the appropriate use of the Ahlbäck knee osteoarthritis grading classification on weight-bearing anteroposterior radiographs, it is recommended to use the Ahlbäck et al.³ publication as the reference, since it contains the description of the knee osteoarthritis grading according to joint attrition. Authors should cite the original sources correctly, including page 2096 in the reference

to the 1980 publication³ and carefully review the description of the classification grades, avoiding adaptations or modifications not grounded in the original literature, as these may impact therapeutic approaches, particularly in the evaluation of outcomes.

Our study has some limitations. It was not possible to obtain all publications identified in the search, even after library requests and direct attempts to contact the authors by email. Furthermore, we excluded articles in which only the osteoarthritis categorization was described but not cited in the bibliography, and vice versa. We also did not perform comparisons between the Ahlbäck classification and other classifications used internationally, nor those including lateral radiographs, since our aim was solely to compare the original texts of Ahlbäck's 1968 article,² and the 1980 publication by Ahlbäck et al.³, with what was written in subsequent works that used the classifications and cited them in their references. The clinical relevance of this study lies in emphasizing the importance of correctly using the Ahlbäck classification, aiming at standardization of therapeutic decisions and accurate evaluation of outcomes.

CONCLUSION

Although the Ahlbäck classification continues to be used for radiographic assessment of knee osteoarthritis, only 10 of the articles in our systematic review (15.6%) correctly described both the classification and its citation, whereas in 37 of them (58.4%), both were incorrectly reported. The latter were cited as references in 766 publications, which may have contributed to the dissemination of bias and methodological inconsistencies in the scientific literature.

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PROPOSAL FOR A REHABILITATION PROTOCOL AFTER CALCANEAL TENDON RECONSTRUCTION: FROM THE IMMEDIATE POST-OPERATIVE PERIOD TO RETURN TO SPORTS PRACTICE

PROPOSTA DE PROTOCOLO DE REABILITAÇÃO PÓS RECONSTRUÇÃO DE TENDÃO CALCÂNEO: DO PÓS OPERATÓRIO IMEDIATO AO RETORNO A PRÁTICA ESPORTIVA

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ABSTRACT

The calcaneal tendon is the strongest tendon in the human body, and therefore the most commonly injured in the lower limbs. The aim of this study is to present a rehabilitation protocol, based on the literature, according to the physiology of tissue regeneration in the postoperative period of acute rupture of the calcaneal tendon, carried out through a bibliographic survey of the last 20 years and proposed by the Physiotherapy Service of the Institute of Orthopaedics and Traumatology of the Hospital das Clínicas of the University of São Paulo. The findings demonstrated that, despite the differences in surgical techniques, the proposed rehabilitation protocol presents minimal risk of damage to the surgical site. **Level of Evidence III; Systematic Review.**

Keywords: Rupture; Achilles Tendon; Rehabilitation Protocols.

RESUMO

O tendão calcâneo é o tendão mais forte do corpo humano, portanto o que apresenta maior prevalência de lesão nos membros inferiores. O objetivo desta pesquisa é apresentar o protocolo de reabilitação, embasado na literatura de acordo com a fisiologia de regeneração tecidual no pós-operatório do reparo da ruptura aguda de tendão do calcâneo, realizado através de levantamento bibliográfico dos últimos 20 anos e proposto pelo Serviço de Fisioterapia do Instituto de Ortopedia e Traumatologia do Hospital das Clínicas da Universidade de São Paulo. Onde ficou evidenciado que apesar das diferenças das técnicas cirúrgicas o protocolo proposto de reabilitação apresenta risco mínimo de dano ao sítio cirúrgico. **Nível de Evidência III; Revisão Sistemática.**

Descritores: Ruptura; Tendão Calcâneo; Protocolo de Reabilitação.

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INTRODUCTION

The calcaneal tendon is a structure composed of type I collagen, proteoglycans, and elastin that converges from the gastrocnemius and soleus muscles and inserts into the posterior surface of the calcaneus.¹⁻⁴ It is covered by a paratenon, which runs externally from its muscular origin to its bony insertion, and its main innervation is provided by the tibial nerve.^{5,6} Despite being the strongest tendon in the human body,⁷ it has the highest prevalence of injury in the lower limbs.^{4,3} Its primary function is to transmit the force produced by the triceps surae to the heel, enabling ankle plantarflexion, as well as to store and release energy as a shock absorber during gait and running.⁸

Rupture of the calcaneal tendon causes a significant functional impact, with a global incidence of 11 to 37 cases per 100,000 individuals per year,^{1,3,7} predominantly in men, with the first peak between 25 and 40 years of age and the second after 60 years, occurring more frequently during physical activity.^{1,3,7,9-11} The etiological factors include reduced tendon vascularization, sports practice in individuals with an unprepared musculoskeletal system, biomechanical foot abnormalities or tendon structural abnormalities, exercise-induced hyperthermia, overweight, decreased strength and/or flexibility of the plantar flexor muscles, and the negative influence of topical corticosteroids and fluoroquinolone antibiotics.^{5,12,13} Mechanisms of injury include resisted plantarflexion, sudden and exaggerated ankle dorsiflexion, and forced dorsiflexion with the joint in plantarflexion.¹²

All authors declare no potential conflict of interest related to this article.

The study was conducted at Instituto de Ortopedia e Traumatologia do Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo, R. Dr. Ovidio Pires de Campos, 333, Cerqueira Cesar, São Paulo, SP, Brazil, 05402-000.

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This type of injury damages the organized architecture of collagen fibers and increases type III collagen content at the site, with a mean tendon elongation of 1.5 to 3.5 cm, while surgical repairs may achieve only up to 1.2 cm of elongation.^{3,14}

Diagnosis of acute calcaneal tendon rupture includes patient history, typically reporting a popping sound and/or a sensation of being struck in the posterior leg, and physical examination, which may reveal edema, acute pain, palpable gap, increased passive ankle dorsiflexion, decreased strength of the ankle plantar flexors, inability or difficulty standing on tiptoe, and positive Thompson and Matles tests.^{3,5,15,16} Imaging exams may be performed to confirm rupture, assess its extent and location, and detect tendon pathology.⁷

Treatment of acute calcaneal tendon rupture is divided into two modalities: non-surgical and surgical.^{3,9,17,18} Surgical treatment options described in the literature include open, minimally invasive, and percutaneous techniques.^{19,20}

The stages of tissue healing are as follows:

- **Inflammatory Response:** begins immediately after injury, laceration, or surgical repair and ends within 6 days. The bleeding caused by the rupture leads to hematoma formation and activation of platelets and neutrophils, releasing growth factors, chemotactic factors, and vasoactive mediators.^{21,22} This response triggers fibrin clot formation and consequently stimulates fibroblast activity.²³ Subsequently, leukocytes and macrophages invade the area to clear cellular and tissue debris.²⁴ At this stage, protection of the lesion is necessary, controlling inflammation with rest, immobilization, and elevation to promote healing.¹³

- **Repair and Proliferation:** begins 48 hours after injury and lasts up to 6–8 weeks. The main agent in this stage is the macrophage, which activates fibroblasts that secrete type III collagen for tendon repair, forming a disorganized collagen matrix with smaller, less resistant fibers that elongate easily.^{2,3} After 10 to 14 days, scar tissue forms at the site joining the ruptured tendon ends. As the process continues, collagen deposition shifts from type III to type I, characterized by greater cross-linking, larger fibrils, and increased strength. In this phase, where the healing tissue is still disorganized and susceptible to reinjury if excessively tensioned, light and pain-free isometric contractions may be initiated. These contractions promote blood circulation, aid fibril organization through mechanical loading, stimulate proper muscle use awareness, and prevent reflex inhibition of immobilized muscle groups.¹³ Isometric contractions performed in a shortened muscle position enhance actin-myosin fiber mobility without overloading the ruptured tissue, while dynamic joint traction or passive compression along the contraction plane allows tendon excursion, promoting healing and reducing adhesion formation. Tendons also heal faster when subjected to mechanical loading, with daily episodes of tensile stress sufficient to stimulate healing without excessive elongation.²⁵ Controlled physical activity is a specific physiological stimulus that can enhance functional capacity and reverse disuse atrophy, provided that intensity, frequency, and duration parameters are appropriately managed.²⁶

- **Remodeling and Maturation:** the third healing stage, beginning 1 to 3 months post-injury and lasting for years. This stage is marked by reduced cellularity and synthetic activity, increased organization of the extracellular matrix, and a biochemical profile closer to normal.^{2,24,27} Functional linear alignment of collagen typically appears in the second month, with greater tensile strength.^{2,28,29} Due to the limited neuromuscular control in this phase, controlled forces simulating normal tissue loading are important, and adhesions need to be broken down. Healthy, repetitive loads promote tendon remodeling, improving structure and function. However, the material properties of these scars never fully replicate those of intact tendon,

and biomechanical properties may be reduced by up to 30%, even when healing stages are complete, due to the persistent proportion of type III collagen.^{28–30} Thus, repaired tendons do not fully restore their original characteristics, resulting in an altered biological and mechanical environment.

Accordingly, the objective of this study is to present a rehabilitation protocol based on the tendon healing phases, following surgical repair of acute calcaneal tendon rupture, as proposed by the Physiotherapy Department of the Institute of Orthopedics and Traumatology of the Hospital das Clínicas, University of São Paulo (IOT-HCFMUSP).

MATERIALS AND METHODS

A literature review was conducted over the last 20 years using the following keywords to identify relevant studies within the databases: “Calcaneal Tendon,” “Rupture,” “Open Surgery,” “Minimally Invasive Surgical Procedures,” “Physiotherapy,” and “Rehabilitation.” The search strategies involved first identifying descriptors in the DeCS portal and then applying the descriptors in both Portuguese and English within the PubMed, BVS, and PEDro databases. The keywords “Calcaneal Tendon” and “Rupture” were essential for the relevance of the search results, with the research direction further refined by the complementary terms related to the different types of surgical and therapeutic interventions.

Protocol

The protocol was developed by the Physiotherapy Department of the Institute of Orthopedics and Traumatology of the Hospital das Clínicas, Faculty of Medicine, University of São Paulo, and is presented in this study to outline the objectives and appropriate interventions for each physiological stage of the lesion within post-operative rehabilitation of the calcaneal tendon.

The first phase comprises the two firsts postoperative weeks, with the objectives of reducing edema, promoting circulation, and maintaining the strength of muscle groups adjacent to the lesion.

Phase 1

- Positioning/elevation of the lower limb (training in changing decubitus);
- Gait training without weight-bearing on the operated limb;
- Isometric exercises during immobilization;
- Toe flexion-extension exercises;
- Active knee extension exercises in sitting position;
- Straight leg raise in the supine position.

The second phase occurs in the 3rd postoperative week, aiming at gait training, improved activation, maintenance, and strengthening of the lower limb muscles. At this stage, dorsiflexion is not permitted, in order to avoid placing tension on the suture site.

Phase 2

- Gait training with immobilizing orthosis (progressive load tolerated by the patient);
- Isometric strengthening of invertors, evertors, and plantar flexors without joint movement, to be performed while immobilized;
- Free active toe flexion-extension exercises during immobilization;
- Straight leg raises with load in the supine, lateral, and prone positions;
- Active knee extension with load in sitting position.

The 3rd phase covers the period from the 4th to the 6th postoperative week, with the objective of protecting the healing process, joint mobilization, strengthening of ankle and foot muscles, and progressive strengthening of the lower limbs. At this stage, ranges of motion of plantar flexion, inversion, and eversion are allowed, returning only to the neutral position to protect the sutured area.

Phase 3

- Straight leg raises with load in the supine, lateral, and prone positions with progressive load increase;
- Active joint mobilization of plantar flexion, inversion, and eversion with return to neutral position;
- Active resisted strengthening with elastic bands for plantar flexion, inversion, and eversion with progressive load increase. **Do not perform exercises for dorsiflexors;**
- Soleus strengthening in the sitting position, with the foot placed forward of the knee (knee flexion angle less than 90°).

The 4th phase, occurring between the 8th and 12th postoperative weeks, aims to achieve full ankle range of motion and progressive lower limb strengthening, in addition to improving cardiorespiratory condition. Removal of the orthosis heel lift, when indicated, and discontinuation of immobilization will occur according to medical clearance.

Phase 4

- Straight leg raises with load in the supine, lateral, and prone positions with progressive load increase;
- Active dorsiflexion mobilization;
- Maintenance of active resisted strengthening with elastic bands for plantar flexion, inversion, and eversion, with initiation of dorsiflexor strengthening;
- Stationary cycling;
- Squats;
- Sensorimotor training.

The 5th phase begins after completion of 12 weeks, aiming to achieve full ankle mobility, posterior chain stretching, strengthening of the triceps surae, improvement of balance and gait, and training for preparatory jumping movements. At this stage, posterior chain stretching is permitted while keeping the ankle in neutral position, protecting stress on the sutured tendon. Sensorimotor control training aims to prepare the patient for return to sports practice.

Phase 5

- Progressive strengthening of the triceps surae on a step, with concentric and eccentric bipodal exercises, progressing to unipodal;
- Protected posterior chain stretching;
- Advanced sensorimotor control training with direction changes;
- Bipodal plyometrics progressing to unipodal, according to the patient's ability.

DISCUSSION

The purpose of this study was to present the rehabilitation protocol of the Physiotherapy Department of IOT-HCFMUSP and to compare it with findings from the literature based on a bibliographic review. Maquirriain J. reported that early tension and weight-bearing on a repaired tendon improved muscle strength and tendon vascularization. Suchak et al. compared early weight-bearing beginning 2 weeks after repair with weight-bearing allowed only after 6 postoperative weeks.^{31,32} At the sixth week, the group that underwent early weight-bearing presented significantly better scores in the domains of physical and social functionality, emotional health, and vitality in a quality-of-life questionnaire, in addition to reporting fewer limitations in daily activities. At six months postoperatively, no significant differences were observed between the groups in any outcome, and both showed low muscle strength in the triceps surae. It is noteworthy that there was no rerupture in either group. Based on this evidence, early weight-bearing is adopted as an important part of the proposed protocol.

Immobilization with an orthosis is used to avoid early dorsiflexion and thus prevent stretching of the suture at the calcaneal tendon,^{31,33} Kisner et al. warned that early or excessive mobilization may damage

the injured tissue, meaning that the range of motion should not be performed when it negatively interferes with the healing process.^{13,31} Bevoni et al. stated that dorsiflexion is permitted up to 5° at 6 postoperative weeks. At this stage, type I collagen production increases and the tendon callus reaches its largest size. Although the tissue is more fragile at this point, the greater transverse area of the callus compensates for its weaker composition.⁹ In the proposed protocol, dorsiflexion is initiated at the 8th week, without range restrictions except for patient tolerance, since it is functionally unfeasible to control dorsiflexion degrees at minimal ranges during home-based exercises without therapist supervision.³³

Rosenzweig e Azar describe that the foot is placed in the plantigrade position 4 to 6 weeks after repair, without specifying the moment when dorsiflexion beyond neutral is permitted. They recommend that the patient use an equinus positioning splint from the 2nd to 4th weeks, a removable orthosis allowing only plantar flexion from the 6th to 8th weeks, and an orthosis with a lock in the neutral position starting from the 12th week, until the patient presents at least 80% muscle strength of the contralateral limb and an unspecified ROM.³⁴ In the proposed protocol, the immobilizing orthosis is introduced at the 2nd week and removed within 12 weeks at the physician's discretion. From this period onward, the patient is allowed to perform ankle dorsiflexion and propulsion through triceps surae activation during gait, consistent with Medeiros et al., who state that wound resistance reaches 80% of the original tissue strength after 3 months.³⁵

Direct stretching of the calcaneal tendon is not allowed because, as cited by Maquirriain J., creep is a mechanical property in which a constant load causes lengthening over time, leading to tension loss in the initial postoperative phase. Therefore, tendon stretching results in morbidity and triceps surae weakness at the end of movement, impairing rehabilitation.³¹

Suchak et al. also applied an accelerated rehabilitation method in which the neutral position of the operated ankle was already permitted between the 2nd and 3rd postoperative weeks, concurrently with the allowance of active dorsiflexion, apparently without restriction in the maximum angle reached by the patient.³² In the proposed protocol, strengthening of plantar flexors, invertors, and evertors is allowed from the 4th postoperative week, since these movements do not place tension on the sutured tendon. At the 8th week, exercise progression is initiated, along with the release of ankle dorsiflexion and strengthening of the triceps surae with bipodal support, as by this time the tendon repair and proliferation healing phase is completed. At this stage, type I collagen deposition begins and accelerates, establishing a biomechanical and biochemical profile closer to the physiological tissue.

According to Maquirriain J., it is important to maintain or increase contraction strength of the muscles of the operated lower limb, with emphasis on the triceps surae, thereby reducing the risk of injury and preventing stretching of the calcaneal tendon, which is consistent with the approach proposed in this protocol. Another essential aspect is sensorimotor training, given that patients with calcaneal tendon injury present deficits in this area.³¹

The time to return to sports practice coincides with findings in the literature and with the protocol developed by this group. It is recommended that return to prior sports activity occur 5 to 6 months after surgery. However, for this return to be adequate, it requires prior preparation promoted by rehabilitation.^{13,33,34,36} Postoperative rehabilitation guidelines for calcaneal tendon repair published by the Department of Sports Medicine of the University of Wisconsin consider patients eligible to return to sport-specific activities from the 16th postoperative week, through exercises simulating sports activities, similar to the protocol proposed here.³³

A protocol similar to the one proposed was identified, in terms of exercise progression, weight-bearing permission, use of assistive devices, release of dorsiflexion movement, and return to sport-specific training.³⁶ However, this approach was applied to the postoperative period of a modified open surgical technique, associated with a gastrocnemius tendon flap and deep posterior compartment fasciotomy.

Outcomes were satisfactory in both surgical techniques, as patients presented no differences between the operated and contralateral limbs in functional test results, and no long-term postoperative failures were observed. This evidence shows that, despite different surgical techniques, the proposed rehabilitation protocol presents minimal risk of damage to the surgical site.

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