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KOVÁCS KRISZTIÁN BALÁZS

A támasztó és mozgató szervrendszer működésének fiziológiája

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Biomechanics of Acromioclavicular Joint Reconstruction

Ph.D. Thesis

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Surgical Medicine Division

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„The man who moves a mountain begins by carrying away small stones."

Confucius

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1. LIST OF ABBREVIATIONS

AC	acromioclavicular
ACJ	acromioclavicular joint
AP	antero-posterior
ASES	American shoulder and elbow surgeons
CC	coracoclavicular
chr	chronic
CT	computer tomography
DASH	disabilities of the arm, shoulder, and hand
diff.	difference
E value	Elasticity, Young's modulus value (GPa)
FE	Finite Element
FEA	Finite element analysis
K-wire	Kirschner wire
LD	Linear dichroism
MA	meta-analysis
MCID	minimal clinically important difference
ML	medio-lateral
NA	not available
NRS	numerical Rating Scale
ORTSD	open reduction and suspensory device fixation
OSS	Oxford shoulder score
postop	postoperative
preop	preoperative
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROCESS	Preferred Reporting of Case Series in Surgery)
QCT	Quantitative Computed Tomography
spf.	superficial
SR	systematic review
SST	simple shoulder test
UCLA	University of California-Los Angeles shoulder score
US	Ultrasound/ultrasonic

2. STUDENT PROFILE

2.1. Vision and mission statement, specific goals

Everyone has the right to live a pain-free life and have the freedom of movement without limitations due to any condition. My vision is to provide state-of-the-art orthopaedic care to patients with musculoskeletal conditions and enhance orthopedic care through standardized, data-driven approaches that improve implant design and surgical treatment outcomes.

To achieve this, my mission is to integrate biomechanical precision with clinical effectiveness for more reliable, personalized musculoskeletal interventions. We investigate key factors influencing bone elasticity and evaluate surgical techniques like the Lockdown procedure through systematic research and clinical studies.

My specific goal is to create a comprehensive reference for Young's modulus variations and validate the Lockdown technique as a safe, effective option for AC joint reconstruction. These insights will inform surgical decisions, improve finite element modeling, and guide evidence-based orthopedic practice.

2.2. Scientometrics

Number of all publications:	6
Cumulative IF:	12.597
Av IF/publication:	2.0995
Ranking (SCImago):	D1:1; Q1: 2; Q2: 1; Q3: 1; Q4: 1
Number of publications related to the subject of the thesis:	2
Cumulative IF:	6.3
Av IF/publication:	3.15
Ranking (SCImago):	Q1: 2
Number of citations on Google Scholar:	17
Number of citations on MTMT:	12
H-index:	2

The detailed bibliography of the student can be found on pages 60-61.

2.3. Future plans

My plan is to deepen my knowledge and experience in prosthetic implantations, and continue my research related to this topic in order to provide high-quality care for patients, while, in parallel, being updated on the recent field developments.

3. SUMMARY OF THE PH.D.

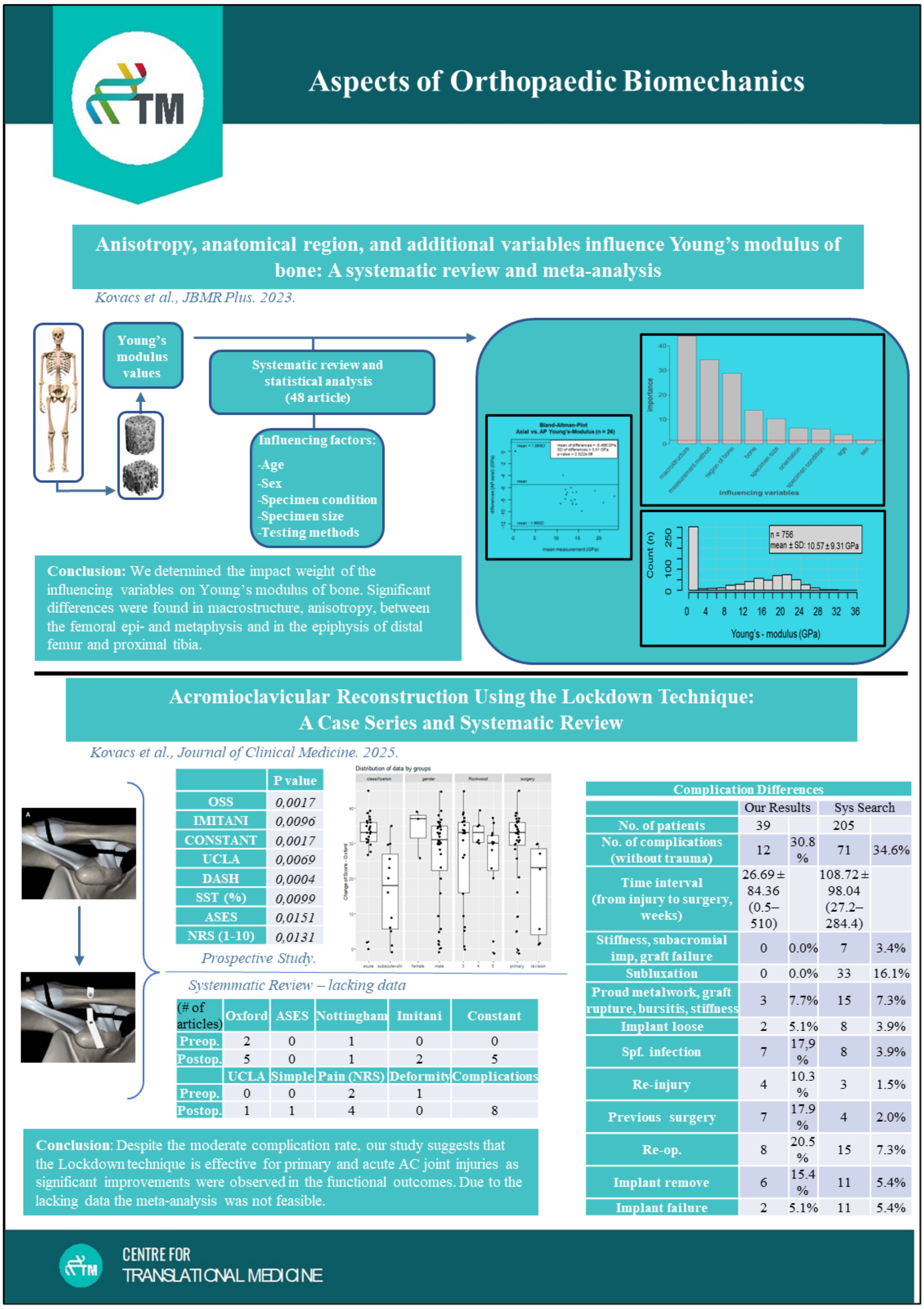
In musculoskeletal surgeries, preoperative planning and implant behaviors are crucial. Acromioclavicular (AC) joint dislocations are common injuries of the shoulder girdle, which occur in 3,5-12%.(1, 2) Over 150 operative techniques exist, yet consensus on optimal management remains limited.(3-5) This research comprised two studies: (I) mapping bone elasticity to support finite element (FE) modeling, and (II) evaluating the efficacy of the Lockdown implant in AC joint injuries. Given the rarity of cases, we conducted a systematic review supplemented with data from a Hungarian multicenter prospective cohort study (three centers). A second systematic review and meta-analysis were conducted on bone elastic modulus.

Study I identified significant heterogeneity in measurement methods, predominantly compressional, nanoindentation, and tensile testing, mostly on cortical, wet specimens. Frequently assessed bones were the femur, tibia, and fibula. Subgroup and random forest analyses revealed that cancellous femoral epiphysis values were higher than those of the metaphysis ($p=0.010$). Compression-based values showed epiphysis stiffness approximately twice that of metaphysis ($p<0.001$). Tibial epiphysis was stiffer than femoral epiphysis ($p=0.026$). Factors most influencing bone modulus were macrostructure, measurement method, and anatomical site.

Study II analyzed outcomes of the Lockdown technique. Mean age at surgery was 38.9±12.7 years in our cohort and 39.2±3.0 in the literature. Follow-up averaged 24.5±10.1 months versus 32.5±19.8 months. Improvement in Oxford Shoulder Score (OSS) was significantly greater in acute than chronic cases ($p=0.0017$). Complications occurred in 30.8% of our patients, mainly minor infections, with 5.1% requiring revision for implant failure. The systematic review reported similar overall complication rates (34.6%), including 5.4% implant-related issues. Meta-analysis was not feasible due to heterogeneity.

Based on our results, more standardized measurement parameters would be advised, depending on the parameters, and current FE models should consider these findings with bone anisotropy and the region of bone. Our conclusion regarding Study II. is that the Lockdown technique is effective for primary and acute AC joint injuries. The three most common score systems are recommended for further clinical studies, due to the heterogeneity of shoulder score results in the literature.

4. GRAPHICAL ABSTRACT (including all studies)



5. INTRODUCTION

5.1. Overview of the topic

5.1.1. What is the topic?

My research focuses on gaining a deeper understanding of implant behavior concerning musculoskeletal surgeries.

5.1.2. What is the problem to solve?

Following the Lockdown surgery, we noticed an unusual complication. Rarely, the coracoid process may break off. Our initial idea was to try to build a finite element model to assess the stress and strain aspects of the coracoid, but we bumped into the problem of the large scatter of Young modulus values of bone in the literature. Therefore, we decided to take a systematic approach to clarify how much exactly the elastic modulus of the bone tissue is. The topic is approached from two aspects. Study I. aims to improve finite element analysis by highlighting the issue of validating bone's elasticity values. Finite element analysis is a numerical stress analysis technique that estimates the bone's Young's Modulus values (*E* values) from Computer Tomography (CT) data, which ignores the anisotropic feature of bone. Nevertheless, there is no standardized measurement method for ex vivo *E* value measurement, compromising the possibility of proper validation. The different *E* value measuring techniques can lead to two-fold magnitude differences in *E* values. With the appropriate calculations, better implant designs could be created and planned before operation, which could help create a gold standard method for the surgical reconstructions in AC joint luxations, which is the focus of Study II. In that Study, we wanted to clarify the true incidence of coracoid fracture following this procedure, so we decided to build a study to assess the whole surgical procedure. During the assessment, the issues were the rate of complications and the heterogeneity of the shoulder score used for the efficacy of the Lockdown implant. Also, this heterogeneity and the low number of patients lead to fewer cases for comparison.

5.1.3. What is the importance of the topic?

The use of implants during musculoskeletal surgeries is increasing due to the existing rate of sports injuries and also to the increasing number of the elderly population. The rate of orthopedic prosthetic implantations is rising alongside the growing prevalence of arthritic joints in older people. By 2030, the number of hip and knee arthroplasties is expected to increase by more than 670% and 170%, respectively. As a result, the growing demand for implantations and advancing technology presents new opportunities for custom-made implants and further research in implant development.(6)

As for sports injuries, more than 150 surgical techniques exist for severe AC joint injuries without gold-standard surgical therapy.(3-5) Without proper management, the pain and the restriction of upper limb movement can cause a poor quality of life.

5.1.4. What would be the impact of our research results?

The outcomes of our research have the potential to enhance the process of finite element analysis, and can be applied to new implants or preoperative planning, and improve the treatment with Lockdown implant in case of AC joint luxation. By using our proposed shoulder scores, the variability in the literature would be reduced, making it more suitable for future comparisons and systematic reviews.

5.2. Further introductory chapters, if necessary

5.2.1. Finite element analysis and Young's Modulus

Advancements in technology and the increasing number of implantations are creating new opportunities for custom-designed implants and innovative implant research. Finite element analysis (FEA) is a valuable method for researching new implant designs. This numerical stress analysis technique enables the evaluation of injuries and pre-surgery simulations, helping to model how implants interact with bone.(7-9) In FEA, the analyzed region is divided into smaller elements, each assigned appropriate material properties.(10) To accurately recreate the virtual model, assigning precise material properties to each element is essential. However, bone is an anisotropic material, which means the elasticity (characterized by Young's modulus, or E value, which measures a material's tensile or compressive stiffness when a force is applied along its length) varies depending on the measurement orientation. (11, 12) Disregarding anisotropy can result in a relative error of up to 50% in FEA.(9) The elasticity of bone can be assessed using various in vitro or in vivo methods. However, estimating Young's modulus based on computed tomography (CT) has limitations, as it cannot accurately capture the non-homogeneous microstructures of bone, given its anisotropic nature. Besides, bone tends to behave more like a composite material, and CT scans may fail to capture the biomechanical differences caused by collagen structure. On the other hand, the most common in vitro bone specimen measurements are micro-macro mechanical, ultrasonic (US), and nanoindentation tests.(13, 14)

Young's modulus, or modulus of elasticity, is a mechanical property that measures the stiffness of a solid material under tensile or compressive force applied along its length. It quantifies the relationship between tensile or compressive stress (force per unit area) and axial strain (the resulting proportional deformation).(15) The accuracy of the input parameters is one of the key factors influencing the reliability of these models. However, E values reported in the literature vary widely. For example, a study by Wu et al. found that E values for trabecular bone in the same anatomical region ranged from 1.28 to 30.6 GPa.(14) Similarly, a review by Nobakhti et al. reported E values between 0.61 and 25 GPa for bulk-scale specimens, while some studies have even reported values as high as 60 GPa.(16-18)

Given these conflicting results, we aimed to explore the factors influencing E values in human bones. We hypothesized that a bone's E value is correlated with demographic data, specimen characteristics, and measurement parameters.

5.2.2. Acromioclavicular joint luxation, classification, and surgical management

Acromioclavicular (AC) joint dislocations are common injuries, accounting for 3.5% to 12% of all shoulder girdle injuries. They most frequently occur in males and young athletes, particularly in contact sports like rugby, wrestling, or hockey, due to direct impacts to the shoulder. The injury was first classified by Tossy and Allmann, later modified by Green and Rockwood, resulting in six distinct types of AC joint injuries.(1, 2)

There is no consensus among surgeons regarding the treatment of AC joint injuries. However, low-energy injuries (Rockwood type I and II) are typically managed conservatively using a harness or sling.(3) For more severe injuries, classified as Rockwood type III and above, surgery is necessary. Over 150 surgical techniques are available for managing these injuries, which can be grouped into six main categories: AC fixation (e.g., hook plates, Kirschner wire), coracoclavicular (CC) fixation (e.g., Bosworth screw, cerclage), distal clavicle resection with coracoacromial ligament transfer (Weaver-Dunn procedure), CC ligament reconstruction using soft tissue (e.g., free tendon grafts, dynamic muscle transfer), and CC ligament reconstruction with synthetic grafts (e.g., Lockdown, Tightrope).(4, 5) While high-energy injuries (Rockwood type IV and above) are generally treated surgically, the management of type III injuries remains a topic of debate in the literature.(3)

One of the earliest techniques for acromioclavicular (AC) joint reconstruction involved the use of Kirschner wires (K-wires), but this method has been associated with significant complications, including wire migration leading to nerve and vascular injuries.(19) Alternative approaches, such as the Bosworth screw—with or without K-wire reinforcement—also present issues due to the rigid nature of these repairs, which do not accommodate the joint's inherent dynamic movement.(20) Variants of hook plate fixation offer direct AC joint stabilization but necessitate a second surgery for implant removal. This technique is also linked to complications involving the hardware, as well as conditions such as AC joint arthritis, subacromial impingement, and acromial erosion.(21, 22) Reported complication rates for hook plate fixation are as high as 26.3%, with shoulder stiffness and pain during elevation being the most common complaints.(20, 23)

The Weaver–Dunn procedure (1972) is a non-anatomical repair and is known for its low repair stability. The repair is 70% weaker than native ligaments, resulting in a high rate of recurrent deformity and a high reoperation rate.(24-26)

As for the synthetic grafts, the Lockdown implant originated in Nottingham and has been used since 2001. Previously known as the Surgilig procedure, it involves the use of a double-braided polyester ligament. The distal end of the synthetic ligament loops around the coracoid process, while the proximal end is fixed to the lateral end of the clavicle. This graft replaces the coracoclavicular (CC) ligaments and helps to stabilize the clavicle by pulling it down toward the coracoid process.(27) **Figure 1**.

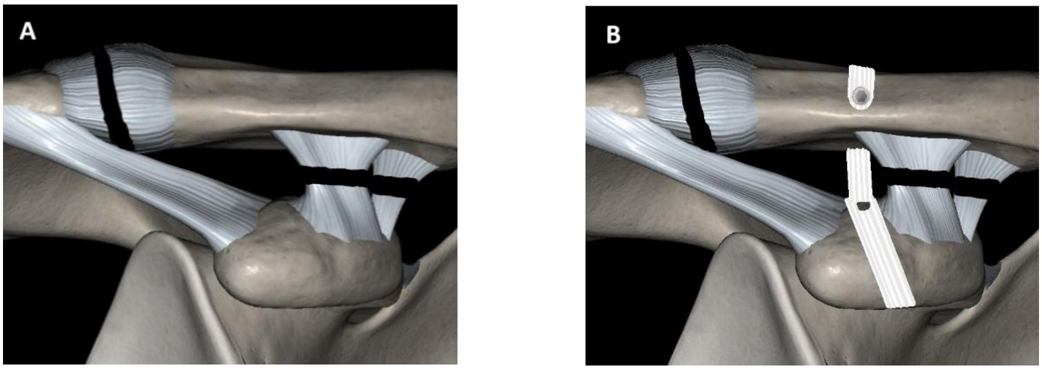


Figure 1. Lockdown technique (**A**) acromioclavicular joint (ACJ) dislocation and coracoclavicular (CC) ligament rupture. (**B**) Lockdown synthetic graft looped around the coracoid process: ACJ stabilization.

Various comparisons have been made regarding the surgical management of AC dislocations. The Surgilig technique has a low failure rate and yields high functional outcomes postoperatively; however, the quality of most studies on this technique is considered to be low.(28)

6. OBJECTIVES

6.1. Study I. - Anisotropy, anatomical region, and additional variables influence Young's modulus of bone: A systematic review and meta-analysis

Our goal was to examine the factors that influence E values in human bones. We hypothesized that a bone's Young's Modulus value is correlated with demographic information, specimen characteristics, and measurement details.

6.2. Study II. - Acromioclavicular reconstruction using the Lockdown technique: a case series and systematic review

Our study aimed to assess the efficacy, safety, and patient satisfaction of the Lockdown technique in treating Rockwood type III and above AC injuries at three Hungarian centers while comparing our findings with existing literature. We hypothesized that the Lockdown technique would be more effective in acute and non-revisional AC injuries than in chronic or revisional cases.

7. METHODS

We performed our systematic review and meta-analysis based on the recommendation of the PRISMA 2020 guideline (Preferred Reporting Items for Systematic reviews and Meta-Analyses). (**Table S1**),(29) while we followed the Cochrane Handbook.(30) Furthermore, we registered the study protocol on PROSPERO (registration number: CRD42021286292 – Study I.; CRD42024578461 – Study II.).

In Study I., we included only case series and case reports in our analysis reporting on individual measurements. The first part of Study II. is a multicentric retrospective data collection with prospective follow-up of patients treated in three Hungarian hospitals (two traumatology centers and one university orthopedic department). The study received ethical approval from the Semmelweis University Regional and Institutional Committee of Science and Research Ethics (approval ID: BMEÜ/2832-3/2022/EKU). All procedures followed the PROCESS 2020 (Preferred Reporting of Case Series in Surgery) guidelines (**Table S2**). (31) All procedures were performed by three senior surgeons across the centers who followed the same surgical technique.

7.1. Study I.

7.1.1. Information sources and search strategy

We conducted our systematic search on November 21, 2021. The used databases were PubMed, the Central Library (Cochrane), and Embase. During the systematic search, we used the following search key: "bone AND (trabecula* OR cortical OR trabeculae OR cancellous) AND (elastic* OR young OR modulus OR "mechanical properties"). No publication date, language, or any other filters were applied during the search.

7.1.2. Selection process

We used Endnote v21.0 (Clarivate Analytics, Philadelphia, PA, USA) reference manager software for the selection. After the removal of duplicate references (manual and automatic), the selection was performed by two independent review authors (KK and VW) by reference title and abstract. At this point, Cohen's kappa coefficient for the selection was 0.99. Next, the same authors made the full-text selection with a 0.84 Cohen’s kappa coefficient value. A third review author resolved disagreements.

7.1.3. Data collection process and data items

From the eligible articles, data were collected by four authors (KK, KB, BK, GS) in pairs. Each entry was extracted by one review author and verified by another. Ambiguous data were reviewed by all authors to minimize the risk of extraction error.

We extracted the following data: first author, country, the year of publication, repetition count in case of repeated measurements, specimen size (each dimension), exact anatomical location, sex, age, measuring method and equipment type, the condition of the specimen, the direction of loading (with respect to the *in situ* anatomical orientation: anteroposterior (AP), axial, mediolateral (ML)) and, finally, the *E* values recorded in GPa. Each extracted entry corresponds either to a single measurement or to the mean of a series of repeated measurements carried out on a specimen. A specimen is a portion of a bone cut and prepared for measurement.

7.1.4. Eligibility criteria

Eligible articles included healthy human bones reporting *E* values based on different variables. In order to reach our goal, we included articles that contained human bone elastic modulus results from non-imaging techniques, such as in vitro testing machines. Articles with animal specimens, imaging-based measurement techniques, and patients who had any kind of hormonal, corticosteroid, or other bone-affecting therapy were excluded. Patients with bone tumors or any bone disease were also excluded, together with pediatric patients (i.e., males below 16 and females below 14).(32) We included case reports, case series, and cohort analyses with individual patient data, regarding demographic data, bone type, specimen size and condition, measuring method, and loading orientation. Conference abstracts or studies with unavailable full text were excluded.

7.1.5. Study risk of bias assessment

Four authors (KK, KB, BK, GS) independently performed the risk of bias assessment. Each article was assessed in duplicate using the CARE tool.(33) Domain number 7 and 10 were omitted (details in supplementary material). Disagreements were resolved by consensus discussion with a third experienced reviewer.

7.1.6. Synthesis methods

For primary data extraction and organization Microsoft Office Excel (Microsoft Office Professional Plus 2013) was used. Statistical analysis was carried out in Excel and R (R Core Team 2022, v4.1.3). The functions of the "party" package (version 1.3-10) were used to fit a random forest and calculate variable importance.(34-36) There was an attempt to build a statistical model describing the dependence of the magnitude of *E* value on different explanatory variables; however, the structure of the extracted data did not enable this (Table S3). Instead, we carried out a series of systematic pairwise comparisons with various subgroups of the explanatory variable values, we reported mean±standard deviation, and the significance of the difference between the means of the subgroups was tested by Welch's *t*-test with a level of significance of 0.05. During the analysis, a 10% difference was considered as clinically relevant in *E* values between the analyzed groups. Additionally, anisotropy was investigated by the Bland-Altman method where data differing only in loading orientation were available for the same specimen.(37) Finally, the variable importance measure was calculated for the explanatory variables.(35, 36, 38)

7.2. Study II.

7.2.1. Case-series study

7.2.1.1. Patient selection

This multicentric prospective cohort study enrolled 39 patients who underwent Lockdown synthetic ligament surgery between January 2018 and January 2023. Eligible patients were over 16 years of age, with isolated injury of the AC joint, and free from mental illness affecting postoperative rehabilitation. Patients with no data or who were unable to give consent were excluded. Enrollment occurred in three centers (at the Department of Orthopaedics, Semmelweis University, Dr. Manninger Jenő Traumatology Center, and the Department of Traumatology, Hungarian Defence Forces Medical Centre).

7.2.1.2 Data extraction, data types, and measures

Trained physicians, who did not participate in the operations at any center, extracted data from hospital electronic records to ensure accuracy. Follow-up data were collected through medical records, outpatient visits, and telephone interviews. The sample size was determined by recording the number of patients. Data included sex (male or female), age at surgery, shoulder function scores, classification of surgeries as primary or revision, and injury severity according to the Rockwood classification (types III, IV, V). Information documented also included surgical complications, discharge (fluid released from the wound) status, trauma details, and any reoperations. Patients were categorized as acute (trauma within three weeks) or chronic (trauma more than three weeks prior). Our nonsignificant findings were evaluated in the context of minimal clinically important difference (MCID) values reported in the literature.(39)

7.2.1.3. Surgical technique

Patients were positioned in a beach chair position, and a vertical incision was made over the clavicle. A lasso was formed around the coracoid process to reposition the clavicle to measure the implant. The selected implant was inserted using the lasso and length gauge loop. After fixation of the lasso, the clavicle was stabilized with a 3.5-mm cortical screw placed through a pre-drilled hole in the clavicle itself. The wound was closed in layers. A detailed description is provided in the article by Jeon et al.(40)

7.2.1.4. Outcomes

The study measured several outcomes both preoperatively and postoperatively. These included the Oxford Shoulder Score, the IMITANI Score, the CONSTANT Score, and the UCLA (University of California-Los Angeles) Shoulder Score. Additionally, the DASH Score (Disabilities of the Arm, Shoulder, and Hand), the SST Percentage (Simple Shoulder Test), the ASES Score (American Shoulder and Elbow Surgeons), and the Numerical Rating Scale (NRS, on a scale between 0 and 10) were evaluated.

7.2.1.5. Statistical Methods

Statistical analysis was carried out in "R" (R Core Team 2022, v4.3.1) and MESS 1.3.1. using data structured in Excel. Two-sample t-tests were used for subgroup comparisons. Boxplots were utilized to represent each outcome based on baseline characteristics. All p-values were two-sided, and the significance level was 5%.

7.2.2. Systematic Review

7.2.2.1 Methods of the Systematic Review:

We conducted our systematic review and meta-analysis according to PRISMA 2020 guidelines (**Table S4**) and the Cochrane Handbook.(29, 41) Only case series and case reports with individual measurements were included. The study protocol was registered on PROSPERO (CRD42024578461).

7.2.2.2. Information sources and search strategy

On August 10, 2024, we conducted a systematic search using PubMed (Medline), Cochrane Central Library, Embase, Scopus, and Web of Science. We also included an additional report from other reviews. The search terms used were "acromioclavicular AND (lockdown OR surgilig OR synthetic)," with no filters applied.

7.2.2.3. Selection process

We used Endnote v21.0 (Clarivate Analytics) for reference management. After removing duplicates, two independent reviewers (KK and GS) selected studies based on titles and abstracts, achieving a Cohen's kappa of 0.99. Full-text selection was performed by the same reviewers with a Cohen’s kappa of 0.91. A third reviewer resolved any disagreements.

7.2.2.4. Eligibility criteria

Eligible studies reported outcomes of the Lockdown (or Surgilig) technique for acute or chronic acromioclavicular injuries. Exclusion criteria included studies involving cadavers or nonhuman specimens, multiple injuries, conference abstracts, editorials, biomechanical studies, descriptions of techniques, non-Lockdown procedures, systematic reviews, or meta-analyses. We included case series and clinical trials on Rockwood III or higher injuries assessed by shoulder scores.

7.2.2.5. Data collection process and data items

Two authors (KK, GS) collected data from eligible articles, with a third author reviewing them to minimize extraction errors. Data extracted included the first author, DOI, country, publication year, number of cases, gender ratio, mean age at surgery, duration of follow-up, injury classification, time to surgery, pre- and postoperative shoulder scores, pain, deformity, duration of physiotherapy, and postoperative complications. Implant-related complications were identified when reoperation led to implant removal.

7.2.2.6. Evaluation of the studies and study risk of bias assessment

Due to the low number of studies, heterogeneous data, and incomplete outcome reporting, we decided not to perform a meta-analysis of the extracted data. We summarized the results of the systematic review in a narrative form and presented data in summary tables. The risk of bias assessment was performed by two authors (KK, GS). Each article was assessed using the JBI critical appraisal tool for case series and the ROBINS-I tool.(42, 43)

8. RESULTS

8.1. Study I

8.1.1. Search and selection

Altogether 22114 records were identified using our search key, and finally, 48 articles contained individual results of *E values* (**Figure 2**).(12, 44-91)

8.1.2. Characteristics of the included studies

The main characteristics of these articles are summarized in **Table 1**. The years of publications ranged from 1966 to 2020. The articles were published in 13 countries, the USA (n=20), France (n=7), and Belgium (n=3) being the most frequent ones.

8.1.3. Characteristics of the Cohort

Detailed article characteristics are shown in **Table 2**. We had bone measurements in a total of 756 entries from 397 specimens. The most frequent measurement techniques were compressional, nanoindentation, and tensional tests. The majority of specimens were cortical and wet, and the three most commonly tested bones were the femur, tibia, and fibula. The range of age was between 15 and 96 years. More than half of the specimens came from male subjects, and the range of specimens was between 0.035mm and 20mm.

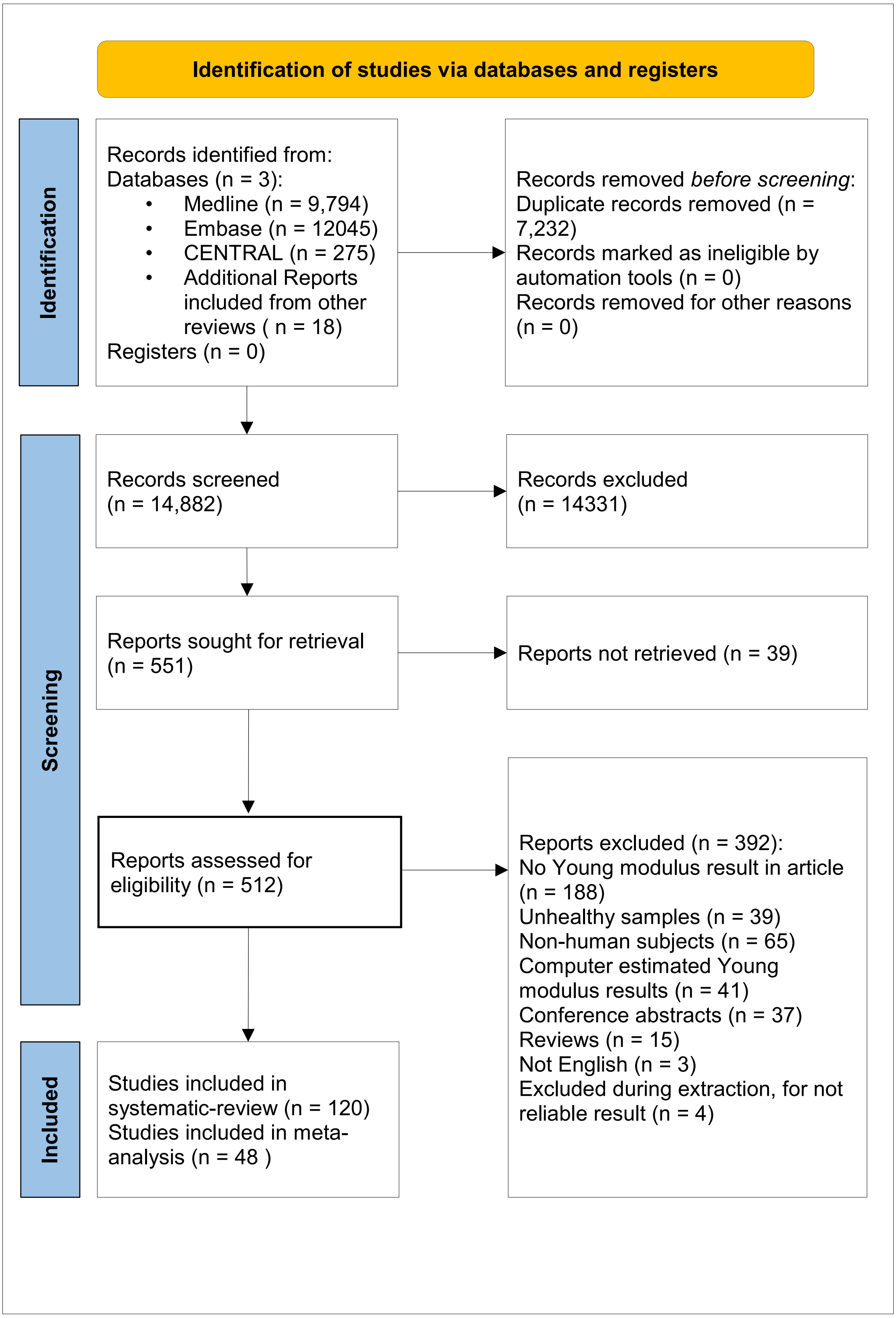


Figure 2. PRISMA 2020 flowchart representing the study selection process.

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Table 1. Main characteristics of the included studies

Author	**Country**	**Element number**	**Specimen size**	**Bone specimen origin**	**Sex (male, female, mixed, NA)**	**Age (mean, years)**	**Testing method**	**Specimen condition**	**Orientation of loading**
Anglin, C. (1999)	Canada	10	1mm< <5mm	scapula	female	80	nanoindentation	dry	side
Ashman, R.B. (1988)	USA	3	1mm< <5mm	femur	NA	NA	UH	wet	non defined
Banse, X. (1996)	Belgium	20	>5mm	femur	male	63	compression	wet	non defined
Bargren, J. H. (1974)	UK	2	1mm< <5mm	femur	female	23	tension	wet, dry	axial
Bensamoun, S. (2004)	France	1	1mm< <5mm	femur	male	70	UH	wet	axial
Bensamoun, S. (2008)	France	3	1mm< <5mm	femur	male	70	nanoindentation	wet, dry	axial
Berteau, J.P. (2014)	France	34	1mm< <5mm	fibula	mixed	40	UH, 3p-bending	wet	side, non defined
Bini, F. (2002)	Italy	3	<1mm	femur	NA	NA	pressure, tension	NA	non defined
Birnbaum, K. (2001)	Germany	21	>5mm	femur	NA	73	compression	NA	non defined
Bry, R. (2012)	France	12	1mm< <5mm	humerus	male	65	compression, tension	NA	AP, axial
Carretta, R. (2013)	Switzerland	1	<1mm	femur	female	56	tension, 3p-bending	dry	non defined
Choi, K. (1990)	USA	2	<1mm	tibia	male	60	3p-bending	wet	non defined
Cuppone, M. (2004)	UK	30	1mm< <5mm	femur	mixed	78	3p-bending	wet	non defined
Dall'ara, E. (2013)	Austria	12	1mm< <5mm	vertebra	mixed	80	nanoindentation	dry	AP, side, axial
Dong, N. X. (2004)	USA	18	1mm< <5mm	femur	NA	56	tension	NA	AP
Ducheyne, P. (1977)	Belgium	15	1mm< <5mm	femur	male	47	compression	wet	axial
Dunham, C. E. (2005)	Canada	7	1mm< <5mm	humerus	female	79	compression	wet	axial
Evans, F. G. (1976)	USA	6	1mm< <5mm	fibula	male	57	tension	wet	non defined
Fan, Z. (2003)	USA	1	<1mm	tibia	male	52	nanoindentation	dry	non defined
Fan, Z. (2002)	USA	2	1mm< <5mm	tibia	male	52	nanoindentation	dry	AP, side, axial
Franzoso, G. (2009)	Italy	1	1mm< <5mm	femur	male	81	nanoindentation	dry	side, axial
Guérard, S. (2011)	France	12	>5mm	calcaneus	mixed	81	compression	wet	non defined

Hengsberger, S. (2001)	Switzerland	2	1mm< <5mm	femur	female	86	nanoindentation	dry	axial
Jensen, N. C. (1988)	Denmark	4	>5mm	tibia	NA	68	compression	wet	axial
Katsamanis, F. (1990)	USA	1	>5mm	femur	male	50	tension	dry	axial
Keller, T. S. (1990)	USA	9	1mm< <5mm	femur	mixed	62	4p-bending	wet	AP
Korsa, R. (2015)	Czech Republic	3	<1mm	humerus	male	37	nanoindentation	NA	AP, side, axial
Kuhn, J. L. (1989)	USA	5	<1mm	iliac crest, femur	male	39	3p-bending	wet	non defined
Mansat, P. (1998)	France	6	>5mm	scapula	NA	NA	UH	wet	AP, side, axial
Martens, M. (1983)	Belgium	45	>5mm	femur	mixed	55	compression	wet	AP, side, axial
Moreschi, H. (2011)	France	3	NA	calcaneus	NA	79-88	compression	wet	axial
Nomura, T. (2007)	Japan	12	>5mm	mandibula	female	66	UH	wet	non defined
Odgaard, A. (1989)	USA	17	1mm< <5mm	tibia	male	54	compression	wet	non defined
Odgaard, A. (1991)	Denmark	18	>5mm	tibia	male	55	compression	wet	axial
Pattijn, V. (2001)	Belgium	1	NA	femur	NA	NA	compression, UH	wet	non defined
Pattin, C. A. (1996)	USA	9	1mm< <5mm	femur	male	31	compression, strain	wet	axial
Reilly, D. T. (1974)	USA	19	1mm< <5mm	femur	NA	53	strain/compression	wet	axial
Reilly, D. T. (1975)	USA	11	1mm< <5mm	femur	mixed	21-71	strain/compression	wet	axial
Reisinger, A. G. (2020)	Austria	1	1mm< <5mm	femur	female	61	strain	wet	non defined
Rho, J. Y. (2002)	USA	9	1mm< <5mm	femur	male	55	nanoindentation	dry	non defined
Rho, J. Y. (1993)	USA	2	<1mm	tibia	NA	60	strain, UH	wet	non defined
Rho, J. Y. (1997)	USA	4	1mm< <5mm	tibia, vertebra T12	male	59	nanoindentation	dry	axial, non-defined
Rho, J. Y. (1999)	USA	1	<1mm	femur	male	56	nanoindentation	wet	axial
Sedlin, E. D. (1966)	Sweden	14	1mm< <5mm	femur	mixed	59	3p-bending	wet	non defined
Stern, L. C. (2011)	USA	10	1mm< <5mm	femur	male	49	strain	wet	non defined
Subit, D. (2013)	USA	6	<1mm	rib VI-VII	NA	64	strain	wet	non defined
Winwood, K. (2006)	UK	2	1mm< <5mm	femur	female	54	strain, compression	wet	axial
Zysset, P. (1998)	USA	8	<1mm	femur	mixed	75	nanoindentation	wet	non defined

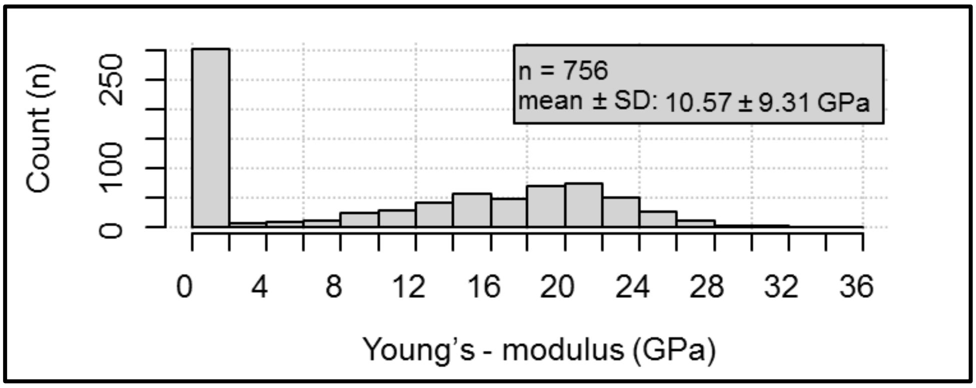
Table 2. Detailed characteristics of the acquired cohort

		n	mean E (Gpa)	SD (Gpa)	min (Gpa)	max (Gpa)
	Distinct donor	212				
	Specimen	397	-	-	-	-
	Entry count	756	10.61	± 9.22	0.008	33.70
All bone	Femur	419	12.17	± 9.29	0.008	27.00
	Tibia	125	6.46	± 9.43	0.073	27.10
	Fibula	58	13.47	± 4.6	3.000	21.60
	Vertebra	44	12.56	± 2.61	5.320	15.72
	Humerus	40	14.99	± 7.51	0.117	24.10
	Scapula	28	0.19	± 0.12	0.010	0.42
	Talus	27	0.35	± 0.25	0.068	1.22
	Calcaneus	15	0.24	± 0.12	0.080	0.51
	Mandibula	12	24.97	± 5.96	14.400	33.70
	Rib	6	13.52	± 2.59	11.400	18.50
	Iliaca	4	4.05	± 0.93	3.030	5.26
Sample conditions	Wet	541	8.56	± 8.98	0.008	33.70
	Dry	144	17.80	± 7.12	0.010	27.10
	NA	93	11.44	± 7.69	0.118	24.10
Sex	Male	440	12.66	± 9.23	0.008	27.10
	Female	98	9.67	± 9.01	0.010	33.70
	NA	240	7.25	± 8.2	0.068	21.35
Anisotropy	Axial	360	10.44	± 9.75	0.019	27.10
	AP	54	9.15	± 5.39	0.008	19.70
	ML	74	5.74	± 5.67	0.010	18.50
	NA	290	12.35	± 9.35	0.080	33.70
Sample size	<1 mm	108	15.64	± 6.58	1.150	26.80
	>1 mm	665	9.87	± 9.32	0.008	33.70
	NA	5	0.35	± 0.17	0.148	0.54
Macro-structure	Cortical	437	16.78	± 6.03	0.107	27.10
	Cancellous	341	2.70	± 5.9	0.008	33.70
Age	<40y	111	12.62	± 8.4	0.071	25.00
	>60y	375	9.47	± 9.2	0.008	33.70
	Other	264	12.12	± 9.23	0.019	27.10
	NA	28	2.28	± 4.48	0.148	13.10
Method	Compression	302	2.96	± 6.33	0.008	23.50
	Nanoindentation	203	18.22	± 6.42	0.010	27.10
	Tension	114	15.44	± 4.34	1.890	23.41
	Bending	88	10.75	± 7.38	0.107	21.35
	Ultrasound	71	13.50	± 9.3	0.148	33.70
Anat location	Proximal	180	2.10	± 4.3	0.008	22.50
	Distal	143	7.03	± 9.19	0.019	24.66
	NA	455	15.10	± 7.66	0.010	33.70
Within bone	Diaphysis	392	16.53	± 6.28	0.107	27.10
	Epiphysis	193	0.75	± 2.14	0.010	22.50
	Metaphysis	48	3.10	± 4.84	0.008	16.24
	Lumbar	30	12.19	± 2.79	5.320	15.72
	Thoraco-lumbar	14	13.36	± 2.03	8.200	15.50
	NA	101	9.21	± 11.27	0.068	33.70

8.1.4. Subgroups comparisons

In the overall histogram of all entries, *E* values of cortical and cancellous specimens showed a disjunct distribution (**Figure 3**). We focused on the three most common bones (femur, tibia, and fibula) to achieve more homogeneous groups and investigated them by variable subgroupings or pair comparisons. The summary of the applicable findings can be seen in **Table 3**, and their explanatory variable comparisons are shown in **Table S2**.

Figure 3. Absolute distribution of *E* values.



Both femoral and fibular cortical bone specimens showed higher *E* values overall in the elder subgroup (femur: 19.35±3.72 GPa for those above 60 years vs 14.57±9.21 GPa for those below 40 years; $p<0.001$) (**Table S4** row 1-57).

For cortical bone specimens with sufficient entry counts (i.e., femur, fibula) male sex was associated with significantly higher *E* values in femoral diaphysis cortical bone (male: 19.20±6.17 GPa; females: 11.25±6.17 GPa; $p<0.001$). This trend changed in the subgroup of entries measured by bending. Female specimens tended to have greater *E* values in the cortical bone of the fibula and femoral cancellous bone, but without significant difference (**Table S4** rows 104-159).

An appreciable amount of data was only available for the cortical femoral diaphysis. As for the overall comparison, the mean *E* value was higher in dry (22.42±2.36 GPa) than in wet (16.87±6.33 GPa) specimen entries (p<0.001). This tendency was consistent for subgroup comparisons, too. (**Table S4** row 82-103).

Table 3. Summary of Young's modulus subgroup comparisons' applicable findings (NA = not applicable)

Bone region	Sample count	Age	Anisotropy	Sex	Condition	Size	Testing method
Cortical bone tissue							
		<40 vs >60	axial vs AP vs ML	male vs female	dry vs wet	<1mm vs >1mm	bending vs strain vs compression vs nanoindentation vs US
Fibula diaphysis	58	*p > 0.05*	NA	*p > 0.05*	NA	*p > 0.05*	***p < 0.05***
Tibia epiphysis	1	NA	NA	NA	NA	NA	NA
Femur epiphysis	1	NA	NA	NA	NA	NA	NA
Femur diaphysis	274	***p < 0.05***	***p < 0.05***	***p < 0.05***	***p < 0.05***	***p < 0.05***	***p < 0.05***
Cancellous bone tissue							
Bone region	**Sample count**	**Age**	**Anisotropy**	**Sex**	**Condition**	**Size**	**Testing method**
		<40 vs >60	axial vs AP vs ML	male vs female	dry vs wet	<1mm vs >1mm	bending vs strain vs compression vs nanoindentation vs US
Fibula diaphysis	0	NA	NA	NA	NA	NA	NA
Tibia epiphysis	66	NA	NA	NA	NA	NA	NA
Femur epiphysis	97	NA	NA	*p* > 0.05	NA	NA	NA
Femur diaphysis	3	NA	NA	NA	NA	NA	NA

Both in fibular and femoral (<1 mm: 20.24±3.33 GPa; >1 mm: 17.22±6.25 GPa; p<0.001) diaphysis of cortical bones, small (<1mm) specimen size entries had higher E values. However, nanoindentation measurements in femoral bone specimens showed an opposite trend, but this difference was not significant (**Table S4** rows 160-194).

A comparison was only possible for cortical fibular and femoral diaphysis specimens. In femoral specimens, the nanoindentation measurements had the highest *E* values (21.71±2.48 GPa), followed by compressional (17.93±4.13 GPa) and tensional measurements (15.38±4.24 GPa). The smallest *E* values were measured by bending (12.76±8.85 GPa). US entries could not be included in the comparison due to their low number. In the fibula, bending showed smaller *E* values (9.10±1.55 GPa) than US (17.14±1.89 GPa), but no other measuring method had a sufficient entry for comparisons (**Table S4** row 195-412)(**Figure 4**).

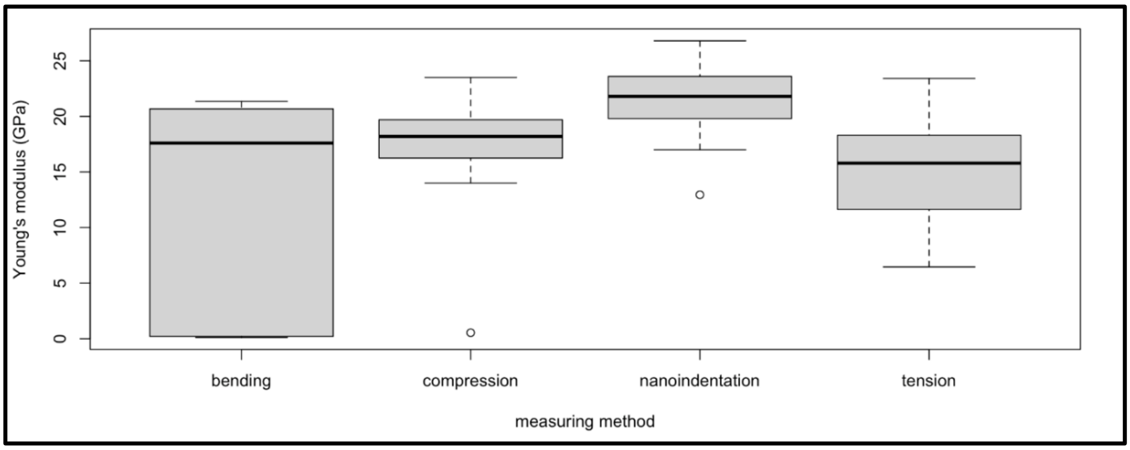


Figure 4. *E* values by measuring methods in the cortical bone of the femoral diaphysis.

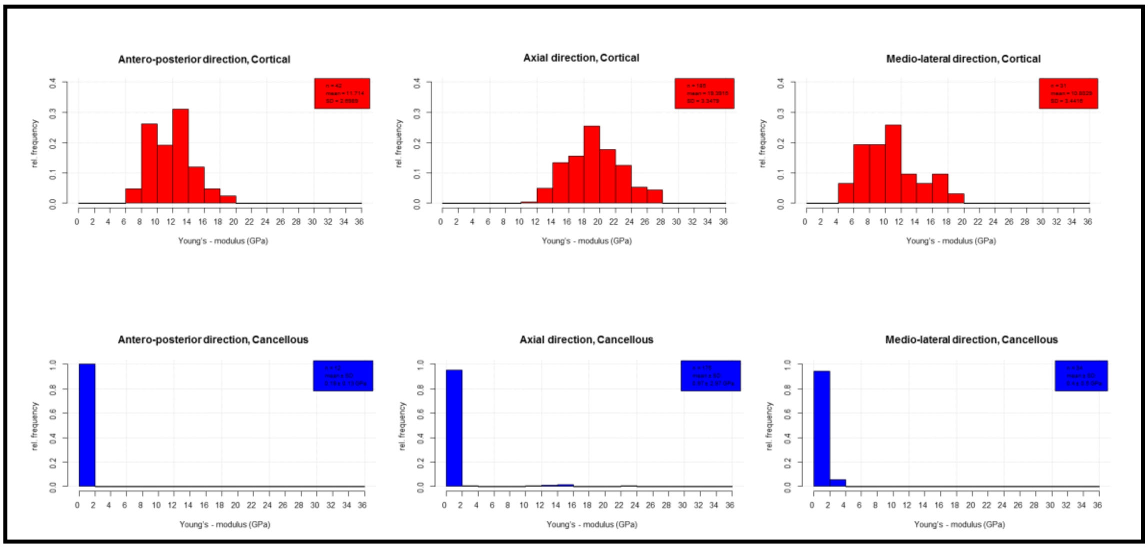


Figure 5. Relative distribution of cortical and cancellous bones by anisotropy.

The variation of E values with load orientation was investigated for all bones together, as shown in As well as separately for the three most common bones. In both ways, the axially (19.39±3.34 GPa) loaded specimens had the highest E values. Between AP (11.71±2.69 GPa) and ML (10.80 ± 3.44 GPa) orientations, the difference was significant in cortical bones, but not in cancellous bones (**Figure 5**). In case of femoral cortical bone, significant difference ($p<0.01$) in anisotropy was seen between AP (10.46±1.98 GPa) and axial (18.87±3.08 GPa), and in femoral cancellous bone between axial (0.77±2.86 GPa) and ML (0.59±0.61 GPa)($p=0.015$)(**Figure 6**). The figures (**Figure 7**) depicting Bland-Altman plots suggested a significant difference between the mean values of axial and AP as well as of axial and ML entries. Among the most common bones, applicable data were available only in the cortical bone of femoral diaphysis for axial and AP comparisons (**Table S4** row 58-81).

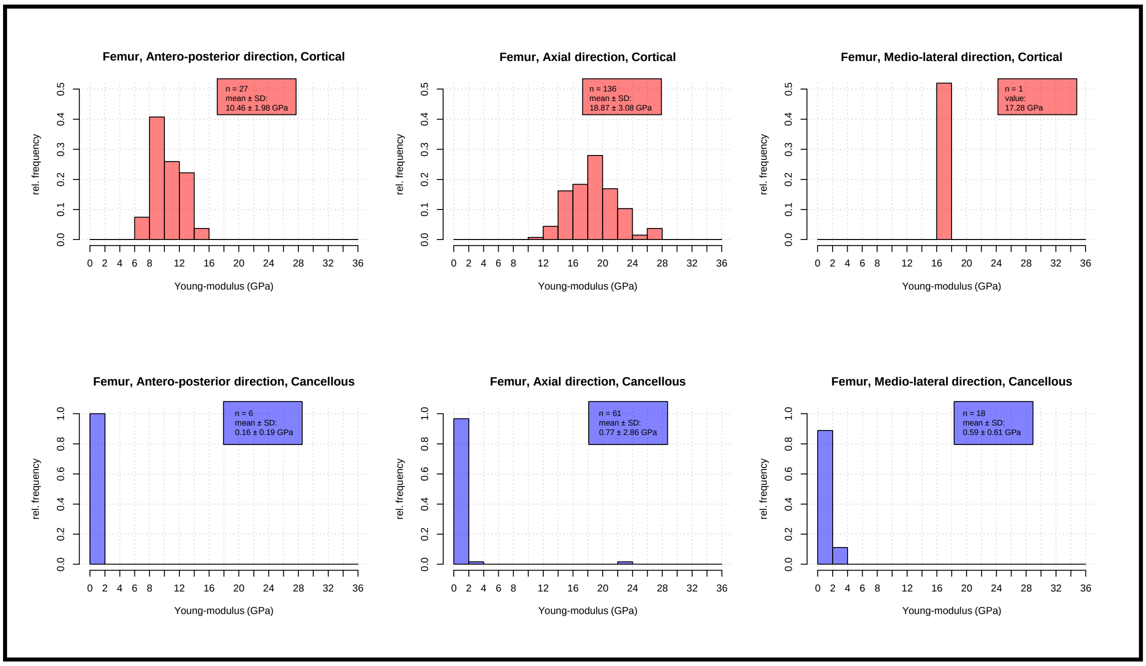


Figure 6. Relative distribution of cortical and cancellous femoral diaphysis by anisotropy.

Of the available data, the relationship in terms of E value for bone regions was only possible for the cancellous bone of the femoral epiphysis and metaphysis. In overall comparison, the epiphysis *E* values (0.87±2.35 GPa) were three times higher (p=0.010) than those of the metaphysis (3.01±5.04 GPa). Nonetheless, in values by compression, the epiphysis became two times higher (0.67±0.52 GPa; 0.30±0.38 GPa;p<0.001) **(Table S4** row 432-457).

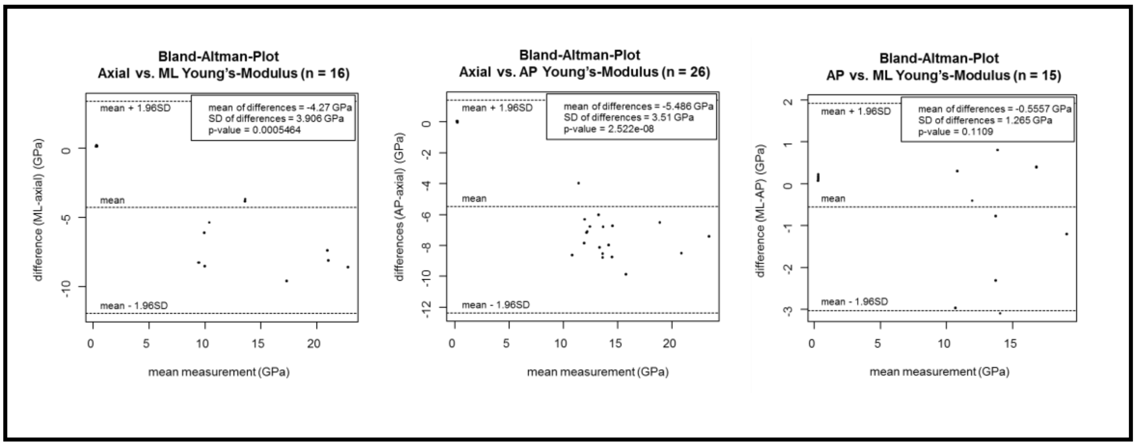


Figure 7. Bland-Altman plots, comparing the E values of the identical specimens loaded from more than one angle.

The overall comparison of the tubular bone ends in the knee joint revealed that the epiphysis of the tibia (1.05±1.21 GPa) was stiffer (p=0.026) than that of the femur (0.38±0.39 GPa) (**Table S4** row 413-431)(**Figure 8**).

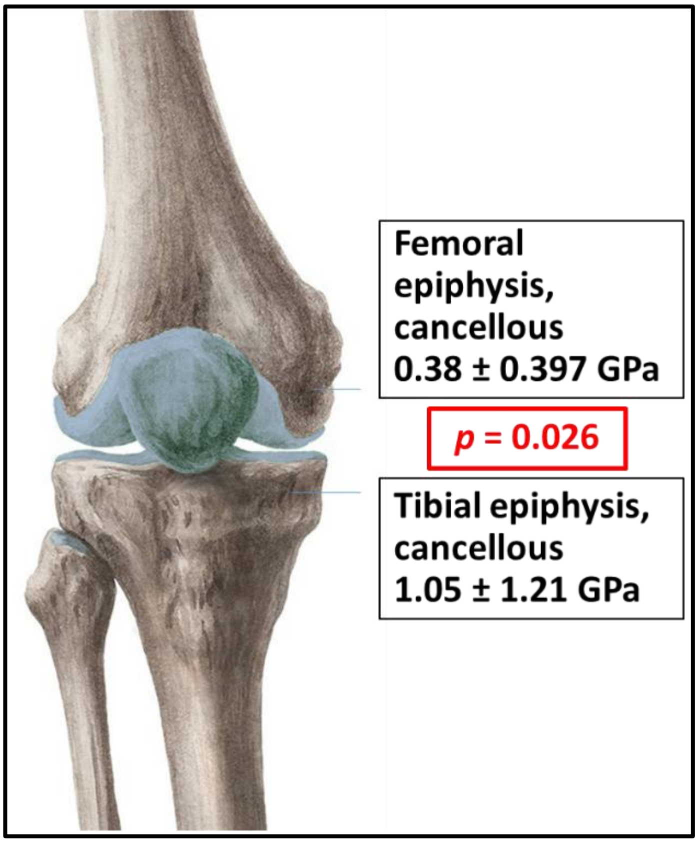


Figure 8. Comparison of *E* values between the femoral and tibial epiphyses.

8.1.5. Ranking

The direct regression analysis of the extracted data was not possible due to the unfavorable data structure (**Table S3**). However, with the help of the random forest method, the software calculated the variable importance and generated a weighted ranking of the explanatory variables of Young's modulus of bone. Here, the macrostructure, the measuring method, and the specific bone region had the most considerable impact on *E* values (**Figure 9**).(38)

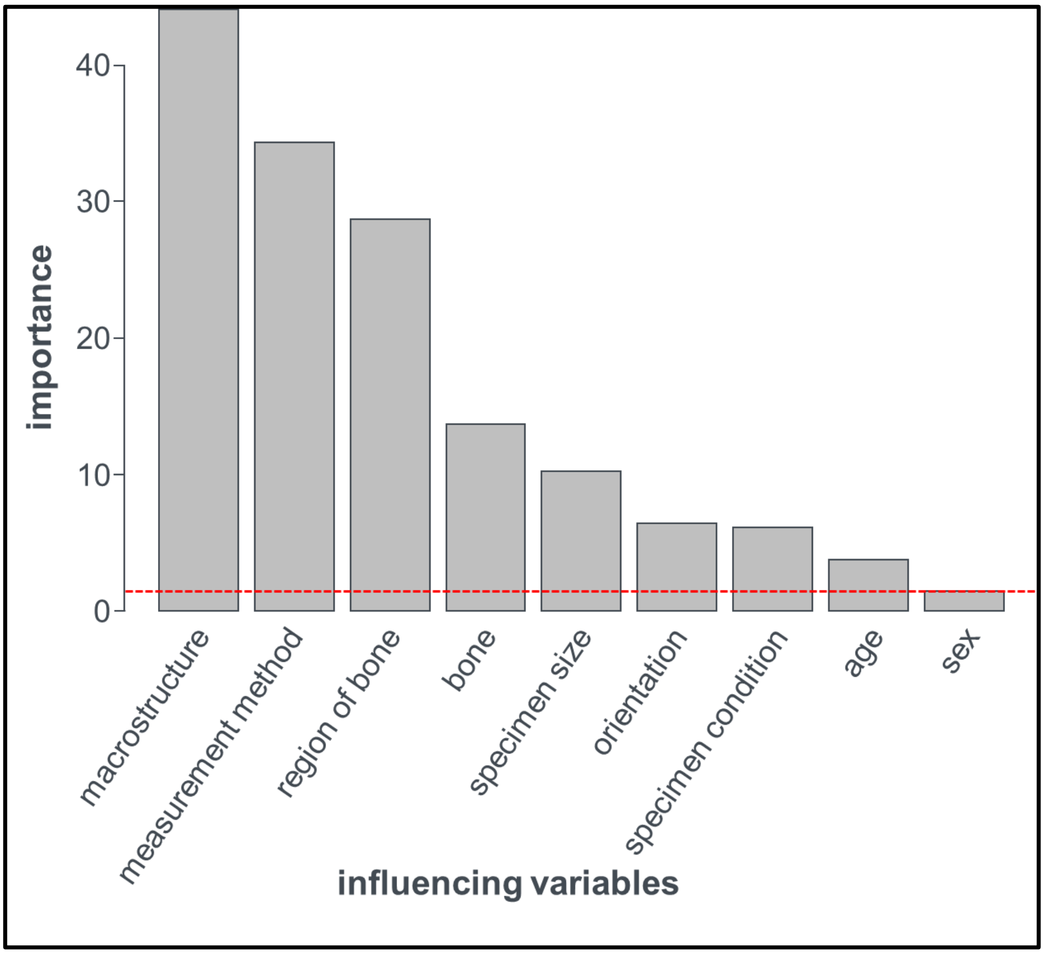


Figure 9. The impact of different variables on Young's modulus of bone (cut-off level marked as red broken line)

8.1.6. Risk of bias assessment

The result of the risk of bias assessment is presented in **Table S5** in the supplementary material.

8.2. Study II

8.2.1. Case-series study, basic characteristics

In total, 46 patients underwent Lockdown procedures in three centers combined, but complete follow-up data were available for only 39 patients (3 females, 36 males). Seven patients were lost during follow-up (not responding to available communication channels, not attending to follow-ups). The mean age was 38.90 ± 12.68 years (range: 16–76 years). The Lockdown procedure was used as a non-primary surgical option in seven cases (two acute, five chronic). The average interval between injury and surgery was 26.69 ± 84.36 weeks (range: 0.5–510 weeks). Of the injuries, 21 (54%) were classified as Rockwood type III, 6 (15%) as type IV, and 12 (31%) as type V. The mean follow-up period was 24.51 ± 10.12 months (range: 12.8–48.9 months), as the last outpatient visit date when the functional scores were taken. The injury involved the dominant arm in 17 cases and the non-dominant arm in 15 cases (NA in 7 cases). The mean time to return to work for all patients was 7.73 ± 9.95 weeks. The duration of physiotherapy averaged 5.38 ± 6.09 weeks. Detailed results are in **Table 4**.

Table 4. Basic characteristics of the case series.

Basic Characteristics	All Patient	Time		Surgery	
		Acute <3 Weeks	Chronic >3 Weeks	Primary (Non-Previously Operated)	Non-Primary Operation (Revision)
No. of patients	39	27	12	32	7
Primary/Revision	32/7	25/2	7/5	-	-
Acute/chronic		-	-	25/7	2/5
Gender (M/F)	36/3	25/2	11/1	29/3	7/0
Mean age at op. (years)	38.90 ± 12.68	35.52 ± 9.46	46.5 ± 15.2	36.69 ± 12.08	36.91 ± 14.33
Mean time of interval (injury—op) (weeks)	26.69 ± 84.36	1.07 ± 0.65	84.33 ± 139.11	25.44 ± 87.90	23.62 ± 87.86
Mean time to return to work	7.73 ± 9.95	6.87 ± 10.49	9.66 ± 8.73	8.57 ± 11.68	8.84 ± 11.73
Follow-up (months)	24.51 ± 10.12	23.18 ± 8.98	27.53 ± 12.19	23.84 ± 10.45	22.76 ± 9.72
Rockwood classification:					
III	21 (54%)	15 (55%)	6 (50%)	18 (56%)	3 (43%)
IV	6 (15%)	4 (15%)	2 (17%)	5 (16%)	1 (14%)
V	12 (31%)	8 (30%)	4 (23%)	9 (28%)	3 (43%)

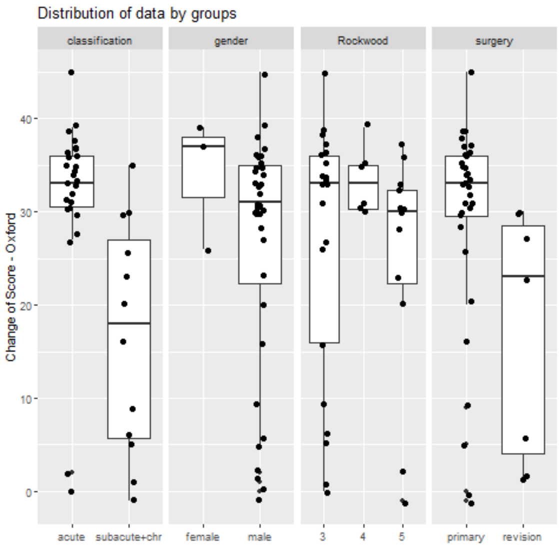
8.2.2. Case-series study, outcomes

Significant improvements were observed in all postoperative functional scores and pain levels. The NRS decrease was in favor of both acute (mean difference: −2.26; 95% CI: −3.99–−0.53; p = 0.013) and primary (previously non-operated) cases (mean difference: −2.37; 95% CI: −4.42–−0.32; p = 0.027). The patient-reported significant visible deformity was present preoperatively in 63% and 75% of acute and chronic cases, which decreased to 33% and 8% postoperatively. Still, in previously operated cases, there was no relevant change. The mean postoperative Oxford Shoulder Score (OSS), Constant, and Imitani scores were 44.92 ± 7.63, 90.20 ± 15.08, and 91.66 ± 16.36, respectively. Notably, OSS improved from 12.93 ± 7.14 to 44.56 ± 9.09 in acute cases, and from 29.17 ± 12.60 to 45.83 ± 2.29 in chronic cases, and the difference between the two improvements was 14.96 (95% CI: 6.45–23.47; p = 0.0017). Similar significant improvements were noted across all measured shoulder scores (Imitani, Constant, UCLA, DASH, SST, ASES). **Table 5** presents detailed preoperative and postoperative functional outcomes for both acute and chronic cases. In all instances, the observed improvements are statistically significant, with consistently more favorable results in the acute cases (**Table 5**). A subgroup analysis was also conducted comparing previously non-operated cases with revision cases. The box plots reveal notable differences across both the surgical subgroups and the acute vs. chronic cases. However, no substantial differences were observed between the subgroups concerning gender or Rockwood classification, as demonstrated in **Figure 10**. In the non-previously operated cases, the results are similar to the acute vs. chronic comparison, but the change is not significant (only relevant, according to the MCID values) in the OSS, Constant, and Imitani scores.(39, 92-95)

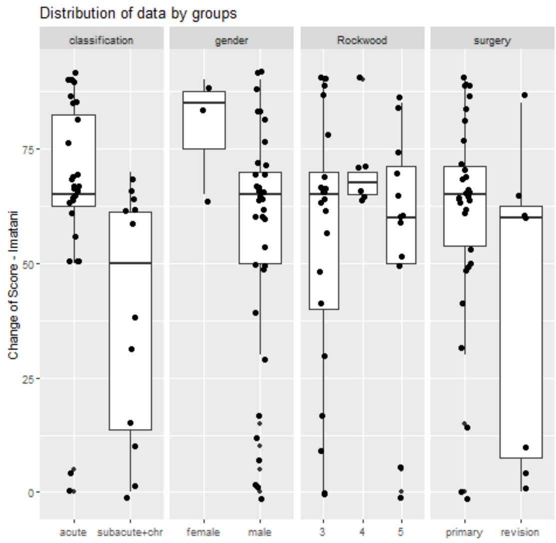
Table 5. Case series, changes in scores. Table of pre-and postoperative scores in acute and chronic cases with significant differences ($p < 0.05$). (diff.: difference).

	Acute				Chronic				Difference				*p* Value
	Preop		Postop		Preop		Postop		Acute		Chronic		(diff. Acute - diff.chr)
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
OSS	12.93	±7.14	44.56	±9.08	29.11	±12.60	45.83	±2.29	−31.63	±9.62	−16.67	±12.42	0.0017
IMITANI	26.11	±16.78	91.67	±19.22	52.08	±30.41	91.67	±9.13	−65.56	±22.12	−39.58	±27.26	0.0096
CONSTANT	18.22	±15.37	91.11	±17.33	47.83	±25.66	88.17	±9.53	−72.89	±22.07	−40.33	±26.96	0.0017
UCLA	8.52	±4.85	32.59	±6.20	17.00	±6.86	32.58	±3.63	−24.07	±7.78	−15.58	±8.27	0.0069
DASH	73.64	±16.35	7.65	±17.41	41.90	±21.55	6.97	±8.69	65.98	±20.24	34.93	±22.85	0.0004
SST (%)	6.47	±17.51	88.59	±19.65	34.74	±27.72	86.12	±10.26	−82.12	±25.91	−51.38	±32.54	0.0099
ASES	26.63	±15.07	90.44	±20.09	52.08	±26.12	93.25	±6.55	−63.81	±20.83	−41.17	±25.67	0.0151
NRS (1–10)	6.78	±1.76	0.85	±2.38	4.58	±2.81	0.92	±0.94	5.93	±2.34	3.66	±2.42	0.0131

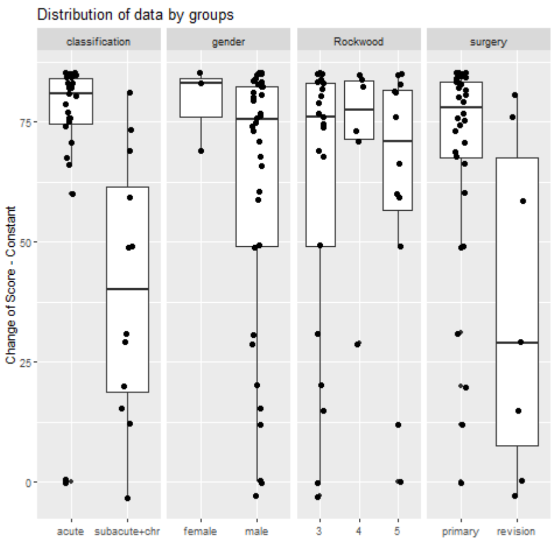
Preop: preoperative; Postop: postoperative; diff.: difference; chr.: chronic., ASES: American Shoulder and Elbow Shoulder score; UCLA: University of California Los Angeles Shoulder Score; NRS: Numerical Rating Scale; DASH: Disabilities of the Arm, Shoulder, and Hand Score; SST: Simple Shoulder Test Score


Distribution of data by groups
classification
gender
Rockwood
surgery
Change of Score - Oxford
0
10
20
30
40
acute
subacute+chr
female
male
3
4
5
primary
revision

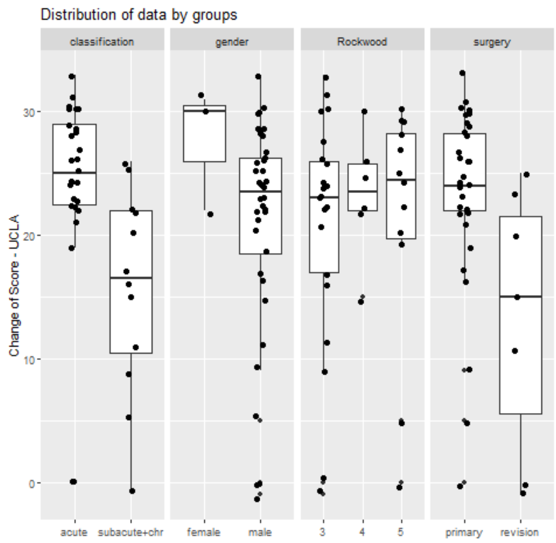
(a)


Distribution of data by groups
classification
gender
Rockwood
surgery
Change of Score - Imatani
0
25
50
75
acute
subacute+chr
female
male
3
4
5
primary
revision

(b)

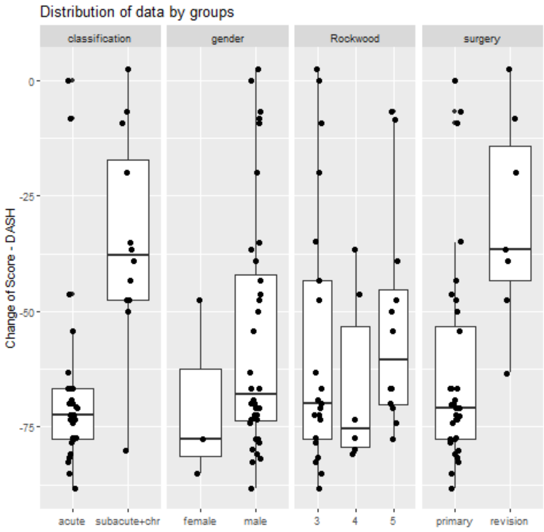

Distribution of data by groups
classification
gender
Rockwood
surgery
Change of Score - Constant
0
25
50
75
acute
subacute+chr
female
male
3
4
5
primary
revision

(c)

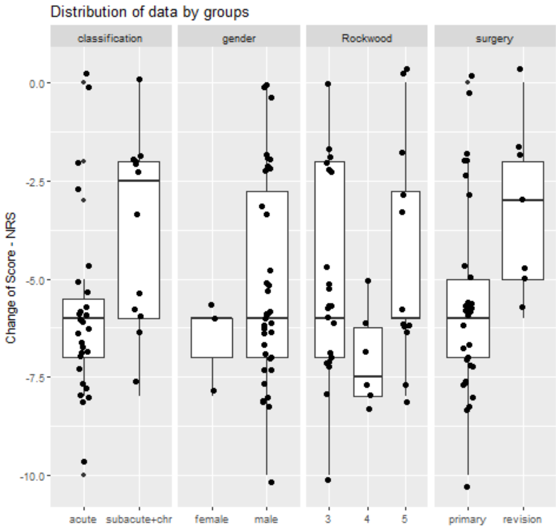

Distribution of data by groups
classification
gender
Rockwood
surgery
Change of Score - UCLA
0
10
20
30
acute
subacute+chr
female
male
3
4
5
primary
revision

(d)

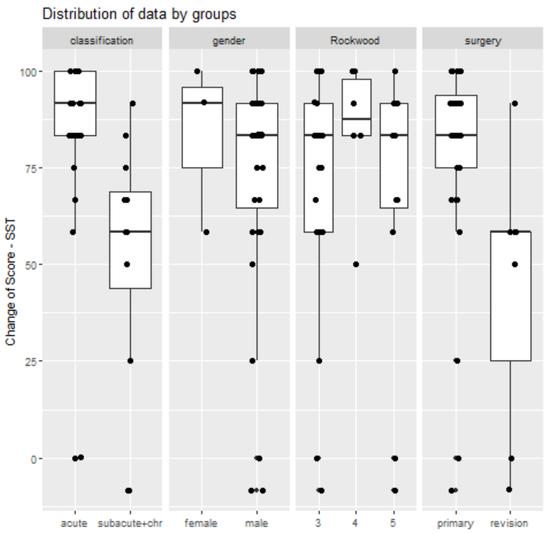
DOI:10.14753/SE.2025.3311



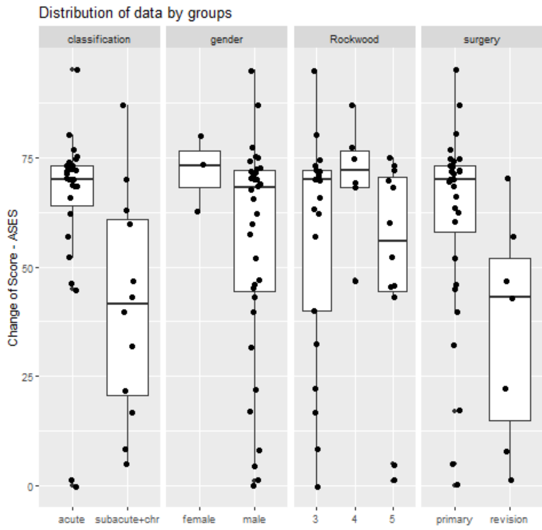
(e)



(f)



(g)



(h)

Figure 10. The data distribution is shown in box plots for each score by classification in time, gender, severity by Rockwood, and previous surgery. The figures demonstrate that acute and non-previously operated cases have better outcomes in all scores. The box plots represent the median and quartiles of the dataset. The horizontal line within the box represents the median, while the upper and lower quartiles are the upper and lower edges of the box. Box plots of functional outcomes: (**a**) Oxford score; (**b**) Imitani score; (**c**) Constant score; (**d**) UCLA (University of California Los Angeles Shoulder) score; (**e**) DASH (Disabilities of the Arm, Shoulder, and Hand) score; (**f**) NRS—Numerical Rating Scale; (**g**) SST (Simple Shoulder Test) score, (**h**) ASES (American Shoulder and Elbow Surgeons) score.

Complications were observed in 12 cases (30.8%) (in eleven patients), 7 in the acute group and 5 in the chronic group. Of these, seven cases were associated with wound redness and discharge, and four required revision surgery between two weeks and two months. Deep infection was confirmed in three cases (S. aureus; C. acnes), leading to implant removal in two cases. Thus, out of seven cases of infection, only two (5.1%) required implant removal and were considered implant failure. Three of the seven cases of varying discharge were managed conservatively with antibiotics. No pathogen was found behind superficial (spf.) infections. Six to thirty-four months after surgery, four patients experienced re-injury after their AC reconstruction, three of whom had been treated for spf. infections. All re-injured patients underwent revision surgery with implant removal. No other implant migration was observed. A detailed table of complications is presented in **Table 6**.

Table 6. Case series complications. A detailed table of complications is included in our case series.

	No. of Group	Patient ID	Previous Surgery	Proud Metal-work	Implant Loosening	Discharge	Trauma	Reoperation	Reason for Reoperation	Time Until Reoperation (days)	Lockdown Implant Extracted	Result of Bacteriogram
Acute	27		1	2	1	4	3	5		525.6 ± 613.48	4	
		H1	1	0	0	1	0	1	discharge	18	1	*S. aureus*
		H7	0	0	1	1	1	1	trauma	1045	1	0
		H8	0	0	0	1	0	1	discharge	58	0	0
		H27	0	0	0	0	1	1	trauma	1326	1	0
		P4	0	0	0	1	1	1	trauma	181	1	*S. aureus*
		H13	0	1	0	0	0	0	0	0	0	0
		H22	0	1	0	0	0	0	0	0	0	0
Chronic	12		1	1	1	3	1	3		141.33 ± 216.23	2	
		O3	0	0	1	1	0	1	discharge	19	0	*C. acnes*
		O4	1	0	0	1	1	1	trauma	391	1	0
		P5	0	0	0	1	0	1	discharge	14	1	*S. aureus*
		O2	0	1	0	0	0	0	0	0	0	0

8.2.3. Systematic Search, Basic Characteristics

Of 273 articles, 14 met the inclusion criteria, but only nine articles were eligible for data extraction.(4, 27, 40, 96-106) These studies involved 205 patients from 2007 to 2024, with a mean age of 39.17 ± 2.96 years (range: 16–76 years). The detailed flowchart of selection by PRISMA 2020 is demonstrated in **Figure 11** extraction.(4, 27, 40, 97, 98, 103-106)

The mean time from injury to surgery was 27.18 ± 24.51 months (range: 0–120 months). Previous surgeries, including the Weaver–Dunn procedure and Kirschner wire fixation, were noted in some studies (40, 98), but data on prior surgeries were not consistently reported. Time to return to work ranged from 5 to 6 weeks. Postoperative physiotherapy ranged from 6 to 8 weeks. The Rockwood classification of injuries was not consistently reported across studies. However, patient satisfaction exceeded 90% in four studies, with occasional pain reported in two studies; patient satisfaction, however, was not described in three studies. Detailed basic characteristics are presented in **Table 7**.

Table 7. Basic characteristics of the systematic search. Basic characteristics of the systematic search. (RCS: retrospective cohort study; PCS: prospective cohort study).

	Year of Publication	Origin of Authors	No. of Cases	Study Design	Male	Female	Mean Age (year)	Rockwood Classification	Mean Interval (months)	Mean Follow Up (months)
Narang et al. (27)	2023	UK	42	RCS	39	3	42.2	8:III; 4:IV; 30:V;	71.1	68
Jeon et al. (40)	2007	South Korea	11	RCS	11	0	39	9:III; 1: IV; 1:V;	18	55
Bhattacharya et al. (97)	2008	UK	11	PCS	10	1	35.1	>III	21	24
Wood et al. (105)	2009	UK	10	RCS	NA	NA	NA	>III	NA	6
Carlos et al. (4)	2011	UK	45	PCS	32	13	37.6	>III	7.2	26.9
Cetinkaya et al. (98)	2018	Turkey	16	RCS	16	0	38.5	>III	NA	20
Kumar et al. (103)	2014	UK	24	RCS	NA	NA	42	13:III; 4:IV; 7:V;	39	30
Saraglis et al. (104)	2022	UK	25	RCS	22	3	36	IV: 19; V:6	NA	NA
Wright et al. (106)	2015	UK	21	RCS	21	0	43	12:III; 1:IV; 8:V;	6.80	30
No. of patients			205							
No. of studies	9									

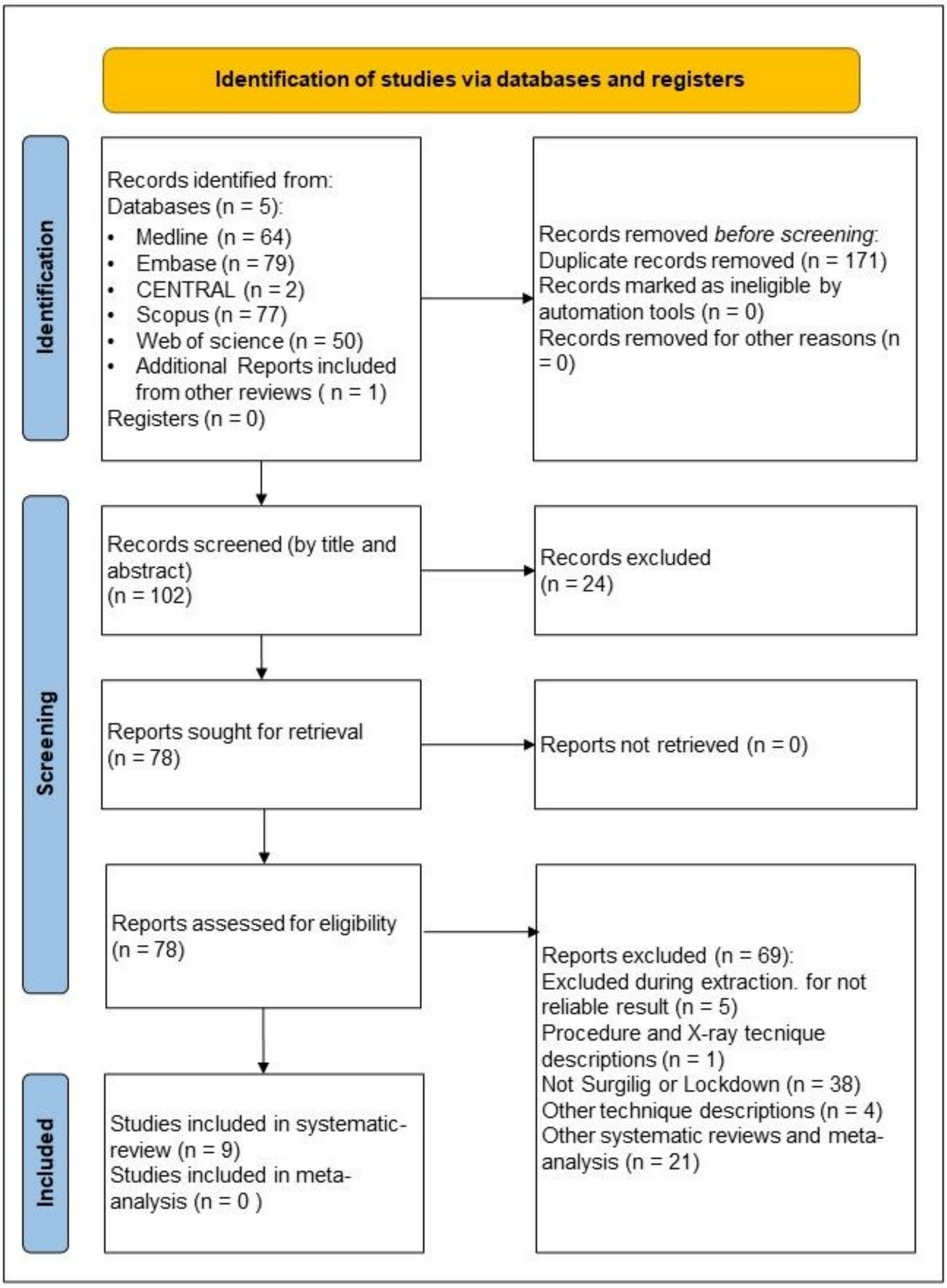


Figure 11. Systematic Review flowchart (PRISMA 2020). In this systematic review, nine studies were evaluated from the 102 screened records after the initial search results of 273 records.

8.2.4. Systematic Search, Outcomes

Due to incomplete data, an accurate statistical analysis of shoulder scores was not possible. Preoperative scores were available only for OSS and Nottingham scores in three articles, whereas postoperative data were more commonly reported. The mean postoperative OSS from four articles was 38.46 ± 13.36 (4, 27, 103, 104, 106), and Constant and Imitani scores from five and two articles were 85.46 ± 4.20 (40, 97, 98, 104, 106) and 85.85 ± 6.57, respectively (40, 97). UCLA and Simple scores were only available from Carlos et al.(4) Detailed basic characteristics are presented in Table 4. The heterogeneity of the data prevented our group from completing the meta-analysis. (4, 27, 40, 97, 98, 103-106) **Table 8** presents the available pre- and postoperative article numbers for each functional outcome value, reports of deformity, and pain levels.

Table 8. Heterogeneity of the literature. Summary of data collected from the articles. Presentation of the heterogeneity of the literature. (ASES: American Shoulder and Elbow Shoulder score; UCLA: University of California Los Angeles Shoulder Score; NRS: Numerical Rating Scale).

	Oxford	**ASES**	**Nottingham**	**Imitani**	**Constant**
Preop.	2	0	1	0	0
Postop.	5	0	1	2	5
	UCLA	**Simple**	**Pain (NRS)**	**Deformity**	**Complications**
Preop.	0	0	2	1	-
Postop.	1	1	4	0	8

Preop: preoperative; Postop: postoperative; diff.: difference; chr.: chronic., ASES: American Shoulder and Elbow Shoulder score; UCLA: University of California Los Angeles Shoulder Score; NRS: Numerical Rating Scale; DASH: Disabilities of the Arm, Shoulder, and Hand Score; SST: Simple Shoulder Test Score

8.2.5. Systematic Search, complications

The rate of complications rate across the studies was 34.6% (71/205 patients), with the most common issues being implant-related problems such as proud metalwork (a noticeable, protruding bulk of metalwork beneath the skin), loosening, stiffness, joint subluxation, and subacromial impingement, occurring in 30.7% of cases. Spf. infection and discharge occurred in eight cases. Reoperations were performed in 15 cases (7.3%), and 11 (5%) implants were removed due to re-injury, subacromial impingement, and infection. The cases were considered as implant failures that had to be removed during revisions due to non-reinjury. Therefore, the aggregated implant failure rate was 11/205 (5.4%). A detailed list of complications in the SR is in **Table 9**.

8.2.6. Risk of Bias Assessment

The result of the risk of bias assessment is presented in **Table S6**, **Figures S1** and **Figure S2** in the Supplementary Material, which shows a low level of evidence due to their study designs.

Table 9. Complications in the systematic review. Detailed table of complications in the literature

Article	Number of Patients	Implant Loosening, Osteolysis, Fracture	Subluxation	Other (Stiffness, Graft Rupture, Subacromial Impingement)	Proud/Prominence Metalwork	Superficial Infection, Discharge	Trauma	Previous Surgery	# of Reoperation	Reoperation Due to Non-Reinjury	Reasons for Reop	Previous Surgery	Time Until Reoperation (months)	Lockdown Implant Extracted	Result of Bacteriogram
Narang et al. (27)	42	0	8 (X-ray)	3 (stiffness)	5 (proud)	1	0	0	2	2	Proud metal.	NA	NA	2	NA
Jeon et al. (40)	11	1 (coracoid fr,)	11 (X-ray)	2 (sub)	0	0	1	3 (Weaver Dunn)	2	2	Subacr. Burs.	0	6–10	1	NA
Bhattacharya et al. (97)	11	4 (looseening)	0	1 (graft)	4 (prom.)	0	NA	0	1	1	Graft rupture	0	6	1	NA
Wood et al. (105)	10	0	0	0	0	0	0	NA	0	0	0	0	0	0	0
Carlos et al. (4)	45	1 (loosening)	13 migration = sublux (X-ray)	0	6 (skin irritation)	NA	0	NA	7	7	6 inf., 1 loosening	NA	9	6	0
Cetinkaya et al. (98)	16	1 (lysis)	1 (X-ray)	0	0	0	0	1 (K-wire)	0	0	0	0	0	0	0
Kumar et al. (103)	24	0	0	0	0	4	1	NA	1	0	0	0	NA	0	0
Saraglis et al. (104)	25	1 (osteolysis)	0	0	0	3	0	0	1	1	infection	0	NA	1	0
Wright et al. (106)	21	0	0	1 (subacrom. imp.)	0	0	1	NA	1	1	Subacr. Burs.	0	NA	0	0
	205	8	33	7	15	8	3	4	15	14			6–10	11	0
	100%	3.9%	16.1%	3.4%	7.3%	3.9%	1.5%	2.0%	7.3%	6.8%				5%	

NA: not available; #: number; prom: prominent; fr: fracture;

9. DISCUSSION

9.1. Summary of findings, international comparisons (including all studies)

Both studies reveal a deeper, shared narrative centered around biomechanics, material behavior, and system adaptability. In addition, these studies highlight the significance of understanding structural integrity and the need for tailored approaches in fields that intersect engineering principles with biological realities.

Our studies originated from a clinical observation that the Lockdown ligament has a very high tensile strength, and sometimes it is able to break off the coracoid process. For this reason, the clinical results were assessed via our own study and a literature review. Also, it was our intention to create an FE model of the coracoid to analyse the risk of fracture. The latter plan, however, could not be accomplished as a seemingly simple step, i.e., what mechanical properties bone tissue has, proved to be a question that required extensive research due to the complexity of the problem. Therefore, the idea of a finite element model was abandoned as it would have exceeded the boundaries of this thesis. The study of Young's modulus emphasizes how bone's mechanical properties, like stiffness and elasticity, vary based on factors such as macrostructure, orientation, and moisture content. Bone tissue often seems to behave like a complex composite material rather than isotropic metals. (The result that macrostructure had the most significant impact was consistent with the observation by Rho et al., who explained that the cortical and the trabecular bones did not behave mechanically in the same way.(83)) This concept parallels the Lockdown surgery's focus on restoring the biomechanical function of the AC joint using anatomical reconstruction. The Lockdown artificial ligament's ability to achieve a pull-out strength of 1700N, surpassing traditional CC slings (483-500N) from Fiberwire, reflects the application of biomechanical principles in surgical innovation.(27) In both cases, achieving optimal mechanical performance relies on recognizing the distinct properties of the biological materials being manipulated—whether bone or soft tissue—and leveraging them to achieve stability and strength.

Anisotropy, or the directional dependence of material properties, is critical in implant fitting and finite element planning. The first study showed that cortical and trabecular bones behave differently under mechanical loads, with orientation playing a pivotal role in *E* value variability. (Our results were in agreement with the results of Fan et al.(12)

They also concluded that measurements using axial load yield higher *E* values than those using AP and ML loads. Many FEAs use isotropic and homogeneous elements (107-111) because they make calculations faster and easier, and because the resolution of clinical quantitative computed tomography (QCT) is insufficient for detecting anisotropy.(112) Taddei et al. demonstrated that FEA results could be improved by transforming Hounsfield unit values into *E* values before sending the data for further finite element (FE) calculations.(113) This FE model was also isotropic. Trabelsi et al. investigated inhomogeneous and orthotropic FE models, and their conclusion was that a more realistic FEA was needed.(114) The question in brief is as follows. CT scans detect the radiopaque part of bone, the mineralized components, but do not give information about the elastic components, such as the collagen structure. If we accept the theory that bone is a composite material, we have to question whether any correlation may exist between Hounsfield units and bone mechanical properties.) This insight directly correlates to Lockdown surgery, where anatomical reconstruction aims to restore the original dynamic behavior of the AC joint's ligamentous structures. This artificial ligament can promote favorable tissue reactions and ingrowth, contributing to the strength and flexibility of the reconstructed system, which explains the functional outcomes.(115) In our cohort, functional outcomes were notably superior in the acute group and most metrics of the non-previously operated group, as detailed in **Table 5** and **Figure 9**. While minimal clinically important differences (MCIDs) have not been explicitly defined for AC joint dislocations, thresholds derived from rotator cuff pathology, as referenced by Lindborg et al., offer a useful benchmark.(39) In subgroup comparisons between primary and revision cases, most functional outcomes showed statistically significant differences - except for the OSS, Constant, and Imitani scores. Nevertheless, these values still surpassed established MCID thresholds, indicating clinical relevance. Specifically, the mean difference for the OSS was 12.22 (95% CI: −0.34–24.78; p = 0.051), and for the Constant score, it was 32.07 (95% CI: −0.73–64.86; p = 0.054), both exceeding the MCIDs of 3.3 and 10, respectively.(92, 116) No MCID has yet been defined for the Imitani score in the existing literature. A sample size of 71 is needed for 80% power, but the MCID and the visualization by box plots confirm better results in the non-previously operated group. Our postoperative results for the Lockdown cohort align closely with existing literature. Aggregated data from prior studies report mean postoperative scores of 38.46 ± 13.36

(OSS), 85.46 ± 4.20 (Constant), and 85.85 ± 6.57 (Imitani). Our cohort demonstrated comparable outcomes, with scores of 44.92 ± 7.63, 90.20 ± 15.08, and 91.66 ± 16.36, respectively. Systematic reviews by Sircana and Borbas et al. reported mean postoperative Constant scores ranging from 87.2 to 90.6, consistent with our findings.(117, 118) Similarly, Kumar et al. observed favorable trends in Nottingham scores, echoing our improvements. (103). However, the absence of preoperative scores in most of the existing literature limits the ability to make direct comparisons, as the majority of published studies focus solely on postoperative outcomes. Narang et al. and Kumar et al. concluded that the Lockdown procedure outperformed the Weaver–Dunn technique regarding functional outcomes and recovery time. (27, 103) (As already mentioned in the introduction section, the older alternative methods, such as Bosworth screw, Kirschner wire, or Hook plates, offer instant fixation, but the metal implants, due to their rigid nature, can lead to subacromial erosion, impingement, shoulder stiffness, and pain.(20, 23))

Both studies emphasize the adaptability of biological materials and the need for context-specific responses. In the case of Young's modulus, the finding that wet specimens exhibited lower *E* values than dry specimens underscores the influence of environmental factors on material properties. (We found that wet specimens had smaller *E* values than dry ones, which was in accordance with the literature.(14, 65, 119, 120) A possible explanation for this could be connected with the behavior of collagen. Without water, collagen fibrils might stiffen and contract axially, leading to a higher bone *E* value.(121)) Similarly, Lockdown surgery outcomes demonstrated variability depending on patient-specific factors such as prior surgeries, injury chronicity, and high-energy trauma. Both fields highlight the responsiveness of biological materials to their environment, whether it's the hydration state of bone or the physical demands placed on a reconstructed AC joint. By accounting for these context-dependent variables, researchers and clinicians can develop more robust models and improve patient-specific surgical interventions.

Other factors, such as size, sex, age, and location, were also investigated in Study I. We intended to compare more bones from different locations; however, insufficient data were available in the literature. In the case of size, we used the smallest dimension of the specimen as the size parameter for our analysis. According to our results, specimens with a size less than 1 mm showed higher *E* values. The reason for this was most probably the fact that small specimens were predominantly measured by nanoindentation, while larger specimens were tested mainly by other methods.

The *E* values of male and female specimens were different. A possible explanation for significantly higher male values could be that the stiffer cortical bone may cause stress shielding. The low number of female specimens from cancellous femoral epiphysis can explain the lack of significance, but similar results were found by Vale et al.(122)

In the study of Ding et al., a peak was observed for elders (between 40 and 50 years), and a decrease of *E* values with higher age.(123) In our results, the specimens were stiffer in the elder subgroup, but a peak like the one mentioned in the literature was not observed. The fact that all the osteoporotic bone specimens were excluded probably caused this disagreement with other studies. In the literature, the explanations for the age-related deterioration include the loss of trabecular bone substance (118), age-related microdamage accumulation, and the change of collagen integrity.(124)

Table 10. Comparison of complications. Comparison of complications in the literature and our case series. (Spf.: superficial, Sys: systematic).

Complication Differences				
	Our Results		Sys Search	
Number of patients	39		205	
Number of complications (without trauma)	12	30.8%	71	34.6%
Time interval (from injury to surgery, weeks)	26.69 ± 84.36 (0.5–510)		108.72 ± 98.04 (27.2–284.4)	
Stiffness, subacromial imp, graft failure	0	0.0%	7	3.4%
Subluxation	0	0.0%	33	16.1%
Proud metalwork, skin irritation	3	7.7%	15	7.3%
Implant loose, coracoid fracture, osteolysis	2	5.1%	8	3.9%
Superficial infection	7	17,9%	8	3.9%
Re-injury	4	10.3%	3	1.5%
Previous surgery	7	17.9%	4	2.0%
Reoperation	8	20.5%	15	7.3%
Implant remove	6	15.4%	11	5.4%
Implant failure	2	5.1%	11	5.4%

It is worth noting that in Study II. our analysis (**Table 10**) revealed a comparable overall complication rate (30.8% vs. 34.6%), although infections were significantly more frequent in our cohort (17.9% vs. 3.9%). Three of these infections were successfully treated with antibiotics, while two deep infections (5.1%) necessitated implant removal—rates that align with those reported in the literature. The higher incidence of superficial infections in our cohort may be partly attributed to the exclusive postoperative follow-up conducted by surgical teams in Hungary. Notably, two of the seven infection cases were revisions following other surgical techniques, and our cohort included a greater proportion of non-primary Lockdown cases compared to the literature. The reviewed studies did not report any bacterial culture results.

The re-injury rate in our cohort was substantially higher (10.3% vs. 1.5%), likely reflecting the inclusion of mixed patient cases, including at least three involving high-energy trauma capable of damaging the native acromioclavicular (AC) joint. Additional complications observed included prominent metalwork (7.7%) and implant loosening (5.1%), whereas no cases of joint stiffness, subluxation, or subacromial impingement were recorded. In contrast, literature data report subluxation (16.1%), prominent metalwork (7.3%), implant loosening (3.9%), stiffness (1.5%), subacromial impingement (1.5%), and graft rupture (0.4%).

Our cohort demonstrated a higher rate of implant removal (15.4% vs. 5.4%), primarily driven by re-injury, unresolved deep infections, and a higher proportion of revision surgeries from failed previous procedures. When considering infections and implant loosening alone—excluding re-injuries—the "true" implant failure rate was similar between our cohort and the literature (5.1% vs. 5.4%). However, the reoperation rate in our study (20.5%) exceeded reported values (7.3%), primarily due to re-injuries and deep infections caused by S. aureus.

In the literature, reoperations were attributed to subacromial bursitis (three cases), prominent metalwork (two cases), infections (seven cases), implant loosening (one case), and graft rupture (one case). Comparatively, Lockdown procedures have shown less persistent postoperative pain than the modified Weaver–Dunn procedure, while the superficial infection rate remained similar(103). In a study by Saraglis et al. (n = 48), the double endobutton group had a higher infection rate (three vs. zero cases), whereas radiological failure was lower in the Lockdown group (four vs. six cases)(104).

Systematic reviews have reported overall complication rates of 9.1–14.9% for synthetic systems, 15.5–22% for biological grafts, 29.7% for internal fixations, and 17.3% for ligament transfers.(117, 118) Chronic AC joint instability fixation and revision surgeries remain underreported, as noted by Berthold et al. and illustrated in **Table 9**, where four out of nine studies provide insufficient detail.(125) This underreporting may impact the interpretation of results. Across all AC joint reconstruction methods, the general complication rate stands at 20.8%, and 27% specifically for coracoclavicular (CC) ligament reconstruction, according to meta-analyses by Gowd et al. and Martetschlager et al..(126-128) Moreover, rigid fixation devices are associated with loss of motion, which increases the risk of breakage, implant loosening, subacromial erosion, impingement, and the need for additional surgery for implant removal.

In Study II., Comprehensive information on physiotherapy duration, postoperative deformities, and return-to-work timelines was often lacking.(103, 104, 129) Furthermore, variability in reported pain levels across studies made reliable comparisons difficult.(4, 27, 40, 97, 98, 103-105) The study's design also limited the ability to assess potential positive impacts of elapsed time, physiotherapy, and medication on surgical outcomes.

Also, in Study II., The literature often compares conservative and surgical treatments for AC joint injuries. Boström et al. (2022; 124 cases) observed no significant difference between Hook plate fixation and conservative management in Rockwood type III and V injuries.(130) A 2015 randomized controlled trial by the Canadian Orthopaedic Trauma Society (76 cases) similarly compared Hook plate fixation with nonoperative treatment in injuries beyond Rockwood type III, reporting improved short-term function in the nonoperative group but no meaningful differences in long-term outcomes.(131) Murray et al. (2018; 60 cases) also found comparable one-year functional results between open reduction with suspensory device fixation (ORTSD) and conservative treatment for Rockwood type III and IV injuries.(132) While the conservative group had superior OSS scores at six weeks, many patients later required delayed surgery due to dissatisfaction.(132) In a multicenter randomized trial, Tauber et al. (85 cases) found no significant difference between surgical (tightrope or Hook plate) and nonsurgical approaches for Rockwood type III injuries. However, surgical treatment was associated with slower recovery, more complications, and higher rates of posttraumatic osteoarthritis and heterotopic ossification.(133)

System designs are impacted directly by the variability of material properties in both finite element analysis (FEA) models for bone and surgical implant design for Lockdown procedures. Young's modulus study shows how macrostructure, load orientation, and specimen size affect *E* values, which in turn influence the accuracy of FEA models. The limitations of isotropic models for bone are analogous to the limitations of rigid fixation methods in AC joint surgery, as seen in Kirschner wire and Bosworth screw techniques.(20, 22) Lockdown's synthetic ligament, which accommodates natural joint dynamics, echoes the recommendation from bone research to use more context-sensitive and anisotropic models. Both fields emphasize that design choices must respect biological materials' inherent variability and complexity to achieve optimal functional outcomes.

9.2. Strengths (including all studies)

There are several strengths of our studies. We implemented a rigorous methodology to be transparent, to provide precise and detailed data collection, and create a structured analysis of the outcomes.

In Study I., we successfully included a large number of samples from a wide range of publications, which may enhance the generalizability of our findings.

Study II., offers several notable strengths, particularly its thorough assessment of the Lockdown procedure for AC joint dislocations and its comprehensive, up-to-date literature review.

9.3. Limitations (including all studies)

In Study I. a pediatric subgroup was intended to be created; however, this was not possible due to their low number and wide age range. For nanoindentational measurements, there are at least eight methods to calculate the *E* value, of which the Oliver-Pharr method is the most popular. The included studies exhibited significant heterogeneity in both data and reporting. First, many datasets were incomplete or inaccurately reported, leading to gaps in the analysis. Second, we were able to examine only a limited number of subgroups. Third, variability in specimen preparation added to the overall heterogeneity. Key details, such as the time between specimen preparation and testing, were often unreported. Additionally, load orientation was sometimes unspecified. We did not differentiate between platen and end-cap methods in compression techniques, which may have influenced the results.

In Study II., there are certain limitations. The lack of control groups hinders direct comparisons with alternative surgical techniques. While this is a key limitation, it is consistent with the design of many similar studies in the literature. Additional biases include selection bias—stemming from the unavailability of data on the total number of AC joint dislocations treated at the participating centers—and observer bias, due to the absence of blinding and the inherently subjective nature of surgical assessments. Although the sample size is moderate, it remains meaningful given the systematic search approach used, enhancing the robustness of our findings. We integrated prospective data collection with prospective follow-up to address selection bias, thereby improving the study's reliability. The average follow-up period of two years is sufficient to evaluate short-term outcomes, but extended follow-up is necessary to assess long-term results. A meta-analysis could not be performed due to heterogeneity among the included studies, prompting us instead to conduct a systematic review, further underscoring the need for future research in this area.

10. CONCLUSIONS

1) We assessed the influence of various factors on the Young's modulus of bone. Notable differences were observed in macrostructure and anisotropy, particularly between the femoral epiphysis and metaphysis, as well as within the epiphysis of the distal femur and proximal tibia.
2) According to our results, the *E* value of the tibia in the knee joint was twice as much as that of the femur
3) The anisotropic properties of the bone had to be accounted for, which are missing in the in silico calculations.
4) Although a high complication rate was noted both in our cohort and in the literature, our findings indicate that the Lockdown technique is effective for treating primary and acute AC joint injuries, particularly in terms of functional outcomes. The consistently elevated complication rates across different surgical approaches suggest that the anatomical region itself may be inherently susceptible to complications.
5) In both studies, the literature misses essential data, which prevents proper meta-analytic calculations.

11. IMPLEMENTATION FOR PRACTICE

The rapid integration of results into clinical practice is beneficial.(134, 135)

1) Study I.

To support the development of new implant designs, our data can contribute to creating more accurate finite element (FE) models by accounting for anisotropy and regional variations in Young's modulus within the same bone. More importantly, our findings may aid in establishing more standardized measurement protocols across the literature and research designs, enabling a clearer understanding of the type and extent of Young's modulus dependence on various influencing factors.

2) Study II.

In clinical practice, the Lockdown technique is a viable option for acute AC joint reconstruction, demonstrating a complication rate similar to other surgical methods. Among patients undergoing Lockdown revision following a previously failed procedure, we observed only a mild rate of complications.

12. IMPLEMENTATION FOR RESEARCH

1) Study I.

Based on our findings, more standardized measurement parameters are recommended, tailored to the specific variables involved, and current FE models should be updated accordingly. When selecting Young's modulus values, the following factors should be considered in order of decreasing importance: macrostructure, measurement method, bone region, bone type, specimen size, orientation, specimen condition, age, and sex.

2) Study II.

Further research employing robust study designs and high-quality data is essential to effectively compare various reconstruction methods, including Lockdown and other suspension techniques. Notably, there is a significant gap in data concerning patients who have undergone prior non-Lockdown procedures followed by revision to the Lockdown technique.

13. IMPLEMENTATION FOR POLICYMAKERS

The proportion of elderly people is increasing year by year within the total population of Western countries, including Hungary, and this is reflected in the number of joint replacements. This has a serious financial impact in primary cases, but even more so in the treatment of complications (periprosthetic fractures, loosening, dislocations and infections). The number of complications can be reduced in the long term if the most suitable implant is placed for the patient with the most effective implant fitting. In order to achieve this, policymakers and research funders should support the creation of standardized protocols for specimen preparation, measurement methods, and data reporting. To enhance the accuracy of biomechanical simulations used in implant design, policymakers can encourage regulatory bodies and funding agencies to prioritize FE models that account for anisotropy, bone region specificity, and real-world material properties.

In case of ACJ injuries, Policymakers could promote the development and adoption of standardized surgical protocols, which would help improve outcomes and reduce complication variability across institutions. The findings suggest superior functional outcomes in acute (≤3 weeks) cases. Policymakers could consider including this in clinical guidelines as a first-line surgical option for acute AC joint dislocations with no prior history of ACJ reconstruction.

For both studies, the necessary registries and their administration require non-physician medical administrators, who are lacking in our Healthcare. Policymakers should rethink the roles of physicians as “good-for-everything” persons, which is an economic waste for administrative tasks, and should hire more administrative staff to do those.

14. FUTURE PERSPECTIVES

Due to the gap in the literature data in both studies, our plan is to recreate the systematic search and meta-analysis every 5 years, with the hope that the gaps will be filled with other studies.

Synchronization of in vitro studies with in silico measurements in order to cut the gap between the two methods, highlighting the need for including the anisotropy into the in silico calculations. To accomplish this plan, a possible solution could be a cooperation between the biophysicists of Semmelweis University (SE) and the engineers of the Budapest University of Technology and Economics (BME). Such a solution would be an in vitro experiment of the scapula connected with a simultaneous CT scan of the same specimen, before Young modulus testing methods. The following project would be an in silico model for predisposing factors of coracoid fracture following ACJ reconstruction.

Creation of randomized trials in order to better compare the effectiveness of different surgical techniques in AC reconstruction. To achieve this goal, the continuous collaboration between the centers is essential.

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