Cohort Study

A PILOT COHORT STUDY TO DETERMINE THE EFFECTIVENESS OF FOCAL PULSED STIMULATION ON PAIN AND FUNCTION IN PATIENTS WITH SPONDYLOLISTHESIS

A. Mosabbir[1,2], A. Khan[3] and L. Bartel[1,3*]

[1]University of Toronto, Faculty of Music, Toronto, Canada;
[2]Rotman Research Institute, Baycrest Health Sciences Centre, Toronto, Canada;
[3]Neuro Spinal Innovation, Mississauga, Canada

Correspondence to:
Lee Bartel, PhD
Faculty of Music,
University of Toronto,
Toronto, Canada
e-mail: lbartel@chass.utoronto.ca

ABSTRACT

In this retrospective medical records pilot study, a cohort of patients (5F/2M), who were diagnosed with degenerative spondylolisthesis underwent a novel sound-based focal pulsed stimulation over a period of three months. Clinical outcomes included pain intensity and functional disability due to back pain improved from pre- to post-treatment. Clinical outcomes such as shoulder/pelvic tilt, leg length difference, and range of motion are discussed.

KEYWORDS: *vibration, vibroacoustic, spondylolisthesis, spine, rehabilitation*

INTRODUCTION

Spondylolisthesis (SDL) is characterized by a displacement of the vertebral body in reference to the bordering vertebral bodies and can be associated with pain and spinal dysfunction (1). Degenerative lumbar SDL involves slippage of the vertebrae (usually L4 and L5) due to disc degeneration and zygapophyseal joint arthropathy, often in combination with spinal stenosis (2, 3). Although spine-related degeneration can be asymptomatic (4), sometimes these patients report low back pain radiating pain, and present with neurological deficits. For symptomatic patients, the decision of whether surgery or conservative treatment is the best course of action is still an open question, as is the choice of which type of surgery (2, 5, 6). Conservative treatments include medication, physiotherapy, weight loss, external orthosis, injections, etc.

Although SDL is a common diagnosis in aging individuals, there is little empiric evidence to support many of the common conservative treatments for symptomatic individuals, nor is there conclusive evidence to suggest that one is superior to the other (2). For surgical treatments, a systematic review has found that surgery consistently produced better results in pain relief and functional improvement of SDL over a 2-year period (7), but the well-documented complications associated with spondylolisthesis surgery make it undesirable for many patients (8). Therefore, newer non-surgical treatments that may help improve SDL-related disability and pain would be a helpful addition to the multi-faceted approach to the treatment and management of spine-related pain and dysfunction.

Focal pulsed stimulation involves treatment with sound waves transduced into a mechanical vibrotactile sensation. In chronic pain research, sound-based pulsed treatments most commonly use pulsations in the range of 1-200Hz

Received: 15 November 2024
Accepted: 10 January 2025

(9). Research evidence has led to the American Food and Drug Administration's (FDA) approval of general vibration therapy for 3 main claims – reduced pain, increased circulation, and increased mobility (10). A recent review underlines the mechanism behind improvements in neurological, hemodynamic, and musculoskeletal symptoms after vibratory stimuli (9). Therefore, the literature on the effects of sound-based pulsed stimulation on decreasing perceived pain and pain-related dysfunction is growing.

In clinical orthopedic practice, pulsed stimulation has also demonstrated benefits on muscle function, physical performance, patient mobility and balancing, and improving bone mineral density (11). For spine related pain and dysfunction, a growing number of studies have demonstrated that focally applied pulsed stimulus to the spine can improve spinal alignment and reduce pain (12). Focally applied mechanical stimulation generated via vibrations can stimulate genetic expression of anabolic proteins such as aggrecan and collagen, helping to regenerate health in the intervertebral discs (13). Mechanical stimulation of the bony structures also stimulates pro-osteogenic factors that stimulate the growth and repair of bone tissue (9). Therefore, the use of focal pulsation applied to the spine may be a promising option for improving SDL related disability and pain.

It must be noted that SDL is not always directly associated with pain and in a clinical context SDL may be an incidental finding. In this pilot study patients were specifically selected who presented with low back pain assessed with palpation among other tests. If a specific segment was tender to touch, and then upon palpatory examination the patient reported greater pain, the prognosis was narrowed. The clinician in those cases then conducted a physical orthopedic examination. If SDL is strongly indicated multiple factors including facet or disc issues are considered and that these conditions could be resulting from SDL. Pain can then be assumed to be originating from these related issues and may be indirectly coming from SDL. If this is the diagnostic direction, we assume the pain mechanisms are complex, but that SDL is a major contributing factor. When treatment based on this diagnosis results in improvement, there is a positive sign that the biomechanical changes indicate that the spondylolisthesis effects are being managed. Causative biomechanical changes of chronic low back pain implicated in SDL include sub-failure spinal injury or micro-trauma just under the major injury threshold originating from ligament or muscle strain, degenerating joints, or degeneration of intervertebral discs causing spinal stenosis and sacroiliac joint, discogenic, and facet joint pain (14).

It must further be noted that pain associated with SDL is frequently a chronic long-standing pain which may result in the recruitment of neurological factors and so become partially neurogenic in origin (9). Research clearly shows changes in brain metabolites and grey matter from chronic low back pain (14). It is, therefore, important to note that pulsed stimulation has been associated with neurological oscillatory reset and circuit function (9). The acoustically derived focal pulsed stimulation used in this pilot study may be contributing to a neurological effect (14).

In this retrospective pilot study, 7 patients with degenerative SDL were given acoustically derived focal pulsed stimuli applied to the spine through a device known as the Khan Kinetic Treatment (KKT) and now also known as SONIK treatment. The actual stimulus of the SONIK treatment can be described as delivering accelerated audible low-frequency kinetically directed impulses (ALKINDI) meaning: “accelerated” – a rapidly increasing frequency curve, “audible low frequency” – at the lowest level of human audibility in the 16 – 100 Hz range, “kinetically directed” – very specifically angled and directed at vertebrae targets, and “impulses” – sound-initiated percussion waves.

In this pilot cohort study the objective was to determine whether ALKINDI applied to the participants’ spine would have an effect of pain and stability-related pain and function outcome measures and if these measures produced a tangible change in medication intake over time. Some published reports have demonstrated improvements in back pain from spinal complications such as disc bulges or atlanto-axial subluxation using this type of stimulation (15, 16). However, to our knowledge, no other type of stimulation with this frequency profile or focused application is clinically available. Therefore, this ALKINDI treatment constitutes a highly novel form of treatment modality.

MATERIALS AND METHODS

Ethics

At the point of intake at the treating clinic, all patients signed consent to allow use of anonymous clinical treatment data for retrospective research purposes.

Cohort selection

Seven patients (5 females and 2 males) with degenerative SDL were included retrospectively from electronic medical records from KKT International orthopedic clinics located in Jeddah, Saudi Arabia, between March 2021 and June 2021. All patients were diagnosed with grade 1 lumbar SDL and presented to the clinic because of pain. Although surgery is usually suggested as a treatment of choice for SDL severity grades 3 and 4, one patient in this study had been recommended for surgery with grade 1 SDL. All had pursued conservative treatment before coming to the clinic for ALKINDI treatments. The baseline parameters of patients can be found in Table I.

Table I. *Demographic and diagnostic data of the patients.*

Patient	Age	Sex	BMI	# of Tx	Site of Tx	Medical Diagnosis	Medication
1	62	F	31.6	12	C, LS, Abd, Ccx	• Lumbar Spondylolisthesis • Intervertebral disc disorders with radiculopathy, lumbosacral region	n/a
2	74	F	35.7	18	C, LS, Abd	• Lumbar Spondylolisthesis • Cervical, thoracic, and lumbar spondylosis	Insulin 11-100mg
3	69	M	29.4	18	C, LS	• Lumbar Spondylolisthesis • Cervical disc disorder with myelopathy • Lumbosacral intervertebral disc disorder with radiculopathy	n/a
4	44	M	37	18	C, LS	• Lumbar Spondylolisthesis • Intervertebral disc disorder with radiculopathy, lumbar region	Metformin 501-1000mg
5	46	F	24.1	18	C, LS, Ccx	• Lumbar Spondylolisthesis • Intervertebral disc disorder with radiculopathy, lumbosacral region • Spinal stenosis, lumbar region without neurogenic claudication	n/a
6	72	F	38.4	18	C, LS	• Lumbar Spondylolisthesis	n/a
7	46	F	24.1	18	C, L, Ccx	• Lumbar Spondylolisthesis • Intervertebral disc disorder with radiculopathy in lumbosacral region • Lumbar spinal stenosis without neurogenic claudication	n/a

All Lumbar SDL was L5 to S1, grade 1 spondylolisthesis; ***BMI****: body mass index;* ***Tx****: Treatment;* ***C****,* ***LS****,* ***Abd****,* ***Ccx*** *refer to the location of the treatment and are cervical (****C1****), lumbosacral (****L1-S1****), Abdomen, and Coccyx respectively.*

Treatment

Participants came in for up to 18 treatment sessions lasting up to 3 months, during which participants were treated focally at the lumbosacral region (L1-S1) as well as the cervical spine (C1). Some patients were occasionally treated at the abdomen or coccyx regions.

Outcome measures

Outcome measures in this study included routine clinical outcome measures taken within the clinic before and after the completion of the full treatment program, which included the visual analog scale (VAS, 0-10 rating scale for pain intensity), shoulder and pelvic tilt measured using calipers, leg length difference, range of motion, and upper/lower body coordination. Cervical range of motion tests included a measure of the ability to turn the neck from a neutral position to the left or right shoulder. Asymmetry in the movement of capabilities of the neck could suggest underlying ligament damage. The degree to which the neck rotated to the shoulder was labelled as "normal", "mild", "moderate", or "severe". The upper/lower limb coordination test involved a clinician to provide a downward pressure to the limb of a patient while asking them to resist upward. Values from 0-5 were given based on how strongly they resisted, with zero being no response to five being full resistance without strain. This method has been adapted from the Oxford method of muscle strength grading (17).

RESULTS

A cohort of 7 patients (5 females and 2 males) with lumbar SDL were selected to be included in this pilot study. The mean age (± standard deviation) was 59.0 ± 13.3 years old, and their mean BMI was 31.47 ± 5.91. All patients were diagnosed with grade 1 lumbar SDL, and 6 out of 7 patients had other conditions. Because SDL is most common with people over 60 years of age, most also typically have other spine-related conditions and so these are described individually. Five participants had intervertebral disc disorder with radiculopathy, two had spinal stenosis, one had spondylosis, and one had cervical disc disorder with myelopathy. Only two patients were reported to have been taking medication. Six out of seven patients underwent 18 treatment sessions whereas 1 patient had 12 treatment sessions. Each patient in this cohort is described here and individual results for outcome measures are described in Table II:

Patient 1: A 62 year old female diagnosed with lumbar SDL and lumbosacral intervertebral disc disorder with radiculopathy. She complained of knee joint pain, back pain, and neck pain. She is diabetic and has self-reported anxiety and depression. Her doctor had advised her for surgery but she had not undergone any. Instead, she took physical therapy with partial benefit and acupuncture with no benefit. She had one accidental fall in 2018.

Patient 2: A 74 year old female diagnosed with lumbar SDL as well spondylosis along the spine. She is a diabetic patient who complained of low back pain. She had one fall accident, but otherwise no major accidents. She was taking insulin three times daily, and no apparent drug use other than 40 years of tobacco use which she had recently quit and some caffeine use. She did physical therapy with partial benefit and massage therapy which worsened her issues.

Patient 3: A 69 year old male diagnosed with lumbar SDL, cervical disc disorder with myelopathy, and lumbosacral intervertebral disc disorder with radiculopathy. He complained of low back pain which radiated to lower and upper limbs on both sides with numbness. He quit tobacco after 26 years of use and drinks caffeine, but otherwise no other drug use. Anxiety was self-reported. Physical therapy was tried with recurrent benefit and massage therapy made his issues worse.

Patient 4: A 44-year-old diabetic man diagnosed with lumbar SDL and lumbar intervertebral disc disorder with radiculopathy. He complained of lower back pain, which radiated to the lower limb with numbness. He is taking metformin and drinks caffeine, but otherwise, no other medical or recreational drugs. He has found benefits in physical therapy.

Patient 5: A 46-year-old female diagnosed with lumbar SDL, lumbosacral intervertebral disc disorder with radiculopathy, and lumbar spinal stenosis without neurogenic claudication. She complained of low back pain which occurred at times due to awkward swimming movements. She drinks caffeine but otherwise no other drugs.

Patient 6: A 72-year-old female diagnosed with lumbar SDL. She complained of low back pain. She has high blood pressure, diabetic, and has self-reported anxiety. She does not use any recreational drugs.

Patient 7: A 46-year-old female diagnosed with lumbar SDL, lumbosacral intervertebral disc disorder with radiculopathy, and lumbar spinal stenosis without neurogenic claudication. The patient complained of low back pain. Other than caffeine use, she does not use any other drugs.

Each of the seven patients improved in VAS pain severity scores from pre-treatment to post-treatment (see Table II for individual outcome measures).

Table II: *Individual clinical outcomes.*

Patient		Pain	RM	ST (º)	PT (º)	LLD (cm)	ULL	ULR	LLL	LLR	ROML	ROMR
1	Pre	8.23	-	1	1	2.5	4	4	3	3	Normal	Normal
	Post	4.35	-	0	0	0	5	3	2	2	Normal	Normal
2	Pre	5.54	13	3	1	0	2	2	1	1	Mild	Mild
	Post	0.68	2	0	0	0	5	5	3	3	Normal	Normal
3	Pre	4.97	8	3	1.25	0	1	1	2	2	Moderate	Moderate
	Post	0.34	1	0	0	0	5	5	3	3	Normal	Normal
4	Pre	6.61	11	1	1.75	1.5	4	4	2	3	Mild	Mild
	Post	1.48	1	0	3.75	0	4	4	3	3	Normal	Normal
5	Pre	6.45	14	1.75	0.75	1.75	3	3	3	3	Normal	Normal
	Post	0.09	1	0	0	0	4	4	3	3	Normal	Normal
6	Pre	8.32	8	1.25	1.75	1	4	4	1	1	Moderate	Moderate
	Post	0.2	1	0	0	0	5	5	1	1	Normal	Normal
7	Pre	6.45	8	1.75	0.75	1.75	3	3	1	1	Normal	Normal
	Post	2.39	1	0	0	0	4	4	1	3	Normal	Normal

***RM**: Roland Morris disability questionnaire; **ST**: shoulder tilt; **PT**: pelvic tilt; **LLD**: leg length difference; **ULL**: left upper limb strength; **ULR**: right upper limb strength; **LLL**: left lower limb strength; **LLR**: right lower limb strength; **ROML**: cervical range of motion on the left side; **ROMR**: cervical range of motion on the right side. Limb strength was measured using the Oxford method to evaluate muscle strength.*

An analysis of the pre- vs post-treatment group results showed the following: The mean visual analog scale (VAS) score decreased from pre-treatment to post-treatment, indicating that pain relief was successfully achieved (6.65 ± 1.25 pre-treatment vs 1.36 ± 1.55 post-treatment respectively; $p<<0.001$; see Table III for mean outcome values).

Table III: *Analysis of means of patient outcome measures.*

Outcome	Pre (m)	Pre (sd)	Post (m)	Post (sd)	Adjusted p-value	Effect size
Pain	6.65	1.25	1.36	1.55	0.0009	3.55
RM	9.8	2.68	1	0	0.0065	3.28
ST	1.82	0.86	0	0	0.0051	2.11
PT	1.18	0.43	0.54	1.42	0.2580	0.529
LLD	1.21	0.94	0	0	0.0390	1.29
ULL	3.00	1.15	4.57	0.53	0.0545	1.12
ULR	3.00	1.15	4.28	0.76	0.1278	0.75
LLL	2.14	0.90	2.86	1.21	0.3115	0.445
LLR	2.29	0.95	2.86	1.21	0.3863	0.353
ROML	0.86	0.9	0	0	0.0829	0.95
ROMR	0.86	0.9	0	0	0.0711	0.953

RM: *Roland Morris disability questionnaire;* ***ST***: *shoulder tilt;* ***PT***: *pelvic tilt;* ***LLD***: *leg length difference;* ***ULL***: *left upper limb strength;* ***ULR***: *right upper limb strength;* ***LLL***, *left lower limb strength;* ***LLR***: *right lower limb strength;* ***ROML***: *range of motion on the left side;* ***ROMR***: *range of motion on the right side. Range of motion values of "normal", "mild", "moderate", and "severe" were given scores of 0-3, respectively, for quantitative statistics. Pre and post-values are represented by mean (**m**) and standard deviation (**sd**). Effect size is measured as Cohen's **d**. P-values are adjusted for multiple comparisons using the Benjamini-Hochberg procedure.*

Mean values of pre- vs post-treatments were assessed using t-tests, and p-values were adjusted for multiple comparisons using the Benjamini-Hochberg procedure. The mean Roland Morris (RM) disability score decreased from pre-treatment to post-treatment (9.8 ± 2.68 pre-treatment vs 1.0 ± 0.0 post-treatment, respectively; p<0.001). Shoulder and tilt improved for all 7 patients and decreased to zero for all patients (1.82 degrees ± 0.86 pre-treatment vs 0.0 degrees ± 0.0 post-treatment, p<0.001; Table III). Pelvic tilt improved for 6 out of 7 patients (1.18 ± 0.43 degrees pre-treatment vs 0.54 ± 1.42 degrees post-treatment). Leg length difference significantly decreased from pre- to post-treatment (1.21 ± 0.94 cm vs 0.0 ± 0.0 cm, respectively, p<0.001) for all patients. Range of motion improved for all patients that began with non-normal values (n=4), and left upper limb strength improved for 6 out of 7 patients (3.00 ± 1.15 pre-treatment vs 4.57 ± 0.53 post-treatment, p=0.0545).

Measures of right upper limb strength and right and left lower limb strength did not see statistically significant improvements.

DISCUSSION

Focally applied pulsed stimulation was successfully able to reduce pain and improve functional disability. Improvements in these measures were the most statistically significant and had large effect sizes, showing promising results for pulsed stimuli as a means of SDL rehabilitation. Other clinical measures in the form of shoulder and pelvic alignment, leg length difference and range of motion also improved. Shoulder and pelvic tilt are measures of postural stability, and its relationship with back pain and functional disability are less clearly defined. Abnormal spinal postures maintained over time may lead to certain types of pain and disability.

For example, a hunched forward posture during computer use can lead to neck or back pain (18, 19). This relationship between pain and postural abnormality may also work in reverse, where pain leads to compensatory changes in one's posture (20, 21). Regardless of the direction of cause, the improvements in spinal and pelvic tilt are suggestive of a positive treatment outcome.

Leg length difference (LLD) also improved significantly for all patients. LLD is also associated with postural instability due to pain (22, 23); however, its association with back pain is inconsistent in the literature (24, 25). This may be due to the fact that LLD is dependent on other factors influencing posture and stability, such as shoulder and pelvic tilt. For example, a pelvic tilt may lead to depression of one leg past the other and can produce an LLD. On the other hand, a pelvic tilt may be compensated by an opposite tilt in the shoulder, nullifying the LLD by curving the spine in the frontal plane while keeping a net zero LLD. Therefore, measures of LLD must be interpreted in the context of other postural measurements. Range of motion improved for all patients with non-normal levels. The limitation of this measurement is that the cervical range of motion is not directly related to SDL; however, the improvement of mobility in another region of the spine suggests positive results from the treatment. Upper and lower limb coordination did not show significant changes.

This paper studies the effect of a novel treatment on a cohort of patients retrospectively selected from an electronic health database to fulfill one of the central purposes of a pilot study: might the treatment be a viable complementary treatment for SDL? The primary strength of this study was to show the effectiveness of a novel complementary treatment that uses non-invasive low-frequency pulsed stimulation despite the presence of other spinal conditions. The lack of homogeneity in the cohort is an important limitation to note since confounding variables may be present. However, the lack of homogeneity in this cohort is the reality among SDL patients and affects all forms of treatment for SDL symptoms. The very nature of a pilot study with a limited number of intentionally selected patients makes generalizability impossible but begs for prospective controlled research.

Given the results of this study, there are two avenues for further inquiry. The first is to complete larger, randomized, controlled trials using focally applied pulsed stimulation using the ALKINDI technology. More research is needed to assess the optimization of pulsation parameters on SDL patients, which should include pulse frequency, amplitude, location of the stimulus, and the number of stimuli. A larger study looking into the use of postural measures for back pain and its treatment will also be helpful. A systematic review of reviews suggested no consensus about the relationship between postural measures preceding first-time low back pain (26).

Postural abnormalities may be what leads to back pain, or back pain may cause postural abnormalities either due to compensatory adjustments to minimize the effect of pain or due to deterioration of tissue. Therefore, exploring postural measures “preceding” first-time low back pain may not yield any relationship. A better measure might be to measure its association with “recurring” low back pain. For example, one systematic review found a relationship between postural measures and recurring lower back pain (3). This detail may be a reason for inconsistent results, and thus, a larger study looking into the change in postural measures and the treatment of pain would be valuable.

Another avenue for further research would be to explore the mechanism behind the positive treatment response. There are currently few reports investigating the mechanism of pulsed or vibratory stimulus on pain relief and improved spine health. Focally applied mechanical stimulation generated via vibrations can stimulate the genetic expression of anabolic proteins such as aggrecan and collagen, helping to regenerate health in the intervertebral discs (13). Mechanical stimulation of the bony structures also stimulates pro-osteogenic factors that stimulate the growth and repair of bone tissue (27, 28). Pre-clinical studies have demonstrated that mechanical stimulation of the bones and discs by vibratory stimuli enhances the genetic expression of pro-osteogenic factors as well as factors promoting disc health (9, 13, 29). The possibility of a neurogenic basis for chronic pain would point to the need for further research into changes in brain structure and function (9, 14). Case reports using MRI imaging have shown reductions of disc bulge or spinal stenosis after focal treatment to the cervical areas. Therefore, a growing number of reports are beginning to emerge indicating the use of focally applied pulses delivered to the spine as a useful solution to degeneration-related pain and spinal dysfunction, which should be explored further in both basic science and clinical research.

CONCLUSIONS

This study demonstrates that ALKINDI delivered to the spine can produce pain relief and functional improvements in a series of SDL patients and shows promise for low-frequency pulsed stimuli as an adjunct therapy for spine-related disorders. Given the complications of surgery, conservative treatment is still preferred up until it fails. ALKINDI treatments may add more options to the range of conservative treatments and may be a promising rehabilitative strategy for spine-related pain and dysfunction.

ACKNOWLEDGEMENTS

We would like to acknowledge Dr Shaker Barker's suggestion to study a cohort of spondylolisthesis patients with ALKINDI and the KKT Orthopedic Spine Centers in Jeddah, KSA for delivering the treatments and generating the data used in this study. We also gratefully acknowledge Dr. Karim Bayanzay for his review of the manuscript after the first draft.

REFERENCES

1. Koslosky E, Gendelberg D. Classification in Brief: The Meyerding Classification System of Spondylolisthesis. Clin Orthop Relat Res. 2020;478(5):1125. doi:10.1097/CORR.0000000000001153
2. Kalichman L, Hunter DJ. Diagnosis and conservative management of degenerative lumbar spondylolisthesis. Eur Spine J. 2008 Mar;17(3):327-335. doi: 10.1007/s00586-007-0543-3.
3. Cummins J, Lurie JD, Tosteson TD, Hanscom B, Abdu WA, Birkmeyer NJ, Herkowitz H, Weinstein J. Descriptive

epidemiology and prior healthcare utilization of patients in the Spine Patient Outcomes Research Trial's (SPORT) three observational cohorts: disc herniation, spinal stenosis, and degenerative spondylolisthesis. Spine (Phila Pa 1976). 2006 Apr 1;31(7):806-14. doi: 10.1097/01.brs.0000207473.09030.0d.

4. Brinjikji W, Luetmer PH, Comstock B, et al. Systematic Literature Review of Imaging Features of Spinal Degeneration in Asymptomatic Populations. AJNR Am J Neuroradiol. 2015;36(4):811. doi:10.3174/AJNR.A4173
5. Jacobs WC, Vreeling A, De Kleuver M. Fusion for low-grade adult isthmic spondylolisthesis: a systematic review of the literature. Eur Spine J. 2006 Apr;15(4):391-402. doi: 10.1007/s00586-005-1021-4.
6. Mannion AF, Pittet V, Steiger F, Vader JP, Becker HJ, Porchet F; Zürich Appropriateness of Spine Surgery (ZASS) Group. Development of appropriateness criteria for the surgical treatment of symptomatic lumbar degenerative spondylolisthesis (LDS). Eur Spine J. 2014 Sep;23(9):1903-17. doi: 10.1007/s00586-014-3284-0.
7. Schulte TL, Ringel F, Quante M, Eicker SO, Muche-Borowski C, Kothe R. Surgery for adult spondylolisthesis: a systematic review of the evidence. Eur Spine J. 2016 Aug;25(8):2359-67. doi: 10.1007/s00586-015-4177-6.
8. Ogilvie JW. Complications in spondylolisthesis surgery. Spine (Phila Pa 1976). 2005;30(6 SPEC. ISS.). doi:10.1097/01.BRS.0000155581.81997.80
9. Bartel L, Mosabbir A. Possible Mechanisms for the Effects of Sound Vibration on Human Health. Healthcare. 2021;9(5). doi:10.3390/HEALTHCARE9050597
10. Campbell EA. Vibroacoustic Treatment and Self-care for Managing the Chronic Pain Experience: An Operational Model. 2019.
11. Cerciello S, Rossi S, Visonà E, Corona K, Oliva F. Clinical applications of vibration therapy in orthopaedic practice. Muscles Ligaments Tendons J. 2016;6(1):147-156. doi:10.11138/mltj/2016.6.1.147
12. Desmoulin GT, Szostek JS, Khan AH, Al-Ameri OS, Hunter CJ, Bogduk N. Spinal intervention efficacy on correcting cervical vertebral axes of rotation and the resulting improvements in pain, disability and psychsocial measures. J Musculoskelet Pain. 2012;20(1):31-40. doi:10.3109/10582452.2011.635843
13. Desmoulin GT, Hewitt CR, Hunter CJ. Disc strain and resulting positive mRNA expression from application of a noninvasive treatment. Spine (Phila Pa 1976). 2011;36(14). doi:10.1097/BRS.0b013e3181fd78b3
14. Mosabbir, A. Mechanisms behind the Development of Chronic Low Back Pain and Its Neurodegenerative Features. Life 2023, 13, 84. https://doi.org/ 10.3390/life13010084
15. Alsalamah NM, Bartel L. Management of severe low back pain with a focused vibro-percussion wave treatment: A case report. Clin case reports. 2022;10(7). doi:10.1002/CCR3.6054
16. Abu Omar AJ, Al Baradie MS, Al Dera H, Vannabouathong C, Bartel L. Management of pain due to cervical multilevel disk bulges and spinal stenosis with a focused vibro-percussion wave treatment: A case report. Clin case reports. 2022;10(4). doi:10.1002/CCR3.5344
17. Naqvi U, Sherman A l. Muscle Strength Grading. StatPearls Publishing; 2023.
18. Straker LM, Smith AJ, Bear N, O'Sullivan PB, de Klerk NH. Neck/shoulder pain, habitual spinal posture and computer use in adolescents: the importance of gender. Ergonomics. 2011;54(6):539-546. doi:https://doi.org/10.1080/00140139.2011.576777
19. Jung KS, Jung JH, In TS, Cho HY. Effects of Prolonged Sitting with Slumped Posture on Trunk Muscular Fatigue in Adolescents with and without Chronic Lower Back Pain. Medicina (B Aires). 2021;57(1):1-8. doi:10.3390/MEDICINA57010003
20. Sohn MK, Lee SS, Song HT. Effects of Acute Low Back Pain on Postural Control. Ann Rehabil Med. 2013;37(1):17. doi:10.5535/ARM.2013.37.1.17
21. Brumagne S, Janssens L, Janssens E, Goddyn L. Altered postural control in anticipation of postural instability in persons with recurrent low back pain. Gait Posture. 2008;28(4):657-662. doi:10.1016/J.GAITPOST.2008.04.015
22. Giles LGF, Taylor JR. Lumbar spine structural changes associated with leg length inequality. Spine (Phila Pa 1976). 1982;7(2):159-162. doi:10.1097/00007632-198203000-00011
23. Defrin R, Benyamin S Ben, Aldubi RD, Pick CG. Conservative Correction of Leg-Length Discrepancies of 10mm or Less for the Relief of Chronic Low Back Pain. Arch Phys Med Rehabil. 2005;86(11):2075-2080. doi:10.1016/J.APMR.2005.06.012
24. Christie HJ, Kumar S, Warren SA. Postural aberrations in low back pain. Arch Phys Med Rehabil. 1995;76(3):218-224. doi:10.1016/S0003-9993(95)80604-0
25. Eliks M, Ostiak-Tomaszewska W, Lisiński P, Koczewski P. Does structural leg-length discrepancy affect postural control? Preliminary study. BMC Musculoskelet Disord. 2017;18(1):1-7. doi:10.1186/S12891-017-1707-X/TABLES/4
26. Azizan NA, Basaruddin KS, Salleh AF. The Effects of Leg Length Discrepancy on Stability and Kinematics-Kinetics Deviations: A Systematic Review. Appl Bionics Biomech. 2018;2018. doi:10.1155/2018/5156348
27. Swain CTV, Pan F, Owen PJ, Schmidt H, Belavy DL. No consensus on causality of spine postures or physical exposure and low back pain: A systematic review of systematic reviews. J Biomech. 2020;102. doi:10.1016/J Biomech.2019.08.006
28. Zhou Y, Guan X, Zhu Z, et al. Osteogenic Differentiation Of Bone Marrow-Derived Mesenchymal Stromal Cells On Bone-Derived Scaffolds: Effect Of Microvibration And Role Of Erk1/2 Activation. Eur Cells Mater. 2011;22:12-25.
29. Rubin CT, Sommerfeldt DW, Judex S, Qin YX. Inhibition of osteopenia by low magnitude, high-frequency mechanical stimuli. Drug Discov Today. 2001;6(16):848-858. doi:10.1016/S1359-6446(01)01872-4.
30. Desmoulin GT, Reno CR, Hunter CJ. Free axial vibrations at 0 to 200 Hz positively affect extracellular matrix messenger

ribonucleic acid expression in bovine nucleus pulposi. Spine (Phila Pa 1976). 2010;35(15):1437-1444. doi:10.1097/BRS.0b013e3181c2a8ec

Case report

AN "ON-THE-TABLE" RECONSTRUCTION TECHNIQUE TO TREAT A COMMINUTED ARTICULAR METACARPAL BONE FRACTURE. A CASE REPORT

M. Saracco[1], V. Circiello[2] and E. Jannelli[3]

[1]Department of Public Health, Division of Orthopaedic Surgery, University of Naples "Federico II", Naples, Italy;
[2]Orthopedics and Traumatology 1, Maria Vittoria Hospital, NHS City of Turin, Turin, Italy
[3]Department of Orthopaedics, Fondazione IRCCS Policlinico San Matteo, Pavia, Italy

Correspondence to:
Michela Saracco, MD
Department of Public Health,
Division of Orthopaedic Surgery,
University of Naples "Federico II"
Via Sergio Pansini, 5
Naples, Italy
e-mail: michelasaracco@gmail.com

ABSTRACT

Metacarpal bone fractures are the most common hand injuries. An "On-the-table" reconstruction is a reliable technique to treat comminuted articular fractures in non-weight-bearing bones. We report the case of a young polytraumatized patient with a complex fracture of the distal part of the second metacarpal bone treated with an "on-the-table" reconstruction since the general clinical conditions did not allow more complex or multistep conventional reconstructive techniques. This surgical procedure allowed us to obtain good clinical and radiographical results without bone resorption or complications. Case series could confirm the reliability of the proposed method.

KEYWORDS: *on-the-table reconstruction, hand injuries, metacarpal bone fractures, comminuted articular fractures*

INTRODUCTION

Metacarpal bone fractures are the most common hand injuries, accounting for 40% of all hand traumatic lesions. Men aged 15-30 have the highest incidence of metacarpal injuries due to road accidents or occupational injuries. Different mechanisms of injury are involved, but high-energy traumas may result in multiple or comminuted fractures.

Wounds may indicate open fractures or concomitant soft tissue injury, such as tendon laceration or neurovascular injury. Crash injuries or multiple fractures are associated with a higher risk of compartmental syndrome. So, complex metacarpal fractures can be functionally disabling. Pain, dorsal hand swelling, and loss of motion are typical symptoms of this pathological condition. X-rays are the first level diagnostic exams: anteroposterior (AP) or posteroanterior (PA), semi-pronation, and lateral views are mandatory to avoid false negativity of the diagnostic tool. In the case of articular/complex fractures that need surgical approaches, a CT-scan execution is essential to correctly plan the procedure (1).

In case of severe comminution, bone loss can be difficult to manage. Reconstructive techniques with microsurgical bone flaps or with simple cortico-cancellous bone grafts, for example, from the iliac crest, are known and

Received: 15 November 2024
Accepted: 13 January 2025

 www.labpublisher.com ISSN 1973-6401 (print) 3035-2916 (Online)

widely used. Cementless induced membrane technique is also described in case of destructive injuries, such as gunshot ones (2-4).

In other body districts, however, as in the case of the radial head or distal humerus, extreme reconstructive techniques have recently gained ground, such as "on-the-table" reconstruction and subsequent re-implantation and osteosynthesis of the fracture fragments. In non-load-bearing bones, these techniques have given good radiographic and functional results, postponing more complex techniques to possible failures (5-7).

We report the case of a young polytraumatized patient with a complex fracture of the distal part of the second metacarpal bone treated with an "on-the-table" reconstruction since the general clinical conditions did not allow more complex or multistep conventional reconstructive techniques. The patient provided written informed consent to allow the disclosure of his case. As far as the authors know, no other similar cases are described in the literature.

CASE REPORT

A 19-year-old Caucasian male patient polytraumatized in a motorcycle-to-car road accident reported a commotional head injury, abdominal injury, and deformity of the left hand with a wound in the volar and inter-digital space between the second and third finger. The patient's clinical history was collected with the help of family members. He was a student and an occasional manual worker. The dominant limb was reported to be the right. He was a smoker (20 cigarettes a day) and a habitual drinker of beer, wine, and spirits. No other diseases were reported.

Investigation and emergency treatment

Upon arrival in the emergency room, he underwent a total body computerized tomography (CT) scan, radiography in two projections of the left hand, and subsequent CT scan of the hand with three-dimensional (3D) reconstructions. Tests performed revealed a cerebral hematoma. He also reported a fragmentary articular fracture of the distal end of the second metacarpal bone (Fig. 1).

Fig. 1. P*re-operative X-rays and CT scan.*

Exposure was localized in the volar and interdigital space between the second and the third finger with the injury of the inter-metacarpal ligament, classified as Gustilo IIIA. There was no appreciable major vascular-nerve damage. The hand injury was initially treated with abundant washing, debridement, skin closure as possible, and splint stabilization. Antibiotic prophylaxis was also administered with a first-generation cephalosporin (cefazolin 2 grams/8 hours) and an aminoglycoside (gentamycin 80 mg/12 hours) for five days after the trauma.

In consideration of the severity of the patient's neurological condition, an intensive care hospitalization lasting about two weeks followed. The patient also underwent splenectomy due to an active intra-abdominal bleeding 7 days after his arrival. Therefore, the orthopedic surgery was postponed.

Treatment

The orthopedic surgical procedure was performed 2 weeks after the trauma. Antibiotic prophylaxis with cefazolin 2g was performed 1 hour before surgery. In supine decubitus, under plexus anesthesia with the left upper limb on a radiolucent table and with a tourniquet at the root of the limb, a curvilinear dorsal skin incision of about 5 cm in length was made at the second metacarpal bone. After the incision of the subcutaneous tissue, the lesion of the sagittal band and the intermetacarpal ligament, the severe comminution of the bone metaphysis, and the displaced and divided metacarpal head in 2 parts were highlighted (Fig. 2).

Fig. 2. *Damage assessment during surgery.*

The surgical procedure consisted of an "on-the-table" reconstruction of the metacarpal head, bone grafting with autologous bone to reconstruct the metaphysis using fracture fragments supporting the metacarpal head, and performing the ORIF (open reduction and internal fixation).

The bone surfaces were then bloodied and the bone graft was implanted, taking care to arrange the cortical anteriorly and trying to regain the physiological metacarpal bone length. Bone fragments were customized to fit at best the bone loss (Fig. 3). Then, the second metacarpal head was re-composed using micro-forceps and a temporary K-wire of small diameter (0.6mm) (Fig. 4).

Fig. 3. *Metaphyseal reconstruction of the second metacarpal bone.*

Fig. 4. *On-the-table reconstruction of the second metacarpal bone head.*

The reconstructed head was placed on the grafted second metacarpal metaphysis (Fig. 5). Finally, osteosynthesis was performed with Hofer (GMBH & CO KG Jahnstrasse, Fürstenfeld, Austria) INTEOS® Mini fragments metacarpal plate 2.0mm 4+4 holes and angular stability screws, under x-ray fluoroscopy control (Fig. 6).

Fig. 5. *Joint surface reconstruction and ORIF.*

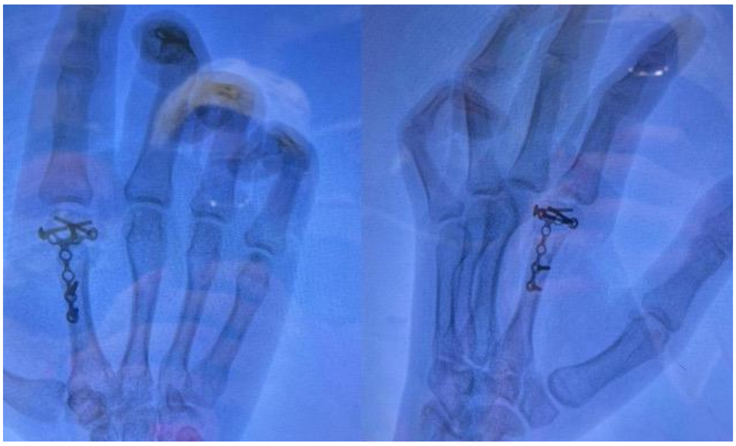

Fig. 6. *Post-operative X-rays.*

At the end of the procedure, the sagittal band and the intermetacarpal ligament were reconstructed as far as possible (Fig. 7). The tourniquet was released, and an accurate hemostasis was conducted before the skin suture.

Fig. 7. *Sagittal band and extension system reconstruction.*

The postoperative course was regular, and the removal of the sutures took place about 2 weeks after the surgical procedure. A splint was used for the first 3 weeks, and then the patient was allowed to move his left hand actively.

Outcomes

At 1-month radiographical and clinical evaluations, tools used for osteosynthesis were intact and in place, even if there was a modest resorption of the autologous bone graft (Fig. 8). The patient did not complain of pain on mobilization despite having a second finger flexion-extension deficit. No signs of vasculo-nervous deficits or infection. Therefore, he began the physiotherapy treatment.

At the check-up 3 months after the surgical procedure, the plate and screws appeared in place with no more bone graft resorption. The patient reported no pain and improvement in the second finger's range of motion. Scars were in order. He returned to manual work. The DASH score was 47, VAS 5 under exertion, and 2 at rest. At 6-month follow-up, tools were in place with complete bone healing, without further resorption of the bone graft (Fig. 9).

Fig. 8. *X-ray at 1-month follow-up.*

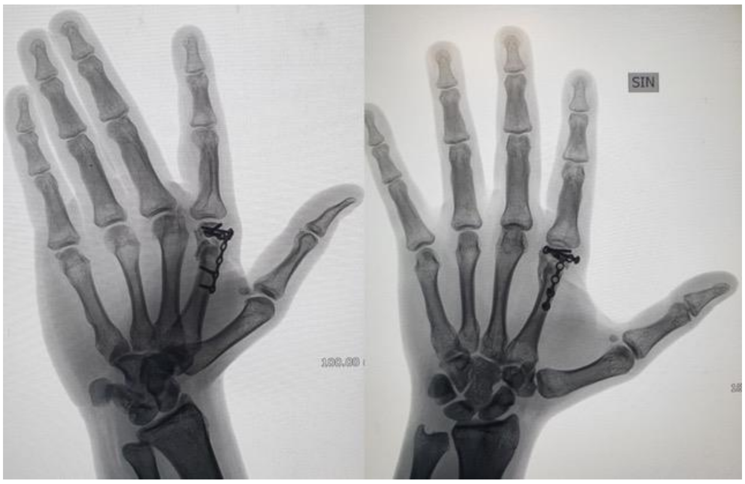

Fig. 9. *X-rays at 6-month follow-up.*

The second finger's length was satisfactory, with no rotation defects. The patient did not show any deficit of the second finger extension with a mild metacarpophalangeal joint flexion deficit, which was well tolerated (Fig. 10). He was then judged clinically and radiographically healed. The DASH score was 23, VAS 2 under exertion, 0 at rest. A strength test (JAMAR test) was also performed, and a force equal to 37 kg was generated with the grip.

Fig. 10. *Clinical examination at 6-month follow-up.*

DISCUSSION

Hand injuries could be disabling, affecting the patient's quality of life. In addition, high-energy trauma often leads to soft tissue and bone loss. As said, bone autologous grafting or microsurgical bone flaps are the most commonly used surgical technique in this field.

Javier Zurriaga-Carda et al. reported a case of metacarpal head reconstruction for a comminuted fracture using a chondrocostal graft. This technique allows for stable fixation and optimal osteointegration, but it is a demanding procedure with few complications during its harvesting, only in the case of skilled surgeons (8).

Microsurgical bone flaps are more commonly used in the case of metacarpal non-union, as reported by Christen et al. These authors described the application of the periosteal medial femoral condyle free flap to treat five patients. Free flaps are long-lasting surgical procedures that require specific microsurgical skills and large teams (9). On the other hand, the use of non-vascularized bone grafts is widely used when it is necessary to fill bone losses, but they are not a guarantee of results since these grafts are non-vascularized bone and are challenging to apply if the bone loss affects the articular surface. Furthermore, the graft must be taken from another body area, e.g., the distal radius or iliac crest, which, in any case, requires two surgical steps (10).

More expensive techniques are also proposed in case of oncological resections or failures of previous reconstructive surgical procedures. They consist of 3D-printed custom-made prosthesis to repair the bone defect (11). However, there are conditions such as the one described in this case report in which it is impossible to subject the patient to prolonged interventions due to associated clinical conditions or when the articular surface is involved, and it is necessary to reconstruct it.

The "on-the-table" reconstruction we proposed was adapted from similar techniques proposed for other anatomical districts, mainly the elbow and, in any case, for unloaded bone segments. It consists of a faithful reproduction of the articular surface by recomposing the fracture fragments and their subsequent repositioning on the metaphysis.

In 2015, Kiran Kumar et al. described 6 cases of Mason III radial head fracture treated with this reconstruction, obtaining good clinical results without complications, which required a surgical revision. The reconstructed articular bone acts as a spacer (12).

Kastenberger et al. reported 14 patients treated with "on-the-table" reconstruction for Mason III and IV radial head fracture. Complete bone union was achieved in 9 cases, partial union in 4 cases, and non-union in one case. One patient needed a revision surgery due to the non-union and implant breakage. This is a reliable technique to restore joint alignment and maintain radial length with a low risk of complications (13). The same results are reported by Everding et al. in their paper (14).

To the authors' knowledge, no cases of metacarpal joint fractures were reconstructed using the same technique. The clinical and radiographic results of our patient at 6 months are optimal, and not only has there been no resorption, but, on the contrary, clear signs of bone healing are visible. Thus, this technique could be a viable option for treating complex cases because we can expect the same results as obtained in the case of radial head reconstruction. However, more cases are needed to confirm this. In any case, the proposed technique could be implemented, for example, using surgical glue, as reported by Chen et al. (15). Surgical glue could upgrade bone fragment coaptation, allowing better healing.

CONCLUSIONS

An "On-the-table" reconstruction in hand traumatology can give good clinical and functional results. It is an excellent option when it is not possible to perform more complex techniques or when it's necessary to postpone them to later times in case of failure. Case series could confirm the reliability of the method.

REFERENCES

1. Lambi AG, Rowland RJ, Brady NW, Rodriguez DE, Mercer DM. Metacarpal fractures. *J Hand Surg Eur.* 2023 Sep;48(2_suppl):42S-50S. doi: 10.1177/17531934231184119.
2. Dimitriou R, Jones E, McGonagle D, Giannoudis PV. Bone regeneration: current concepts and future directions. *BMC Med.* 2011 May 31;9:66. doi: 10.1186/1741-7015-9-66.
3. Kohlhauser M, Vasilyeva A, Kamolz LP, Bürger HK, Schintler M. Metacarpophalangeal Joint Reconstruction of a Complex Hand Injury with a Vascularized Lateral Femoral Condyle Flap Using an Individualized 3D Printed Model-A Case Report. *J Pers Med.* 2023 Nov 2;13(11):1570. doi: 10.3390/jpm13111570.
4. Murison JC, Pfister G, Amar S, Rigal S, Mathieu L. Metacarpal bone reconstruction by a cementless induced membrane technique. *Hand Surg Rehabil.* 2019 Apr;38(2):83-86. doi: 10.1016/j.hansur.2019.01.002
5. Koh IH, Hong JJ, Kang HJ, Choi YR, Kim JS. Minimum four-year clinical outcomes after on-table reconstruction technique for Dubberley type III in coronal shear fractures of the capitellum and trochlea: a report of 10 patients. *BMC Musculoskelet Disord.* 2024 Jul 3;25(1):514. doi: 10.1186/s12891-024-07628-2.
6. Kiran Kumar GN, Sharma G, Farooque K, Sharma V, Jain V, Singh R, Morey V. On-table reconstruction and fixation of Mason type III radial head fractures. *Chin J Traumatol.* 2015;18(5):288-92. doi: 10.1016/j.cjtee.2015.11.005.
7. Businger A, Ruedi TP, Sommer C. On-table reconstruction of comminuted fractures of the radial head. *Injury.* 2010 Jun;41(6):583-8. doi: 10.1016/j.injury.2009.10.026.
8. Zurriaga-Carda J, Rojas-Díaz R, Puertes-Almenar L, Silvestre-Muñoz A. Chondrocostal grafting for lateral osteochondral injury of the metacarpal head. *Orthop Traumatol Surg Res.* 2020 Apr;106(2):325-328. doi: 10.1016/j.otsr.2019.12.006.
9. Christen T, Krähenbühl SM, Müller CT, Durand S. Periosteal medial femoral condyle free flap for metacarpal nonunion. *Microsurgery.* 2022 Mar;42(3):226-230. doi: 10.1002/micr.30826.
10. Liodaki E, Kraemer R, Mailaender P, Stang F. The Use of Bone Graft Substitute in Hand Surgery: A Prospective Observational Study. *Medicine (Baltimore).* 2016 Jun;95(24):e3631. doi: 10.1097/MD.0000000000003631.

11. Xu L, Qin H, Cheng Z, Jiang WB, Tan J, Luo X, Huang W. 3D-printed personalised prostheses for bone defect repair and reconstruction following resection of metacarpal giant cell tumours. *Ann Transl Med.* 2021 Sep;9(18):1421. doi: 10.21037/atm-21-3400.
12. Kiran Kumar GN, Sharma G, Farooque K, Sharma V, Jain V, Singh R, Morey V. On-table reconstruction and fixation of Mason type III radial head fractures. *Chin J Traumatol.* 2015;18(5):288-92. doi: 10.1016/j.cjtee.2015.11.005.
13. Kastenberger T, Kaiser P, Spicher A, Stock K, Benedikt S, Schmidle G, Arora R. Clinical and radiological outcome of Mason-Johnston types III and IV radial head fractures treated by an on-table reconstruction. *J Orthop Surg Res.* 2022 Nov 19;17(1):503. doi: 10.1186/s13018-022-03394-w.
14. Everding J, Raschke MJ, Polgart P, Grüneweller N, Wähnert D, Schliemann B. Ex situ reconstruction of comminuted radial head fractures: is it truly worth a try? *Arch Orthop Trauma Surg.* 2019 Dec;139(12):1723-1729. doi: 10.1007/s00402-019-03250-3. Epub 2019 Aug 5. Erratum in: *Arch Orthop Trauma Surg.* 2020 Mar;140(3):441. doi: 10.1007/s00402-019-03330-4.
15. Chen DW, Hu WK, Zhou JQ. Use of surgical glue for Mason type III radial head fractures: A case report. *Medicine (Baltimore).* 2019 May;98(22):e15863. doi: 10.1097/MD.0000000000015863.

Review

IMPACT OF HIP ARTHROSCOPY ON PROSTHETIC JOINT INFECTION IN ELECTIVE TOTAL HIP REPLACEMENT: A SYSTEMATIC REVIEW OF THE LITERATURE

E. Ghezzi[1], G. D'Andrea[1], M. Alessio Mazzola[2], M. Conca[2], S.Mosca[1] and V.Salini[1]

[1]Vita-Salute University San Raffaele, Milan, Italy;
[2]IRCCS San Raffaele Hospital, Milan, Italy

Correspondence to:
Mattia Alessio Mazzola, MD
IRCCS Ospedale San Raffaele,
Via Olgettina 60,
20132, Milan, Italy
e-mail: mattia.alessio@hotmail.com

ABSTRACT

Total hip arthroplasty (THA) is the definitive surgical treatment for advanced joint diseases, aiming to improve patient quality of life and reduce pain. However, concerns have been raised about whether prior arthroscopy (HA) may increase the risk of postoperative complications, such as surgical site infections (SSIs) and prosthetic joint infections (PJIs), in patients undergoing subsequent arthroplasty. Understanding this relationship is essential for optimizing surgical outcomes and clinical decision-making. This systematic review aims to demonstrate evidence regarding the impact of prior arthroscopy on the risk of SSI and PJI in hip arthroplasty. Comprehensive research was conducted on PubMed, EMBASE, and other databases according to PRISMA guidelines. A total of 13 studies were included in the review. Most studies found no significant increase in SSI/PJI risk following arthroplasty after prior arthroscopy. Current evidence does not suggest a consistent increase in SSI/PJI risk following arthroplasty after arthroscopy. However, targeted management may be beneficial in high-risk populations.

KEYWORDS: *total hip arthroplasty, hip arthroscopy, surgical site infection, prosthetic joint infection, total hip replacement*

INTRODUCTION

Hip arthroscopy (HA) is a minimally invasive surgical procedure for diagnosing and treating hip pathologies, including labral tears, chondral defects, loose bodies, and femoroacetabular impingement (FAI) (1-3). Total hip arthroplasty (THA) is considered the gold standard treatment for patients who fail conservative management and continue to experience persistent and debilitating pain due to hip conditions such as osteoarthritis. Other indications for THA include hip fractures, avascular necrosis, inflammatory arthritis, development of hip dysplasia, and failed previous hip surgeries (3).

This systematic review of the literature aims to summarise the available evidence of the impact of HA before elective total hip replacement, which could increase the risk of infection, surgical site complication, or prosthetic joint infection.

Received: 15 November 2024
Accepted: 10 January 2025

MATERIAL AND METHODS

This systematic review evaluates the risk of surgical site infection (SSI) and prosthetic joint infection (PJI) following total hip arthroplasty. The inclusion criteria comprise undergoing THA, with or without prior arthroscopy on the same joint, and a comparison group of patients undergoing arthroplasty without prior arthroscopy. The primary outcomes assessed include the incidence of SSI/PJI, postoperative complications, and revision rate. The review considered cohort- studies, case-control studies, and systemic reviews. A comprehensive literature search was conducted in major health databases, including PubMed and EMBASE, adhering to PRISMA guidelines. The purpose was to synthesize and analyze information from various sources to meet the study’s aims.

RESULTS

A total of 1759 studies were downloaded from databases and registers, with 283 references removed due to duplication. Of the 1476 studies screened, 1426 were excluded. Fifty studies were assessed for eligibility, and 37 of these were excluded. The review included a total of 13 studies, which comprised a combination of cohort and case-control designs (Fig. 1). The population analyzed in these studies varied widely regarding demographic characteristics, comorbidities, and surgical intervals between arthroscopy and arthroplasty.

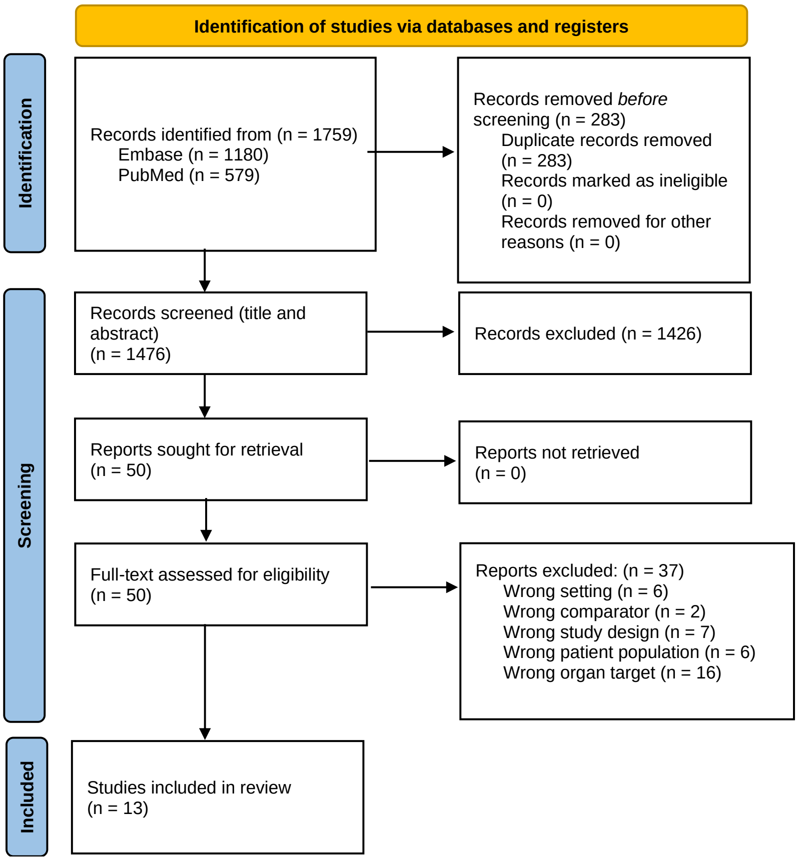

Fig. 1. *PRISMA*

Table I and II summarize the details, outcomes, and results of studies included in this systematic review comparing patients with prior HA (focus on individuals who underwent THA following a previous HA, examining the potential impact of prior HA on functional recovery, complications, and overall surgical success) and Control Group (primary THA). The tables provide detailed insights into the methodology, sample sizes, and key findings from each study, highlighting similarities and differences in functional outcomes, complication rates, and revision risks between the two groups.

Table I. *Study characteristics included within the review.*

Author	Year	Design	Country	Level of evidence	Arthroscopy	Control
Lemme et al.	2021	Retrospective Cohort-study	USA	III	1,940 (648 M)	1,940
Bolarinwa et al.	2020	Retrospective Cohort-study	USA	III	110 (43 M)	10,951
Ross et al.	2022	Matched Cohort-study	USA	III	3,156 (1,119 M)	3,156
Malahis et al.	2021	Retrospective Cohort-study	USA	III	2,600 (1,022 M)	2,600
Lindman et al.	2021	Matched Case-Control study	Sweden	III	135 (84 M)	71,891
Vovos et al.	2019	Matched- Controlled study	USA	III	95 (43 M)	95
Charles et al.	2017	Matched- Controlled study	USA	III	39 (14 M)	39
Perets et al.	2017	Matched-Controlled study	USA, Israel	III	35 (15 M)	35
Jain et al.	2019	Retrospective Cohort study	UK	III	18 (8 M)	63
Rosinsky et al.	2019	Systematic review	USA	III	305 (170 M)	502
Chaundry et al.	2019	Systematic review	USA	III	235 (104 M)	374
Liu et al.	2022	Systematic review and meta-analysis	China	III	16,321	303,625
Bryan et al.	2016	Retrospective Comparative study	USA	III	42 (18 M)	84

Table II. *Summary of key findings and impact of hip arthroscopy on elective total hip arthroplasty.*

Author	Outcomes	Results SSI/PJI in prior HA
Lemme et al.	Dislocations, aseptic loosening, PJI, and revision surgery	Increase of infection rate when THA is performed within a short interval of time
Bolarinwa et al.	90-day readmission, aseptic dislocation/revision, SSI, and hip stiffness	No significant increase in infection rate in SSI (p=0.796)
Ross et al.	Readmission, pulmonary embolism, urinary tract infection, blood transfusion, PJI, dislocation, periprosthetic fracture, mechanical complications, aseptic revision, and opioid claim	Lower rate of PJI (0.6% HA vs 1.3% control, OR 0.50, CI 0.28-0.84, p = 0.010)
Malahis et al.	Revision, dislocation, aseptic loosening, and PJI	Increased risk of PJI within 2 years of THA (OR 1.86, CI 1.26-2.77, P = 0.010) and aseptic loosening (OR 2.81, CI 1.66-4.76, p = <0.001). Increased risk of revision with pre-existing OA (OR 3.72, CI 3.15-4.57, P = 0.012)
Lindman et al.	EQ-5D Index, EQ-VAS, hip pain, satisfaction with surgery	One deep infection (p = 0.3)
Vovos et al.	Intraoperative complications, estimated blood loss, operative time, and postoperative complications	No difference in infection rate, increase rate of postoperative complications (32.6% vs 15.8%, p = 0.007), and higher rate of wound complications (5.3% vs 0%, p = 0.023)
Charles et al.	Operative time, hemoglobin drop, intraoperative blood loss, transfusion, opioids, functional mobility assessment, SSI, PJI, and revision rate.	No significant difference in SSI or deep PJI (p = 0.8)
Perets et al.	HHS, FJS-12, VAS for pain, satisfaction scores, postoperative complications, reoperation rates	No significant increase in risk of infection (p = 0.054)
Jain et al.	Postoperative OHS, intraoperative blood loss, surgical time, infection rate, postoperative complication, superficial wound infection, complex regional pain syndrome, trochanteric pain	Two cases of superficial infection (p > 0.005)
Rosinsky et al.	HHS, dislocation, infection rates, and revisions	Infection rate in HA group = 2.82%, not statistically significant (p > 0.05)
Chaundry et al.	HHS, lower Forgotten Joint Scores, VAS pain, intraoperative measures (operative time, blood loss), postoperative complications (infections, hip dislocation, revision rates), and patient satisfaction	No statistically significant differences in PJI rates
Liu et al.	HHS, revision rates, reoperations, risk of infections, aseptic loosening, periprosthetic fracture risk, and ROM	Significant increase in the risk of infection in (OR 1.83, p < 0.001)
Bryan et al.	HHS, complication rates, revision rates, dislocation, acute infection, and symptomatic leg length discrepancy	No difference in overall complications (p = 0.053)

**M: males; SSI: surgical site infection; PJI: periprosthetic joint infection; THA: total hip arthroplasty; HA: hip arthroscopy; OA: osteoarthritis; HHS: Harris Hip Score; FJS-12: Forgotten Joint Score; VAS: Visual Analogue Scale; ROM: range of motion.*

DISCUSSION

HA is a minimally invasive orthopedic procedure used to treat various hip conditions. Although HA is relatively uncommon, its use has increased steadily over the past decades (1). First described in 1931, the indications for HA have evolved (2), now including labral tears, chondral flap defects, loose bodies, and femoroacetabular impingement (FAI) (3).

The conversion rate from HA to total hip arthroplasty (THA) varies across studies; it was demonstrated that HA could delay but not eliminate the progression to THA, particularly in patients with osteoarthritis (OA). Reported conversion rates range from 9% to 50%, influenced by factors such as patient demographic characteristics, OA severity, and surgical details (4-6). Younger patients and those with milder stages of OA often experience longer intervals before requiring THA, with average durations ranging from approximately 1 to 3 years (5). On the other hand, advanced OA, older age, and obesity are associated with higher and more rapid rates of conversion (5, 6). Despite its benefits, the long-term impact of prior arthroscopy on infection rates and outcomes following THA remains a topic of debate, emphasizing the need for careful patient selection and counseling (6).

Several studies indicated no significant increase in infection following THA in patients with a history of prior HA. However, one study (7) compared 1,940 patients who underwent THA without prior HA to 639 patients who had THA within a year of HA and 1,301 patients who had THA more than a year after. The results demonstrated that arthroscopy was associated with a higher risk of complications, such as periprosthetic joint infections and aseptic loosening, particularly when THA was performed within a short interval after HA (7).

Another study (8), which included 110 patients undergoing FAI treatment between 2005 and 2014, reported no significant increase in surgical site infections ($p = 0.796$) or aseptic dislocations/revision ($p = 0.409$) within three years (8).

Ross et al. (9), in a study involving 3,156 patients, found that prior HA was associated with lower rates of prosthetic joint infection at one year (0.6% vs 1.3%; OR 0.50, 95% CI 0.28–0.84, $p = 0.010$). However, one study (10) indicated an increased risk of PJI within 2 years of THA (OR 1.86, 95% CI 1.26–2.77, $p = 0.010$) and aseptic loosening (OR 2.81, 95% CI 1.66–4.76, $p < 0.001$). Additionally, HA performed in patients with pre-existing OA significantly raised the risk of revision risk post-THA (OR 3.72, 95% CI 3.15–4.57, $p = 0.012$) (10).

A study based on the Swedish Hip Arthroplasty registry compared 135 patients who underwent THA following HA for FAI to 540 matched controls. The results showed one deep infection in the HA group and eight in the control group, with no significant difference between patients with and without prior HA ($p = 0.3$ for reoperations due to infection) (11).

Similarly, a large academic medical center conducted a retrospective analysis of 95 patients undergoing THA after HA with 95 primary THA controls, with the average time from HA to THA being 29 months, no significant difference in infection rates was proved (surgical site infection 4.2% in the HA group vs. 2.1% in the control, $p = 0.410$). However, higher rates of overall postoperative complications (32.6% vs. 15.8%, $p = 0.007$), including wound complications, were found (5.3% vs. 0%, $p = 0.023$) (12). Other studies suggested that the time interval between HA and THA did not significantly influence rates of infections or revisions, suggesting that factors such as surgical techniques and patient comorbidities might play a crucial role (10, 12).

A smaller study by Charles et al. compared 39 patients with prior HA to 39 matched THA controls and found no significant difference in SSI or deep PJI rate ($p=0.8$). This suggests no elevated infection risk in patients with prior HA undergoing THA (13).

Another study involving 35 patients undergoing THA after HA highlighted two minor infections in the HA group versus none in the control group, though this was not statistically significant ($p= 0.054$) (14). Additionally, Jain et al. (15) showed no significant differences in infection rates in a cohort of 18 patients who underwent THA after HA. The study documented only two cases of superficial infections in the HA group, which were successfully treated with antibiotics, and one in the control group (p-value >0.005). While some studies indicate a slightly higher rate of minor infections post-THA, these differences are not statistically significant in most cases. Larger sample sizes and long-term follow-up are needed to definitively assess the impact of prior HA on infection risks following THA.

A 2019 systematic review studied 305 hips with prior HA and 502 control hips and found infection rates were higher in five patients in the HA group (2.82%) compared to one patient in the control group (0.35%); the mean time to conversion was 23 months. However, the difference was not statistically significant ($p > 0.05$) (16). Another systematic review by Chaudhry et al. (17), including 235 HA patients and 374 controls, reported no statistically significant differences in PJI rates between groups. However, Liu et al. (18) meta-analysis demonstrated a significant increase in the risk of infection in the prior HA group compared with the control (OR 1.83, p-value < 0.001). The study emphasizes that prior HA is associated with a higher risk of PJI, particularly within two years. Another study found that the rate of infection and complications did not differ significantly between patients with prior HA and those undergoing primary THA. The infection rate in the arthroscopy group included one acute postoperative deep infection compared to one periprosthetic infection in the control group. Statistical analysis showed no significant difference in overall complications (p=0.53) or revision rates (p=0.42). These findings suggest the need for careful patient selection, follow-up, and optimization of surgical timing (19).

Limitations

This study has several limitations, including the heterogeneity in study designs, which varied in methodology, patient demographics, and time intervals between HA and THA. Many studies had a limited sample size, limiting the statistical power to detect significant differences. Additionally, the retrospective nature of most studies introduces selection bias. The average follow-up period is short and does not allow to asses long-term outcomes and complications. Other factors, such as the severity of pre-existing OA, surgical procedures, and patient comorbidities, increase the risk of confounding.

CONCLUSIONS

Most studies have shown no significant increase in the postoperative superficial or deep infection risk following THA after previous HA compared with controls. The small sample size was a major limitation of some studies; however, those including a greater number of patients also do not generally indicate an increased infection risk. There may be a difference in infection risk based on underlying hip pathology, with one study demonstrating increased risk in OA patients and multiple studies demonstrating no increased risk in FAI. However, there is insufficient data to determine whether this is related to the underlying pathology or to confounding age of onset (FAI patients tended to be younger than OA patients). Further prospective studies with larger sample sizes and standardized methodology are needed to clarify these associations and guide clinical decision-making.

REFERENCES

1. Schairer WW, Nwachukwu BU, Suryavanshi JR, Yen YM, Kelly BT, Fabricant PD. A Shift in Hip Arthroscopy Use by Patient Age and Surgeon Volume: A New York State–Based Population Analysis 2004 to 2016. *Arthroscopy The Journal of Arthroscopic and Related Surgery*. 2019;35(10):2847-2854.e1. doi:https://doi.org/10.1016/j.arthro.2019.05.008
2. Burman M, Peltier LF. Arthroscopy or the Direct Visualization of Joints: An Experimental Cadaver Study. *Clinical Orthopaedics and Related Research*. 2001;390(5):5-9. doi:https://doi.org/10.1097/00003086-200109000-00003
3. McCarthy JC, Lee JA. Arthroscopic Intervention in Early Hip Disease. *Clinical Orthopaedics and Related Research*. 2004;429:157-162. doi:https://doi.org/10.1097/01.blo.0000150118.42360.1d
4. Piuzzi NS, Slullitel PAI, Bertona A, et al. Hip Arthroscopy in Osteoarthritis: A Systematic Review of the Literature. *HIP International*. 2015;26(1):8-14. doi:https://doi.org/10.5301/hipint.5000299
5. Schairer WW, Nwachukwu BU, McCormick F, Lyman S, Mayman D. Use of Hip Arthroscopy and Risk of Conversion to Total Hip Arthroplasty: A Population-Based Analysis. *Arthroscopy*. 2016;32(4):587-593. doi:https://doi.org/10.1016/j.arthro.2015.10.002
6. Haviv B, O'Donnell J. The incidence of total hip arthroplasty after hip arthroscopy in osteoarthritic patients. *BMC Sports Science, Medicine and Rehabilitation*. 2010;2(1). doi:https://doi.org/10.1186/1758-2555-2-18
7. Lemme NJ, Veeramani A, Yang DS, Tabaddor RR, Daniels AH, Cohen EM. Total Hip Arthroplasty After Hip Arthroscopy Has Increased Complications and Revision Risk. *The Journal of Arthroplasty*. 2021;36(12):3922-3927.e2. doi:https://doi.org/10.1016/j.arth.2021.07.020
8. Bolarinwa SA, Aryee JN, Labaran LA, Werner BC, Browne JA. Does Arthroscopic Repair of Femoroacetabular Impingement Pathology Affect Clinical Outcomes after Ipsilateral Total Hip Arthroplasty? *Hip & Pelvis*. 2020;32(1):35-41. doi:https://doi.org/10.5371/hp.2020.32.1.35
9. Ross BJ, Wortman RJ, Lee OC, Mansour AA, Cole WW, Sherman WF. Is Prior Hip Arthroscopy Associated With Higher Complication Rates or Prolonged Opioid Claims After Total Hip Arthroplasty? A Matched Cohort Study. *Orthopaedic Journal of Sports Medicine*. 2022;10(9). doi:https://doi.org/10.1177/23259671221126508
10. Malahias MA, Gu A, Richardson SS, De Martino I, Sculco PK, McLawhorn AS. Hip arthroscopy for hip osteoarthritis is associated with increased risk for revision after total hip arthroplasty. *HIP International*. 2020;31(5):112070002091104. doi:https://doi.org/10.1177/1120700020911043
11. Lindman I, Nåtman J, Öhlin A, et al. Prior hip arthroscopy does not affect 1-year patient-reported outcomes following total hip arthroplasty: a register-based matched case-control study of 675 patients. *Acta Orthopaedica*. 2021;92(4):408-412. doi:https://doi.org/10.1080/17453674.2021.1884795

12. Vovos TJ, Lazarides AL, Ryan SP, Kildow BJ, Wellman SS, Seyler TM. Prior Hip Arthroscopy Increases Risk for Perioperative Total Hip Arthroplasty Complications: A Matched-Controlled Study. *The Journal of Arthroplasty*. 2019;34(8):1707-1710. doi:https://doi.org/10.1016/j.arth.2019.03.066
13. Charles R, LaTulip S, Goulet JA, Pour AE. Previous arthroscopic repair of femoro-acetabular impingement does not affect outcomes of total hip arthroplasty. *International Orthopaedics*. 2016;41(6):1125-1129. doi:https://doi.org/10.1007/s00264-016-3330-0
14. Perets I, Mansor Y, Mu B, Walsh JP, Ortiz-Declet V, Domb BG. Prior Arthroscopy Leads to Inferior Outcomes in Total Hip Arthroplasty: A Match-Controlled Study. *Journal of Arthroplasty*. 2017;32(12):3665-3668. doi:https://doi.org/10.1016/j.arth.2017.06.050
15. Jain MV, Rajpura A, Kumar VS, et al. Functional outcome of total hip arthroplasty after a previous hip arthroscopy: a retrospective comparative cohort study. *HIP International*. 2018;29(4):363-367. doi:https://doi.org/10.1177/1120700018810509
16. Rosinsky PJ, Kyin C, Shapira J, Maldonado DR, Lall AC, Domb BG. Hip Arthroplasty After Hip Arthroscopy: Are Short-term Outcomes Affected? A Systematic Review of the Literature. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*. 2019;35(9):2736-2746. doi:https://doi.org/10.1016/j.arthro.2019.03.057
17. Chaudhry ZS, Salem HS, Hammoud S, Salvo JP. Does Prior Hip Arthroscopy Affect Outcomes of Subsequent Hip Arthroplasty? A Systematic Review. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*. 2019;35(2):631-643. doi:https://doi.org/10.1016/j.arthro.2018.08.055
18. Liu Q, Tian Z, Pian K, et al. The influence of prior arthroscopy on outcomes of primary total lower extremity arthroplasty: A systematic review and meta-analysis. *International Journal of Surgery*. 2022;98:106218-106218. doi:https://doi.org/10.1016/j.ijsu.2021.106218
19. Haughom BD, Plummer DR, Hellman MD, Nho SJ, Rosenberg AG, Della CJ. Does Hip Arthroscopy Affect the Outcomes of a Subsequent Total Hip Arthroplasty? *The Journal of Arthroplasty*. 2016;31(7):1516-1518. doi:https://doi.org/10.1016/j.arth.2016.01.008

Retrospective Study

RADIAL HEAD PROSTHESIS IN THE TREATMENT OF COMPLEX, NON-REDUCIBLE RADIAL HEAD FRACTURES: A RETROSPECTIVE STUDY

A. Benedetto, A. Pulcrano, A. Grosso, S. Rizzo, G. Vicenti and G. Solarino

Orthopaedics University of Bari "Aldo Moro"- AOU Policlinico Consorziale, Department of Translational Biomedicine and Neuroscience, Orthopaedic and Trauma Unit, Bari, Italy

Correspondence to:
Antonella Benedetto, MD
Orthopaedics University of Bari "Aldo Moro"
AOU Policlinico Consorziale,
Piazza Giulio Cesare 11,
70124, Bari (Ba), Italy
e-mail: benedettoantonella95@gmail.com

ABSTRACT

Radial head is an important secondary stabilizer of the elbow and it's essential for the stability in the axial load, valgus and external rotations. Radial head prosthesis is a surgical option that can be used for displaced radial head fractures. This retrospective study evaluated the efficacy of radial head prosthesis in treating complex, non-reducible radial head fractures (Mason III-IV). Twenty-six patients were included. Functional outcomes were assessed using the Mayo Elbow Performance Score (MEPS), Oxford Elbow Score (OES), and Disabilities of the Arm, Shoulder, and Hand (DASH) at 3, 6, and 12-months post-surgery. Results demonstrated a significant improvement in functional scores over time, with a mean MEPS at 12 months of 73.85. Subgroup analysis revealed a correlation between the presence of associated ligamentous injuries and poorer functional outcomes. Radial head prosthesis proved to be an effective treatment, offering good functional recovery. However, the retrospective nature of the study, and limited sample size necessitate further prospective studies.

KEYWORDS: *radial head fracture, radial head prosthesis, Mayo Elbow Performance Score, Oxford Elbow Score, disabilities of the arm, shoulder, hand*

INTRODUCTION

Elbow is a complex articulation composed of three different articulations covered in a single articular capsule: humeroulnar, humeroradial, and proximal radioulnar joint. Radial head is an important secondary stabilizer of the elbow and it's essential for the stability in the axial load, valgus, and external rotations (1). Radial head and neck fractures are estimated to be one third of all elbow fractures (2). They have an incidence varying between 1.7 and 5% with an average of 2.7% (3). The mechanism of fracture is identified in an indirect trauma to the elbow with the limb in slight flexion and semi-pronation. The capitellum hits against the capitulum humeri causing the fracture. They are often associated with ligamentous injuries and consequent elbow instability. Those fractures have been classified by Mason in IV different types depending on the fracture pattern and the grade of displacement (4). Ligamentous and capsular lesions are estimated to be 4% in Mason I fractures, 21% in Mason II and 85% in Mason III fractures (5).

Received: 12 January 2025
Accepted: 20 February 2025

Complex, non-reducible and displaced radial head fractures (Mason IV) represent a significant challenge for orthopedic surgeons. Regardless of the fracture, the main goal of every treatment is to restore elbow stability, maintain the right length of the radius and achieve a good range of motion. Traditional treatments, such as open reduction and internal fixation (ORIF), often have limitations in those complex fractures that often have comminution or bone loss. Recently, radial head prosthesis has emerged as a viable alternative in those cases (6). Short- and mid-term follow-up studies have demonstrated the longevity and efficacy of radial head arthroplasty (RHA) (7). They have been developed to decrease complications following a radial head resection surgery.

The main function of the RHA is to simulate the physiological radio capitellar tracking, reproducing the mechanical function of the native radial head (8). This study aims to evaluate the efficacy of RHA in restoring function and improving quality of life in patients with these complex radial head fractures.

MATERIALS AND METHODS

We designed an observational retrospective study conducted on 26 patients who underwent radial head prosthesis between 2019 and 2023 at the Orthopedics and Traumatology Unit of Policlinico Hospital in Bari. Inclusion criteria were age greater than 18 years, comminuted and displaced radial head fractures (Mason III and IV), absence of neurovascular injuries and/or previous elbow traumatic lesions. The exclusion criteria were patients with age >75 years old, Mason type I and II fractures, and arthritic diseases.

Pre-operative elbow X-rays in two projections and CT scans were taken to classify the fracture with the Mason classification and choose the RHA treatment. All patients gave their consent to be included in this study. All procedures were performed in supine position via Kocher approach or via direct posterior approach to the elbow depending on the fracture pattern (Fig. 1).

Fig. 1. *Pre- and post-operative images of a male, 62 years old. Radial head Mason III fracture associated with an olecranon and coronoid fracture. The patient underwent surgery four days after trauma. A direct posterior approach to the elbow was performed. An ORIF of the olecranon and coronoid fracture with two plates was executed first, then a RHA was implanted with a reinsertion of the lateral ulnar collateral ligament with an anchor.*

A radial neck osteotomy was performed, and a straight, unipolar, modular radial head prosthesis was implanted (The Evolve Proline, Wright Medical Technology, Memphis, TN, USA). Patient demographics, fracture characteristics, and associated injuries were recorded. Functional outcomes were assessed using the Mayo Elbow Performance Score (MEPS), OES, and Shoulder and Hand (DASH) scores at regular intervals (three, six- and twelve-month follow-up). Poor functional results are associated with a total MEPS score lower than 60 or between 60 and 74 points.

Good results are associated with a MEPS score between 75-89 points; complete recovery of the elbow is observed for patients who reach a MEPS score higher than 90 points. An OES score of 48 or higher indicates a good clinical and functional post-operative outcome (9).

The DASH questionnaire is a subjective, district-specific assessment tool investigating the persistence or onset of disability related to upper limb function. It consists of approximately 30 questions related to symptoms or signs of disability with a score ranging from 0 (absence of disability) to 100 points.

RESULTS

Twenty-six patients were included in the study, nine men and seventeen women, with a mean age of 56. The fracture involved the dominant limb in 21 patients. 5 were Mason III type, 18 were Mason IV type. Nineteen patients had ligamentous injury associated with the fracture. All patients were treated at our trauma unit by a senior surgeon. The mean DASH, MEPS and OES scores are shown in Tables I, II and III. At the first follow-up 3 months after surgery, the analysis of the questionnaires administered to the patients revealed the following mean scores: mean MEPS 62.12 (between 40 and 75); mean OES 25.88 (between 14 and 35); mean DASH score 66.73 (between 30 and 90).

Table I. *MEPS, OES and DASH scores in patients divided by ligamentous injuries.*

	Media Legamen. SI	Diff. %	Media Legamen. NO	Diff. %	Diff. Legamento Si / No
MEPS 3 mesi	60,26		67,14		-10,25%
MEPS 6 mesi	65,53	8,04%	77,14	12,96%	-15,05%
MEPS 12 mesi	70,79	7,43%	82,14	6,09%	-13,82%
OES 3 mesi	24,74		29		-14,69%
OES 6 mesi	29	14,69%	33,57	13,61%	-13,61%
OES 12 mesi	32,05	9,52%	36,86	8,93%	-13,05%
DASH 3 mesi	70,53		56,43		24,99%
DASH 6 mesi	63,16	-11,67%	44,29	-27,41%	42,61%
DASH 12 mesi	56,84	-11,12%	37,14	-19,25%	53,04%

Table II. *MEPS, OES, and DASH scores in patients are divided by age.*

	Media > 55 anni	Diff. %	Media < 55 anni	Diff. %	Diff. età > o < 55
MEPS 3 mesi	58,33		67,27		-13,29%
MEPS 6 mesi	65,67	11,18%	72,73	7,51%	-9,71%
MEPS 12 mesi	72	8,79%	76,36	4,75%	-5,71%
OES 3 mesi	24,4		27,91		-12,58%
OES 6 mesi	28,4	14,08%	32,73	14,73%	-13,23%
OES 12 mesi	31,47	9,76%	35,91	8,86%	-12,36%
DASH 3 mesi	70,67		61,36		15,17%
DASH 6 mesi	61,33	-15,23%	53,64	-14,39%	14,34%
DASH 12 mesi	53,33	-15,00%	49,09	-9,27%	8,64%

Table III. *MEPS, OES, and DASH scores in patients are divided by dominant limb.*

	Media Arto Dom. SI	Diff. %	Media Arto Dom. NO	Diff. %	Diff. arto dominante Si / No
MEPS 3 mesi	61,19		66		4,81%
MEPS 6 mesi	67,86	9,83%	72	8,33%	4,14%
MEPS 12 mesi	72,86	6,86%	78	7,69%	5,14%
OES 3 mesi	25,57		27,2		1,63%
OES 6 mesi	29,76	14,08%	32,2	15,53%	2,44%
OES 12 mesi	32,86	9,43%	35,4	9,04%	2,54%
DASH 3 mesi	65,95		70		4,05%
DASH 6 mesi	57,38	-14,94%	61	-14,75%	3,62%
DASH 12 mesi	51,9	-10,56%	50	-22,00%	-1,90%

At the second follow-up at six months: mean MEPS 68.65 (between 45 and 90; increase of 9.51%); mean OES 30.23 (between 16 and 40; increase of 14.39%); mean DASH score 58.08 (between 20 and 85; decrease of 14.89%).

Finally, at the last follow-up at one year: mean MEPS 73.85 (between 45 and 95; increase of 7.04%); Average OES 33.35 (between 17 and 45; increase of 9.36%); average DASH score 51.54 (between 20 and 85; decrease of 12.69%).

The patients were divided into two groups based on the presence or absence of ligament lesions (Table I). The mean MEPS recorded at 3, 6 and 12 months in patients with ligament lesions were 60.26, 65.53 and 70.79 respectively. In patients without lesions, the mean MEPS were 67.14, 77.14, and 82.14, respectively. The mean OES in patients with injury at 3, 6, and 12 months was 24.74, 29, 32.05 respectively; in patients without injury, it was 29, 33.57, and 36.86

respectively. The mean DASH score at 3, 6 and 12 in patients with injury was 70.53, 63.16 and 56.84 respectively; while in patients without ligament injury it was 56.43, 44.29 and 37.14 respectively.

Further dividing the patients into two groups based on age (15 patients >55 years and 11 patients <55 years) (Table II), an average MEPS at 3, 6 and 12 months in patients >55 years of 58.33, 65.67 and 72 can be recorded, respectively; while in patients <55 years of 67.27, 72.73 and 76.36 respectively. The average OES in patients >55 years of age at 3, 6, and 12 months was 24.4, 28.4, 31.47, respectively; while in patients <55 years of age was 27.91, 32.73, and 35.91, respectively. Average DASH score at 3, 6, and 12 in patients >55 years of age was 70.67, 61.33, and 53.33 respectively; while in patients <55 years of age was 61.36, 53.64, and 49.09 respectively. The results demonstrated a significant improvement in functional outcomes over time, with patients experiencing a mean recovery of over 70% at 12 months based on the MEPS. Subgroup analysis revealed that patients with associated ligamentous injuries had poorer functional outcomes.

Lastly, Table III divides patients into two groups based on whether the dominant limb was affected or not (21 patients with fracture had the dominant limb involved and 5 patients had the non-dominant limb involved): an average MEPS at 3, 6 and 12 months can be recorded in patients with injury to the dominant limb of 61.19, 67.86 and 72.86 respectively; while in patients without injury to the dominant limb it is 66, 72 and 78 respectively. The average OES is found to be 25.57, 29.76, 32.86 in patients with fracture of the dominant limb at 3, 6, and 12 months, respectively; while in patients with a lesion in the non-dominant limb, respectively, 27.2, 32.2, and 35.4. Mean DASH score at 3, 6 and 12 in patients with a fracture of the dominant limb, respectively, 65.95, 57.38 and 51.9; while in patients with a lesion in the non-dominant limb, respectively, 70, 61 and 50.

DISCUSSION

Our study highlighted an average MEPS score of 73.8% at one year, an OES of 33.35 and a DASH score of 51.54. Those findings align with previous research, supporting the efficacy of radial head prosthesis in treating complex, non-reducible fractures. The procedure offers a reliable solution for restoring joint stability and function.

Findings indicated successful healing, demonstrating favorable mid-term survival rates upon radiological evaluation and functional scoring. According to Ring et al., radial fractures with more than three fragments need a treatment with radial prosthesis or excision (10). Their studies demonstrated that a radial synthesis led to unsatisfactory outcomes in 54% of patients. A recent meta-analysis confirms that RHA has superior results compared to ORIF for Mason type III and IV fractures (11). 12. Flinkkilä et al. analyzed outcomes of 45 patients operated on radial head prosthesis following complex elbow trauma in their clinic. Over thirteen years, the final follow-up reported a mean MEPS score of 92.6 ± 10. The authors conclude that prosthetic replacement was an excellent choice for functional results for complex fractures that cannot be treated with ORIF (12).

Beingessner et al. concluded that RHA for comminuted fractures is not repairable with the traditional ORIF technique, which has provided excellent functional results over time (13). Moreover, from a vascular point of view, the radial head is contained inside the articular capsule. The vascularization depends on a series of intraosseous vessels that run vertically from the neck of the radius (14). Consequently, Mason type III and IV fractures, even a successful osteosynthesis can result in complications such as osteonecrosis of the fragments, pseudoarthrosis, mobilization or failure of the hardware generating a stiff, unstable, or painful elbow.

The presence of associated ligamentous injuries can negatively impact outcomes of radial head replacement, highlighting the importance of a comprehensive preoperative assessment and individualized treatment plans. Furthermore, RHA can be challenging and must be performed by a dedicated specialized team. Selecting the correct length and head diameter can be difficult for the surgeon without experience or practice in this field (15).

The presented paper has some limitations: firstly, it is a study with a retrospective design, and secondly, we have a relatively small sample size; furthermore, there is no comparative group with patients treated with open reduction and internal fixation of the radial head. Therefore, future prospective studies with larger cohorts are needed to confirm these findings further.

It would be interesting to evaluate the activity of alkaline and acid phosphatases around fractures, as already demonstrated around titanium implants. Previous studies have highlighted that alkaline phosphatase (ALP) plays a crucial role in the bone mineralization process, while acid phosphatase (ACP) is involved in bone resorption (16, 17). A histochemical analysis of ALP and ACP activities could provide valuable insights into the bone healing and remodeling processes at fracture sites.

CONCLUSIONS

In conclusion, treating radial head fractures continues to spread debate among orthopedic surgeons. Based on the results reported in this paper, we believe that radial head prosthesis is a valuable treatment option for complex, non-reducible radial head fractures. It offers patients a good chance of recovering function and improving their quality of life. However, surgeons should be aware of the potential impact of associated ligamentous injuries on outcomes.

REFERENCES

1. Amis AA, Dowson D, Wright V. Elbow joint force predictions for some strenuous isometric actions. *Journal of Biomechanics*. 1980;13(9):765-775. doi:10.1016/0021-9290(80)90238-9
2. Harrington IJ, Tountas AA. Replacement of the radial head in the treatment of unstable elbow fractures. *Injury*. 1981;12(5):405-412. doi:10.1016/0020-1383(81)90012-7
3. Burkhart KJ, Wegmann K, Müller LP, Gohlke FE. Fractures of the Radial Head. *Hand Clinics*. 2015;31(4):533-546. doi:10.1016/j.hcl.2015.06.003
4. Mason ML. Some observations on fractures of the head of the radius with a review of one hundred cases. *Journal of British Surgery*. 1954;42(172):123-132. doi:10.1002/bjs.18004217203
5. Hudak PL, Amadio PC, Bombardier C, et al. Development of an upper extremity outcome measure: The DASH (disabilities of the arm, shoulder, and hand). *Am J Ind Med*. 1996;29(6):602-608. doi:10.1002/(SICI)1097-0274(199606)29:6<602::AID-AJIM4>3.0.CO;2-L
6. Agyeman KD, Damodar D, Watkins I, Dodds SD. Does radial head implant fixation affect functional outcomes? A systematic review and meta-analysis. *Journal of Shoulder and Elbow Surgery*. 2019;28(1):126-130. doi:10.1016/j.jse.2018.07.032
7. Heijink A, Kodde IF, Mulder PGH, et al. Radial Head Arthroplasty: A Systematic Review. *JBJS Rev*. 2016;4(10). doi:10.2106/JBJS.RVW.15.00095
8. van Riet RP, van Glabbeek F. History of radial head prosthesis in traumatology. *Acta Orthop Belg*. 2007;73(1):12-20.
9. Guyver P, Cattell A, Hall M, Brinsden M. Oxford elbow scores in an asymptomatic population. *annals*. 2013;95(6):415-417. doi:10.1308/003588413X13629960048352
10. Ring D, Quintero J, Jupiter JB. Open reduction and internal fixation of fractures of the radial head. *The Journal of Bone and Joint Surgery-American Volume*. 2002;84(10):1811-1815. doi:10.2106/00004623-200210000-00011
11. Sun H, Duan J, Li F. Comparison between radial head arthroplasty and open reduction and internal fixation in patients with radial head fractures (modified Mason type III and IV): a meta-analysis. *Eur J Orthop Surg Traumatol*. 2016;26(3):283-291. doi:10.1007/s00590-016-1739-1
12. Flinkkilä T, Kaisto T, Sirniö K, Hyvönen P, Leppilahti J. Short- to mid-term results of metallic press-fit radial head arthroplasty in unstable injuries of the elbow. *The Journal of Bone and Joint Surgery British volume*. 2012;94-B(6):805-810. doi:10.1302/0301-620X.94B6.28176
13. Beingessner DM, Dunning CE, Beingessner CJ, Johnson JA, King GJW. The effect of radial head fracture size on radiocapitellar joint stability. *Clinical Biomechanics*. 2003;18(7):677-681. doi:10.1016/S0268-0033(03)00115-3
14. Ring D, Psychoyios VN, Chin KR, Jupiter JB. Nonunion of Nonoperatively Treated Fractures of the Radial Head: *Clinical Orthopaedics and Related Research*. 2002;398:235-238. doi:10.1097/00003086-200205000-00032
15. Alolabi B, Studer A, Gray A, et al. Selecting the diameter of a radial head implant: an assessment of local landmarks. *Journal of Shoulder and Elbow Surgery*. 2013;22(10):1395-1399. doi:10.1016/j.jse.2013.04.005
16. Piattelli A, Scarano A, Piattelli M. Detection of alkaline and acid phosphatases around titanium implants: a light microscopical and histochemical study in rabbits. *Biomaterials*. 1995;16(17):1333-1338.
17. Scarano A, Carinci F, Assenza B, Piattelli M, Murmura G, Piattelli A. Vertical ridge augmentation of atrophic posterior mandible using an inlay technique with a xenograft without miniscrews and miniplates: case series. *Clin Oral Implants Res*. 2011;22(10):1125-1130. doi:10.1111/j.1600-0501.2010.02083.x

LAB PUBLISHER RESEARCH IN SCIENCE

Journal of Orthopedics

Review

IMPACT OF ROBOTIC-ASSISTED ORTHOPAEDIC PROCEDURES ON SURGICAL SITE INFECTIONS AND PROSTHETIC JOINT INFECTIONS: A SYSTEMATIC REVIEW OF THE LITERATURE

G. D'Andrea[1], M. Alessio Mazzola[2], M. Conca[2], G. Placella[1], S. Mosca[1] and V. Salini[1]

[1]Vita-Salute University San Raffaele, Milan, Italy;
[2]IRCCS San Raffaele Hospital, Milan, Italy

[*]*Correspondence to:*
Mattia Alessio Mazzola, MD
IRCCS Ospedale San Raffaele,
Via Olgettina 60,
20132, Milan, Italy
e-mail: mattia.alessio@hotmail.com

ABSTRACT

Robotic-assisted technology in orthopedic surgery has gained significant attention in recent years due to its potential to improve surgical precision and patient outcomes. However, concerns have been raised regarding prolonged operative times, increased surgical site complexity, and the potential impact on rates of surgical site infections (SSIs) and prosthetic joint infections (PJIs). Understanding this relationship is essential for optimizing surgical outcomes and clinical decision-making. This systematic review aims to investigate whether robotic-assisted orthopedic procedures increase the risk of subsequent SSIs or PJIs. Comprehensive research was conducted on PubMed, EMBASE, and other databases according to PRISMA guidelines. A total of 69 studies were included in the review. The results indicate no significant difference in SSI/PJI rates between robotic-assisted and conventional techniques, although factors such as prolonged operative times, increased operating room traffic, and additional equipment may temporarily elevate risks during the learning curve. Further long-term, high-quality studies are required to confirm these findings.

KEYWORDS: *robotic-assisted orthopedic surgery, robotic-assisted technology, surgical site infections, prosthetic joint infections*

INTRODUCTION

The adoption of robotic-assisted technology in orthopedic surgery has gained significant attention in recent years, especially in joint arthroplasties and spinal surgeries (1, 2). Initially developed in the 1980s, robotic systems aimed to enhance implant alignment and reduce complications compared to traditional methods (3). Over the years, robotic-assisted surgical systems have advanced considerably, providing greater precision and the ability to tailor surgical procedures to individual patients. By incorporating cutting-edge imaging technologies, real-time feedback mechanisms, and complex algorithms, these systems support surgeons in optimizing surgical outcomes (4).

Received: 30 January 2025
Accepted: 2 March 2025

In joint arthroplasties, they allow for appropriate preoperative planning, optimal selection of implants, and accurate placement of artificial joints (5). Similarly, in spinal surgeries, robotics facilitates minimally invasive approaches, improves screw positioning, and reduces complications (6).

Despite these advancements, concerns persist regarding their impact on infection rates, particularly surgical site infections (SSIs) and prosthetic joint infections (PJIs). Factors such as prolonged operative times, increased operating room traffic, and the use of additional equipment may increase the risk of contamination. Furthermore, the learning curve associated with adopting new technologies may temporarily compromise procedural efficiency and outcomes.

This systematic review aims to investigate whether patients undergoing robotic-assisted orthopedic procedures face an increased risk of subsequent PJI.

By summarising data from various studies in the literature, this review evaluates the risks and benefits of robotic procedures in the field of orthopedics, emphasizing their clinical significance.

MATERIALS AND METHODS

This systematic review aims to assess whether patients undergoing robotic-assisted orthopedic procedures face an increased risk of developing subsequent SSI and/or PJI.

A comprehensive search of the literature was conducted in October 2024 using PubMed, Medline, Web of Science, and Scopus databases, adhering to the PRISMA guidelines. Out of an initial pool of 268 identified articles, 69 studies were included after thorough full-text screening (Fig. 1).

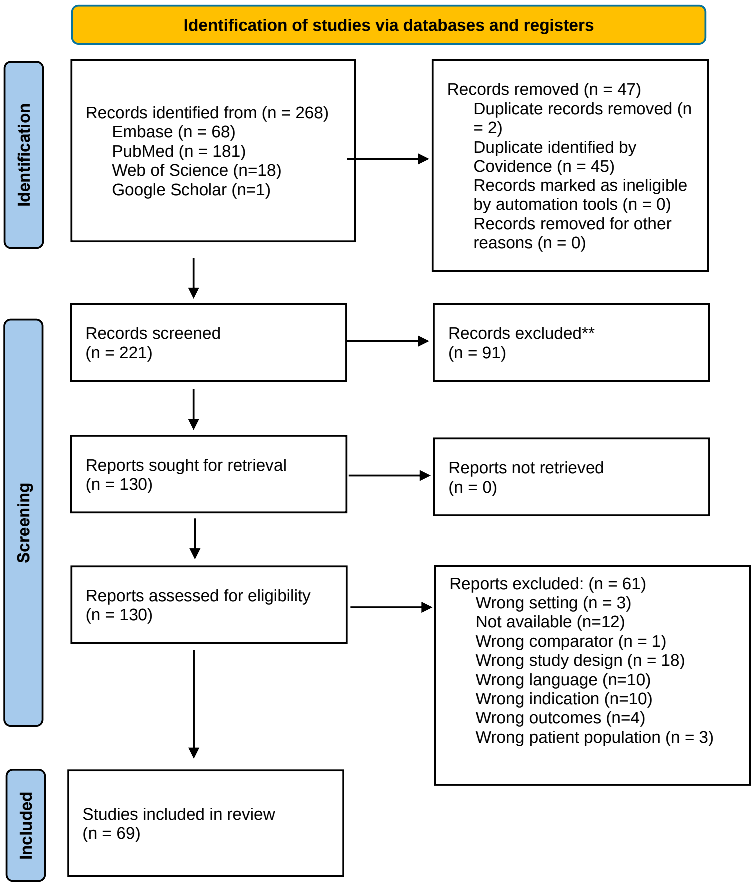

Fig. 1. *PRISMA flowchart of included studies.*

Notably, half of the included studies were published in 2023 and 2024, reflecting the timeliness and relevance of the available evidence.

Most studies on robotic-assisted orthopedic procedures have primarily investigated radiological and functional outcomes. However, a smaller subset focused explicitly on the incidence and risk factors associated with SSI and PJI, providing critical insights into the safety profile of these advanced surgical techniques.

RESULTS

This systematic review summarizes evidence from 69 studies investigating the impact of robotic-assisted orthopedic procedures on infection outcomes, specifically surgical site infections (SSIs) and prosthetic joint infections (PJIs). The findings highlight the current understanding and limitations in assessing infection risks associated with robotic-assisted surgeries.

Joint arthroplasties

Most of the selected studies primarily focus on radiological and functional outcomes of robotic-assisted joint arthroplasties, with only a limited subset specifically addressing infection-related outcomes.

Notably, the follow-up periods among the different studies are variable. Only three studies included in the review had a follow-up duration of at least 10 years. Of these, a randomized controlled trial (RCT) conducted by Kim et al. in 2020 offers the longest follow-up period of 13 years. This study reports no statistically significant differences in infection or complication rates between robotic-assisted and manual total knee arthroplasty (TKA) (7). Similarly, retrospective analyses by Jeon et al. and Lee et al. also demonstrated comparable rates of PJI across both surgical techniques (8, 9). These findings emphasize that, over the long term, robotic-assisted and conventional surgical methods have similar infection outcomes.

In 2023, a systematic review and meta-analysis by Alrajeb et al. provided further support to the evidence. This study synthesized data from seven RCTs encompassing 1,942 knees, comparing robotic-assisted and conventional knee arthroplasties. The results indicated no significant differences in infection rates, clinical outcomes, and functional outcomes, sustaining the equivalency of these approaches concerning PJI and SSI risks (10).

All other included studies, RCTs, prospective and retrospective, had shorter follow-up periods but consistently reported no significant differences in infection rates between robotic-assisted and conventional arthroplasty surgery (11-25).

In 2024, Burgio et al. published a retrospective study focused exclusively on PJI in the context of robotic-assisted TKA without comparison to manual TKA. It was the only study that clearly defined and used criteria for diagnosing PJI, highlighting the importance of standardizing criteria and definitions for PJI (26).

Certain studies highlighted procedural aspects unique to robotic-assisted surgeries that could influence infection risks. Honl et al. observed that prolonged operative times associated with robotic procedures were initially linked to higher rates of SSI. However, these complications were shown to decline as surgeons gained proficiency with the technology, highlighting the impact of the learning curve (25).

Li et al. reported comparable PJI rates between robotic and conventional TKA groups despite robotic-assisted procedures having increased operative times (27, 28)

Other studies, such as those by LaValva et al., pointed to additional procedural factors, including pin-site complications and increased operating room traffic, which could elevate the risk of contamination (29, 30).

Interestingly, some studies suggested that robotic-assisted techniques might offer advantages in minimizing infection risks. Retrospective analyses by O’Rourke et al., Aggarwal et al., Katzman et al., and Khanna et al. reported lower rates of PJI in robotic-assisted surgeries compared to conventional methods (31-34). However, the interpretability of these findings is limited by the lack of detailed follow-up data in these studies. While the results suggest a potential advantage of robotic systems in minimizing infection risks, the absence of robust longitudinal data prevents drawing definitive conclusions about their long-term effectiveness.

In contrast with those studies, Piple et al.’s study reported higher rates of PJI in robotic-assisted total hip arthroplasty, an outlier that necessitates further investigation (35).

Despite these challenges, most studies indicate that robotic-assisted joint arthroplasty does not intrinsically elevate the risk of PJI when compared to conventional methods.

Improvements in surgeon proficiency over the learning curve and advancements in robotic technology have mitigated earlier concerns, as evidenced by the findings of St. Mart (36, 37). Higher infection rates observed with earlier robotic systems were largely attributed to technical and procedural shortcomings rather than inherent deficiencies in the robotic technology itself.

Spinal surgeries

In the field of spinal surgery, infection-related outcomes varied more widely. Yang et al. reported increased complication rates, including SSI, in robotic-assisted lumbar spinal fusion (38). However, other studies presented a more favorable perspective. Keric et al. demonstrated that robotic systems could reduce infection rates in minimally invasive spine surgeries, particularly in high-risk populations (39). This benefit was also observed in studies by Zawar et al., which found that robotic-guided open spine surgeries had lower infection rates than conventional methods (40).

Notably, robotics in spinal surgery was often associated with reduced operative times, potentially lowering intraoperative contamination risks, a finding that contrasts with the extended durations seen in joint arthroplasties.

Overall, the results suggest that robotic-assisted orthopedic procedures do not inherently increase the risk of SSI or PJI. However, factors such as the surgeon’s learning curve, procedural intricacies, and operating room conditions are critical in determining infection outcomes. While advancements in technology and surgical experience have decreased many early concerns, the limited number of long-term studies and the heterogeneity of research methodologies underline the need for further investigation.

DISCUSSION

The introduction of robotic-assisted technology in orthopedic surgery represents a significant innovation, offering numerous benefits, including enhanced precision in implant alignment and the ability to tailor implant selection and positioning to individual patient needs. Despite these advantages, concerns persist regarding infection risks and extended operative times. Nevertheless, the lack of a notable increase in infection rates, such as SSI and PJI, indicates that robotic-assisted surgeries are largely comparable to conventional methods in terms of safety. However, the findings emphasize the critical role of procedural intricacies, ongoing technological advancements, and the surgeon's proficiency in optimizing outcomes.

In joint arthroplasties, studies with long-term follow-up, such as the RCT by Kim et al. (7), provide evidence that robotic-assisted techniques do not lead to higher infection rates. This finding is also supported by retrospective analyses and meta-analyses, including the comprehensive review by Alrajeb et al. (10), which analyzed data from multiple RCTs.

These studies have shown that robotic-assisted knee arthroplasty achieves clinical and functional outcomes comparable to those of traditional methods without compromising infection safety.

Nevertheless, certain procedural aspects unique to robotic surgeries need attention. The extended surgical durations commonly associated with these techniques, particularly during the initial learning curve, have been linked to higher SSI rates. Honl et al.’s findings demonstrate that these complications tend to resolve as surgeons gain experience (25). Additionally, the potential for increased operating room traffic and pin-site complications, as reported by LaValva et al. (29, 30), suggests that strict adherence to infection control protocols is essential to reduce these risks. In contrast to these findings, Piple et al. reported a higher PJI rate in robotic-assisted total hip arthroplasty; highlighting the complexity of evaluating infection risks (35).

In spinal surgeries, the interplay between infection risks and procedural efficiency represents an important factor. While Yang et al. reported increased SSI rates in robotic-assisted lumbar spinal fusion (38). Other studies, however, showed the opposite results. For instance, Keric et al. demonstrated that robotic systems significantly reduced infection rates in minimally invasive spine surgeries, particularly for high-risk patients (39). This benefit is reinforced by Zawar et al., who found that robotic-guided open spine procedures achieved lower infection rates than conventional procedures (40).

The reduced operative times frequently observed in robotic spinal surgeries further underline their potential advantages. Unlike joint arthroplasties, where robotic assistance often prolongs procedures, spinal surgeries benefit from the time efficiency gained by robotic systems.

Early robotic systems were criticized for higher infection rates due to technical and procedural limitations. However, as reported in studies by St Mart et al., these issues have largely been resolved through innovations in robotic technology and improvements in surgical techniques (36, 37) .

Limitations

This study has several limitations that may affect the validity of its findings. First, the heterogeneity in study designs introduces variability in how the studies were conducted, which could influence the consistency of results. Additionally, the follow-up durations varied across studies, with some providing short-term data while others only reported intermediate-term outcomes. Another limitation is the varying definitions of infection, such as the criteria used to diagnose periprosthetic joint infection (PJI). Furthermore, the relatively small sample sizes limit the statistical power to detect significant differences.

CONCLUSIONS

In conclusion, although robotic-assisted orthopedic procedures do not seem to increase the risk of infections, the results underline the importance of procedural and technological factors in determining surgical outcomes. The use of robotic technology in orthopedic procedures should be evaluated, ensuring that their advantages, such as improved precision and consistency, are fully optimized while minimizing potential risks. Future research should focus on generating more evidence about the long-term safety and effectiveness of robotic-assisted surgeries.

REFERENCES

1. Banerjee S, Cherian JJ, Elmallah RK, Jauregui JJ, Pierce TP, Mont MA. Robotic-assisted knee arthroplasty. *Expert Rev Med Devices* . 2015;12(6):727-735. doi:https://doi.org/10.1586/17434440.2015.1086264
2. Davidar AD, Jiang K, Weber-Levine C, Bhimreddy M, Theodore N. Advancements in Robotic-Assisted Spine Surgery. *Neurosurgery Clinics of North America*. 2024;35(2):263-272. doi:https://doi.org/10.1016/j.nec.2023.11.005
3. Suárez-Ahedo C, López-Reyes A, Martínez-Armenta C, et al. Revolutionizing orthopedics: a comprehensive review of robot-assisted surgery, clinical outcomes, and the future of patient care. *Journal of Robotic Surgery*. 2023;17(6). doi:https://doi.org/10.1007/s11701-023-01697-6
4. Li T, Badre A, Alambeigi F, Tavakoli M. Robotic Systems and Navigation Techniques in Orthopedics: A Historical Review. *Applied Sciences*. 2023;13(17):9768. doi:https://doi.org/10.3390/app13179768
5. Chen X, Deng S, Sun ML, He R. Robotic arm-assisted arthroplasty: The latest developments. *Chinese Journal of Traumatology*. 2021;25(3). doi:https://doi.org/10.1016/j.cjtee.2021.09.001
6. Zhang Q, Han XG, Xu YF, et al. Robotic navigation during spine surgery. *Expert Review of Medical Devices*. 2020;17(1):27-32. doi:https://doi.org/10.1080/17434440.2020.1699405
7. Kim YH, Yoon SH, Park JW. Does Robotic-assisted TKA Result in Better Outcome Scores or Long-Term Survivorship Than Conventional TKA? A Randomized, Controlled Trial. *Clinical Orthopaedics and Related Research*. 2020;478(2):266-275. doi:https://doi.org/10.1097/corr.0000000000000916
8. Jeon SW, Kim KI, Song SJ. Robot-Assisted Total Knee Arthroplasty Does Not Improve Long-Term Clinical and Radiologic Outcomes. *The Journal of Arthroplasty*. 2019;34(8):1656-1661. doi:https://doi.org/10.1016/j.arth.2019.04.007
9. Lee YM, Kim GW, Lee CY, Song EK, Seon JK. No Difference in Clinical Outcomes and Survivorship for Robotic, Navigational, and Conventional Primary Total Knee Arthroplasty with a Minimum Follow-up of 10 Years. *Clinics in Orthopedic Surgery*. 2023;15(1):82-82. doi:https://doi.org/10.4055/cios21138
10. Alrajeb R, Zarti M, Zakaria Shuia, Osama Alzobi, Ahmed G, Aissam Elmhiregh. Robotic-assisted versus conventional total knee arthroplasty: a systematic review and meta-analysis of randomized controlled trials. *European Journal of Orthopaedic Surgery and Traumatology*. 2023;34(3). doi:https://doi.org/10.1007/s00590-023-03798-2
11. Oikonomou K, Kiritsis NR, Hopper HM, et al. Clinical Trends and Outcomes in Technology-Assisted Total Hip Arthroplasty. *Journal of Clinical Medicine*. 2024;13(20):6035. doi:https://doi.org/10.3390/jcm13206035
12. Xu Z, Chai S, Chen D, et al. The LANCET robotic system can improve surgical efficiency in total hip arthroplasty: A prospective randomized, multicenter, parallel-controlled clinical trial. *Journal of orthopaedic translation*. 2024;45:247-255. doi:https://doi.org/10.1016/j.jot.2023.12.004
13. Vandenberk J, Mievis J, Deferm J, Janssen D, Bollars P, Vandenneucker H. NAVIO RATKA shows similar rates of hemoglobin-drop, adverse events, readmission and early revision vs conventional TKA: a single centre retrospective cohort study. *Knee Surgery Sports Traumatology Arthroscopy*. 2023;31(11):4798-4808. doi:https://doi.org/10.1007/s00167-023-07524-7
14. King CA, Jordan ML, Bradley AT, Wlodarski C, Tauchen AJ, Puri L. Transitioning a Practice to Robotic Total Knee Arthroplasty Is Correlated with Favorable Short-Term Clinical Outcomes—A Single Surgeon Experience. *Journal of Knee Surgery*. 2020;35(01):078-082. doi:https://doi.org/10.1055/s-0040-1712984
15. Maritan G, Franceschi G, Nardacchione R, et al. Similar survivorship at the 5-year follow-up comparing robotic-assisted and conventional lateral unicompartmental knee arthroplasty. *Knee Surgery Sports Traumatology Arthroscopy*. 2022;31(3):1063-1071. doi:https://doi.org/10.1007/s00167-022-07218-6

16. Bolam SM, Tay ML, Zaidi F, et al. Introduction of ROSA robotic-arm system for total knee arthroplasty is associated with a minimal learning curve for operative time. *Journal of Experimental Orthopaedics*. 2022;9(1). doi:https://doi.org/10.1186/s40634-022-00524-5
17. Bendich I, Vigdorchik JM, Sharma AK, et al. Robotic Assistance for Posterior Approach Total Hip Arthroplasty Is Associated With Lower Risk of Revision for Dislocation When Compared to Manual Techniques. *The Journal of Arthroplasty*. 2022;37(6):1124-1129. doi:https://doi.org/10.1016/j.arth.2022.01.085
18. Vanlommel L, Neven E, Anderson MB, Bruckers L, Truijen J. The initial learning curve for the ROSA® Knee System can be achieved in 6-11 cases for operative time and has similar 90-day complication rates with improved implant alignment compared to manual instrumentation in total knee arthroplasty. *Journal of Experimental Orthopaedics*. 2021;8(1). doi:https://doi.org/10.1186/s40634-021-00438-8
19. Mergenthaler G, Batailler C, Lording T, Servien E, Lustig S. Is robotic-assisted unicompartmental knee arthroplasty a safe procedure? A case control study. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2020;29(3). doi:https://doi.org/10.1007/s00167-020-06051-z
20. Bhimani SJ, Bhimani R, Smith A, Eccles C, Smith L, Malkani A. Robotic-assisted total knee arthroplasty demonstrates decreased postoperative pain and opioid usage compared to conventional total knee arthroplasty. *Bone & Joint Open*. 2020;1(2):8-12. doi:https://doi.org/10.1302/2633-1462.12.bjo-2019-0004.r1
21. Naziri Q, Cusson BC, Chaudhri M, Shah NV, Sastry A. Making the transition from traditional to robotic-arm assisted TKA: What to expect? A single-surgeon comparative-analysis of the first-40 consecutive cases. *Journal of Orthopaedics*. 2019;16(4):364-368. doi:https://doi.org/10.1016/j.jor.2019.03.010
22. Blyth MJG, Anthony I, Rowe P, Banger MS, MacLean A, Jones B. Robotic arm-assisted *versus* conventional unicompartmental knee arthroplasty: Exploratory secondary analysis of a randomised controlled trial. *Bone & joint research*. 2017;6(11):631-639. doi:https://doi.org/10.1302/2046-3758.611.BJR-2017-0060.R1
23. Song EK, Seon JK, Park SJ, Jung WB, Park HW, Lee GW. Simultaneous bilateral total knee arthroplasty with robotic and conventional techniques: a prospective, randomized study. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2011;19(7):1069-1076. doi:https://doi.org/10.1007/s00167-011-1400-9
24. Park SE, Lee CT. Comparison of Robotic-Assisted and Conventional Manual Implantation of a Primary Total Knee Arthroplasty. *The Journal of Arthroplasty*. 2007;22(7):1054-1059. doi:https://doi.org/10.1016/j.arth.2007.05.036
25. Honl M, Dierk O, Gauck C, et al. Comparison of robotic-assisted and manual implantation of a primary total hip replacement. *The Journal of Bone and Joint Surgery-American Volume*. 2003;85(8):1470-1478. doi:https://doi.org/10.2106/00004623-200308000-00007
26. Burgio C, Bosco F, Rovere G, et al. Early and delayed periprosthetic joint infection in robot-assisted total knee arthroplasty: a multicenter study. *European Journal of Orthopaedic Surgery & Traumatology*. 2024;34(6):3155-3162. doi:https://doi.org/10.1007/s00590-024-04043-0
27. Li M, Zhang Y, Shao Z, Zhu H. Robotic-assisted total knee arthroplasty results in decreased incidence of anterior femoral notching compared to posterior referenced instrumented total knee arthroplasty. *Journal of orthopaedic surgery*. 2024;32(1). doi:https://doi.org/10.1177/10225536241241122
28. Li C, Li T, Zhang Z, et al. Robotic-arm assisted versus conventional technique for total knee arthroplasty: early results of a prospective single centre study. *International Orthopaedics*. 2022;46(6). doi:https://doi.org/10.1007/s00264-022-05351-y
29. LaValva SM, Chiu YF, Fowler MJ, Lyman S, Carli AV. Does Computer Navigation or Robotic Assistance Affect the Risk of Periprosthetic Joint Infection in Primary Total Knee Arthroplasty? A Propensity Score-Matched Cohort Analysis. *The Journal of Arthroplasty*. 2024;39(1):96-102. doi:https://doi.org/10.1016/j.arth.2023.08.007
30. LaValva SM, Chiu YF, Fowler MJ, Lyman S, Carli AV. Robotics and Navigation Do Not Affect the Risk of Periprosthetic Joint Infection Following Primary Total Hip Arthroplasty. *The Journal of Bone and Joint Surgery*. 2024;106(7). doi:https://doi.org/10.2106/jbjs.23.00289
31. O’Rourke RJ, Milto AJ, Kurcz BP, Scaife SL, Allan DG, El Bitar Y. Decreased patient comorbidities and post-operative complications in technology-assisted compared to conventional total knee arthroplasty. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2022;31(3). doi:https://doi.org/10.1007/s00167-022-06966-9
32. Aggarwal VA, Sun J, Sambandam SN. Outcomes following robotic assisted total knee arthroplasty compared to conventional total knee arthroplasty. *Archives of orthopaedic and trauma surgery*. 2024;144(5). doi:https://doi.org/10.1007/s00402-024-05231-7
33. Katzman JL, Buehring W, Haider MA, Connolly P, Schwarzkopf R, Fernandez-Madrid I. Clinical outcomes of patellofemoral arthroplasty: robotic assistance produces superior short and mid-term outcomes. *Archives of Orthopaedic and Trauma Surgery*. 2024;144(9):4017-4028. doi:https://doi.org/10.1007/s00402-024-05263-z
34. Khanna V, Sohn G, Khanna S, et al. Lower Intraoperative and Immediate Postoperative Complications in Robotic Versus Conventional Primary Total Hip Arthroplasty: A Retrospective Cohort Analysis of Over 360,000 Patients. *Cureus*. Published online April 6, 2024. doi:https://doi.org/10.7759/cureus.57726
35. Piple AS, Wang JC, Hill W, et al. Postoperative outcomes and trends in computer-navigated and robotic-assisted total hip arthroplasty. *Hip International*. 2024;34(5):569-577. doi:https://doi.org/10.1177/11207000241264256
36. St Mart JP, de Steiger RN, Cuthbert A, Donnelly W. The three-year survivorship of robotically assisted versus non-

robotically assisted unicompartmental knee arthroplasty. *The Bone & Joint Journal*. 2020;102-B(3):319-328. doi:https://doi.org/10.1302/0301-620x.102b3.bjj-2019-0713.r1

37. St Mart JP, Goh EL. The current state of robotics in total knee arthroplasty. *EFORT Open Reviews*. 2021;6(4):270-279. doi:https://doi.org/10.1302/2058-5241.6.200052
38. Yang DS, Li NY, Kleinhenz DT, Patel S, Daniels AH. Risk of Postoperative Complications and Revision Surgery Following Robot-assisted Posterior Lumbar Spinal Fusion. *Spine*. 2020;45(24):E1692-E1698. doi:https://doi.org/10.1097/brs.0000000000003701
39. Keric N, Doenitz C, Haj A, et al. Evaluation of robot-guided minimally invasive implantation of 2067 pedicle screws. *Neurosurgical Focus*. 2017;42(5):E11-E11. doi:https://doi.org/10.3171/2017.2.focus16552
40. Zawar A, Chhabra HS, Mundra A, Sharma S, Kalidindi KKV. Robotics and navigation in spine surgery: A narrative review. *Journal of Orthopaedics*. 2023;44:36-46. doi:https://doi.org/10.1016/j.jor.2023.08.007

Case Report

WHOLE BLOOD OZONATED WITH PROCAINE. A CASE REPORT ON ULNAR NERVE DISLOCATION

A. Barbu[1*], G. Arcuri[2], C. Faletti[3] and O. Bottinelli [4]

[1]Physiatric Clinic, Treviso, Italy;
[2]Head of Orthopedic Rehabilitation at Clinical Institute Città di Pavia del Gruppo San Donato, Pavia, Italy;
[3]Head of the Musculoskeletal Radiology Service at Clinica Fornaca di Sessant del Gruppo Humanitas, Turin, Italy;
[4]Researcher at the Department of Radiology of the University of Pavia, Pavia, Italy

Correspondence to:
Andrei Barbu, MD
Physiatric Clinic,
Treviso, Italy
e-mail: dott.andreibarbu@gmail.com

ABSTRACT

Ulnar nerve dislocation is a complex and challenging condition characterized by the displacement of the ulnar nerve from its anatomical position in the epitrochleo-olecranon groove. This condition can lead to pain, a “snapping elbow” sensation, and, in more advanced cases, sensory and motor deficits. Among the innovative therapeutic options, Platelet-Rich Plasma (PRP) has shown promise in promoting healing and alleviating symptoms. However, the high cost and limited accessibility of PRP pose a barrier for many patients. An alternative therapeutic approach involves mixing ozonated whole blood with procaine, which combines the inflammatory effects of whole blood with the anti-inflammatory effects of oxygen-ozone therapy and procaine. This study is based on a case report of a single patient with a dislocated right elbow ulnar nerve. The solution was prepared by mixing 9 mL of whole blood, 1 mL of procaine (10 mg/mL), and 9 mL of oxygen-ozone (20 gamma) in two 20 mL syringes connected to a three-way system. The infiltration was performed without ultrasound guidance, following the guidelines and best clinical practices of the New Italian Oxygen-Ozone Federation (Nuova FIO). A single infiltration of ozonated whole blood with procaine yielded clinically and ultrasonographically significant results as early as the first week. The patient's subjective "discomfort" correlated with objective observations of a tendency toward ulnar nerve subluxation during dynamic ultrasound maneuvers. Magnetic resonance imaging performed approximately three months post-treatment revealed a thickened, taut Osborne ligament in continuity with a thin fibrous scar tissue on STIR sequences. Although a single infiltration and prolonged immobilization for approximately one month led to noticeable improvements, they were insufficient to ensure complete healing of the ulnar nerve dislocation. This outcome is comparable to PRP studies, as regenerative treatments generally require multiple sessions. Further studies are needed to explore the potential application of this innovative regenerative treatment in other ligamentous and/or tendinous injuries involving substance loss.

KEYWORDS: *ulnar nerve, dislocation, ozone therapy, ozonated whole blood, procaine, conservative treatment*

INTRODUCTION

Ulnar nerve dislocation is a pathological condition that occurs when the ulnar nerve, one of the major nerves of the arm, is displaced from its normal position in the epitrochleo-olecranon groove. This dislocation is commonly associated with direct trauma, particularly in contact sports or automobile accidents, but it can also result from repetitive elbow movements or degenerative conditions such as osteoarthritis.

Received: 19 February 2025
Accepted: 27 March 2025

The ulnar nerve is a branch of the brachial plexus, derived from the C8 and T1 spinal nerves. It runs along the arm, entering the elbow behind the epitrochlea. This position makes the nerve vulnerable to trauma and compression. The ulnar nerve innervates the medial part of the hand, including the fourth and fifth fingers, and plays a crucial role in both motor and sensory function. Preclinical studies have highlighted the importance of proper ulnar nerve function in maintaining fine hand functionality, essential for daily and professional activities.

Ulnar nerve dislocations are primarily caused by direct trauma to the elbow, which can occur in a variety of contexts, ranging from direct blows in contact sports to falls on the elbow. However, repetitive movements or traction forces can also be damaging, particularly in athletes engaged in activities that involve intensive arm use. Anatomical anomalies, such as a shallow epitrochleo-olecranon groove, or conditions like cubital tunnel syndrome, can increase susceptibility to this type of dislocation. Clinical symptoms include paresthesia (tingling or numbness), localized elbow pain, muscle weakness, and atrophy in chronic cases, as well as the characteristic "snap" sensation during elbow movements. These manifestations can vary significantly in intensity and duration, making diagnosis and treatment often challenging.

The diagnosis of ulnar nerve dislocation is based on careful clinical evaluation, supported by ultrasound imaging and, if necessary, magnetic resonance imaging. Ultrasound allows real-time visualization of the ulnar nerve and its position relative to the epitrochleo-olecranon groove, providing crucial information regarding the nerve dislocation. If left untreated, dislocation can lead to significant complications, including permanent nerve damage and functional impairment. Therapeutic options for ulnar nerve dislocation include both conservative and surgical approaches. Conservative treatments include rest, physical therapy, and the use of anti-inflammatory medications. However, in many cases, these measures are insufficient to ensure complete recovery. Surgical procedures, such as anterior transposition of the ulnar nerve or cubital tunnel decompression, are often required to restore nerve function and prevent permanent damage.

In recent years, several biological therapies have emerged as promising options. In particular, Platelet-Rich Plasma (PRP) has shown positive results in tissue regeneration and promoting healing. PRP is an autologous biological therapy that utilizes a concentration of platelets extracted from the patient’s blood, aimed at stimulating tissue regeneration and enhancing healing. The preparation of PRP involves blood collection, centrifugation to obtain the platelet concentrate, and its administration through perineural, intra-articular injections, or during surgical procedures. PRP is rich in growth factors, including PDGF, IGF, VEGF, and TGF-β, which promote cell proliferation, angiogenesis, and reduce inflammation, aiding nerve regeneration, particularly in cases of ulnar nerve dislocation.

Clinical studies have demonstrated that PRP effectively reduces pain, enhances joint functionality, and accelerates nerve regeneration. Despite the documented benefits, the treatment has some disadvantages, including variability in outcomes due to differences in preparation protocols and the need for further research to establish precise indications and optimize therapeutic protocols. PRP emerges as a promising therapeutic procedure, but additional studies are needed to confirm its long-term efficacy and address issues related to cost and insurance coverage (1-4). However, the preparation and administration of PRP incur high costs, which may limit its accessibility for some patients (5-14).

In this context, the use of ozonated whole blood mixed with procaine emerges as an innovative and more accessible option. This combination harnesses the powerful properties of ozone, known for its anti-inflammatory capabilities, and the anesthetic properties of procaine. Oxygen-ozone therapy is gaining popularity as a treatment for many musculoskeletal conditions due to its ability to improve tissue oxygenation and stimulate the repair of damaged tissues (15-22).

The aim of our study is to present the therapeutic approach with ozonated whole blood and procaine for the treatment of ulnar nerve dislocation at the elbow, providing a detailed analysis of the clinical results, implications for managing the condition, and the opportunities offered by this therapeutic approach.

CASE REPORT

A 30-year-old male patient, an active rugby player, sustained an ulnar nerve dislocation at the right elbow during a training session. During the traumatic event, the patient experienced a direct impact to the elbow, immediately followed by intense pain and debilitating weakness in the right hand. On initial clinical examination, the patient reported a sensation of tingling and numbness radiating along the medial side of the forearm and was unable to perform hand flexion movements. The kinetic chain was compromised, resulting in significant difficulty grasping and holding objects.

The patient underwent a thorough clinical assessment, which included:

- **medical history**: no significant past medical conditions and no previous symptoms at the elbow was detected.

- **physical examination**: acute localized pain in the elbow region, with an inability to perform flexion movements beyond 90° was found. Muscle strength in the right hand was significantly reduced, scoring 3/5 on the Medical Research Council (MRC) scale. A neurological exam revealed a reduction in sensation in the areas innervated by the ulnar nerve.

  To confirm the diagnosis, the patient underwent a series of instrumental investigations, including:
- **ultrasound**: showed dislocation of the ulnar nerve from the epitrochlear-olecranon groove, with signs of surrounding tissue edema;
- **MRI**: revealed a lesion of the Osborne ligament, characterized by thickening and disruption of its continuity, complicated by stationary edema.

Following these evaluations, the diagnosis of ulnar nerve dislocation at the right elbow was confirmed. Given the patient's clinical condition and the desire to avoid surgery, a conservative therapeutic strategy was initiated, involving the infiltration of ozonated whole blood in combination with procaine. The primary goal of this approach was pain reduction and the promotion of regeneration of the damaged tissues.

Procedure

The treatment began with the extraction of 9 ml of whole blood, performed using a needle-cannula system for venous blood collection. The blood was then mixed in a syringe with 1 ml of procaine at a concentration of 10 mg/ml and 9 ml of an ozone-oxygen mixture at 20 gamma. The preparation of the mixture was carried out in accordance with strict safety protocols to ensure adequate oxygenation and optimize therapeutic effectiveness.

The infiltration was performed at three targeted points in the elbow, chosen based on the distribution of the injury and the areas of pain reported by the patient:

1. **point 1**: infiltration near the olecranon to relieve localized pain;
2. **point 2**: infiltration along the course of the Osborne ligament, aiming to reduce inflammation and stimulate tissue regeneration;
3. **point 3**: infiltration in the epitrochlear region, to address the mechanical component of the ulnar nerve dislocation.

The procedure was performed with the patient in the supine position and the elbow flexed to approximately 90° to facilitate access to the infiltration sites. The intervention was performed without ultrasound guidance to simplify execution and minimize patient discomfort.

Follow-up

The patient underwent periodic follow-up visits to monitor the progress of treatment and the response to the intervention, with scheduled visits at one week, two weeks, one month, and three months post-infiltration.

1. **follow-up (1 week)**: The patient reported significant pain reduction, with a VAS score decrease from 8/10 to 3/10. Ultrasound revealed a reduction in edema, accompanied by initial scar tissue formation around the nerve.
2. **follow-up (2 weeks)**: Continuous clinical improvement was observed, with the VAS score further decreasing to 1/10. Ultrasound revealed an improved positioning of the nerve, accompanied by a progressive reduction in edema. Additionally, muscle strength showed signs of recovery, with the MRC score rising to 4/5.
3. **follow-up (1 month)**: The patient reported further improvement, with a VAS score of zero, indicating the absence of pain. Ultrasound findings showed improved continuity of the nerve, with stability of the Osborne ligament. Although mild dynamic subluxation was present, the patient resumed normal daily activities without experiencing pain.
4. **follow-up (3 months)**: After three months, the patient demonstrated complete recovery of elbow and hand functionality. Ultrasound and MRI confirmed significant nerve repair, with no signs of dislocation or residual pain. Muscle strength reached the maximum score of 5/5, indicating full functional recovery.

Despite the overall positive results, a single infiltration of ozonated whole blood was insufficient to guarantee complete healing of the ulnar nerve dislocation. It was recommended that consideration be given to additional treatments and revisiting the infiltration approach for patients with similar conditions.

RESULTS

The treatment, which involved infiltrations of ozonated whole blood and procaine, showed promising results in the patient's recovery. The treatment with ozonated whole blood and procaine infiltrations produced favorable outcomes in the recovery of the patient suffering from ulnar nerve dislocation.

- **Pre-treatment:** before the infiltration, dynamic ultrasound showed ulnar nerve subluxation, with the nerve tending to shift within the epitrochlear-olecranon groove at the first degrees of arm supination maneuvers and elbow flexion, and clear signs of dislocation of the nerve to the last degrees of arm supination maneuvers and elbow flexion (Fig. 1, 2).

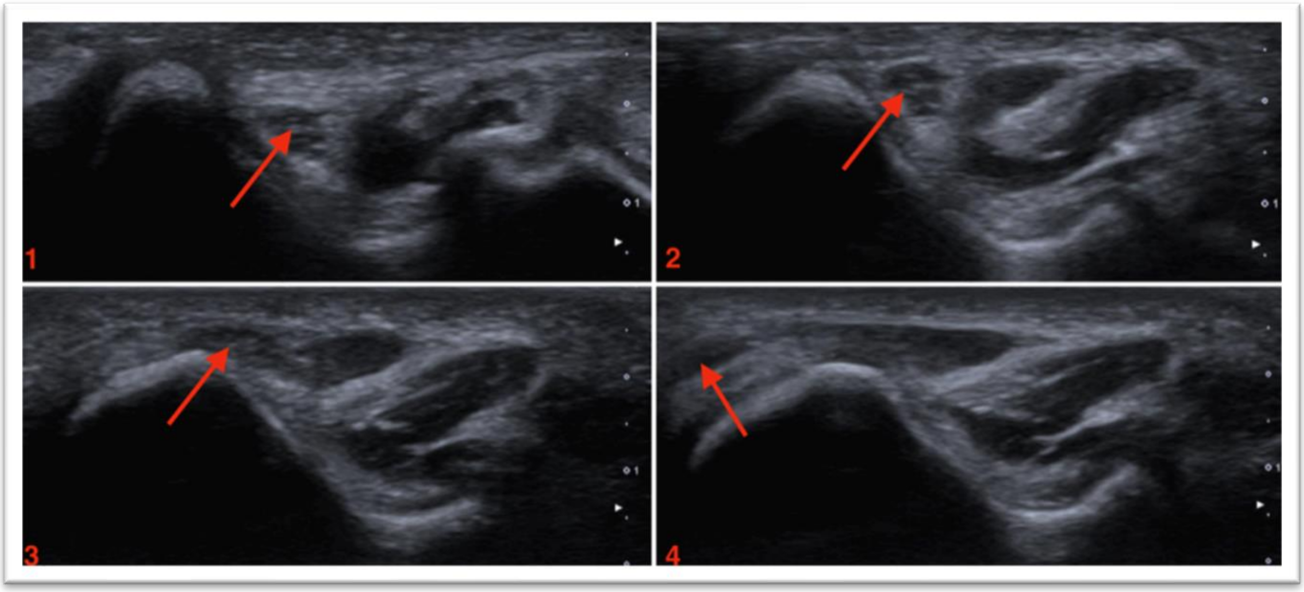

Fig. 1. *The patient exhibited an ulnar nerve dislocation (**red arrow**) during full forearm supination and maximum elbow flexion, as demonstrated by dynamic ultrasound testing.*

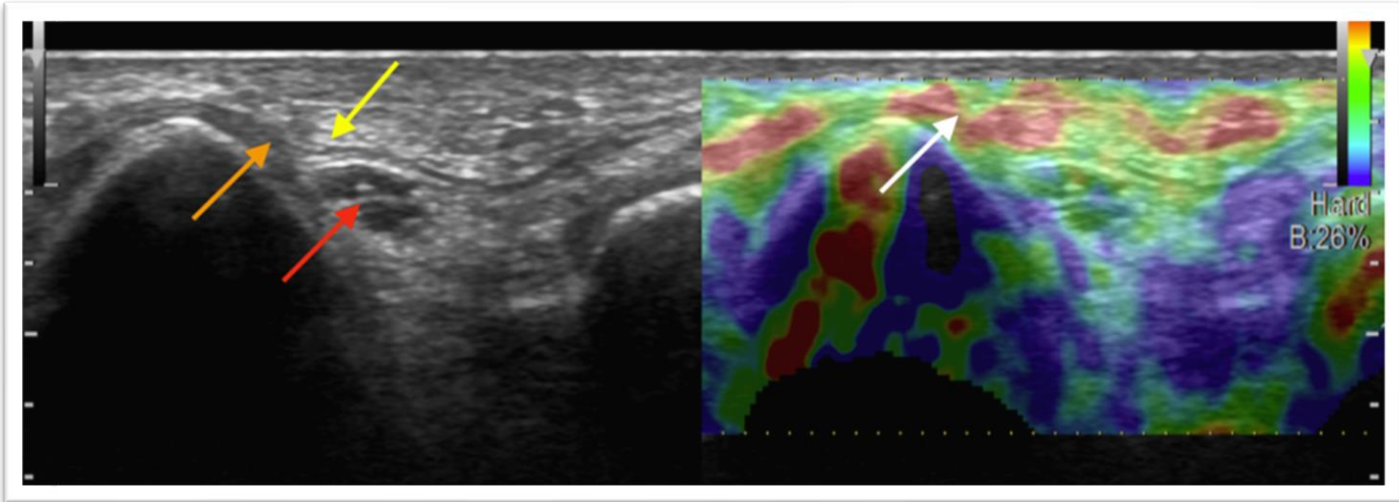

Fig. 2. *The patient with a supinated forearm and extended elbow pre-treatment. The B-mode image shows the tendency of the hypoechoic and enlarged ulnar nerve to localize in the epicondylar portion of the epitrochlear-olecranon groove (**red arrow**) and the discontinuity of the hyperechoic Osborne ligament (yellow arrow) due to the interposition of a hypoechoic epitrochlear tissue (orange arrow). The elastosonographic image demonstrates the soft consistency of the epitrochlear tissue, similar to that of subcutaneous tissue (**white arrow**). The thickness of the Osborne ligament was 0.57 mm, measured above the ulnar nerve.*

- **One-week post-treatment:** one week after the infiltration, the ultrasound showed a reduction in edema and the beginning of scar tissue formation around the ulnar nerve. During dynamic maneuvers, a mild subluxation of the ulnar nerve was observed, but with a significant reduction in pain reported by the patient (Fig. 3).

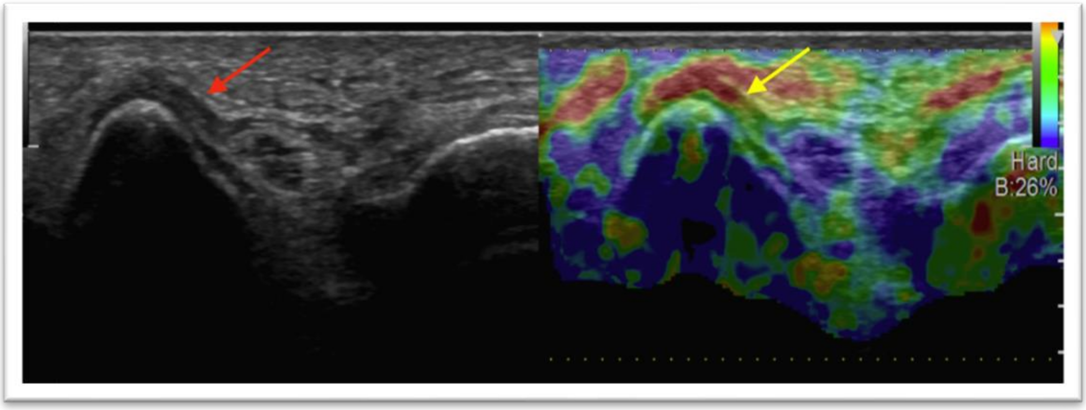

Fig. 3. *Patient with supinated forearm and extended elbow at approximately 1 week post-treatment. The B-mode image shows the formation of hyperechoic, triangular-shaped scar tissue in the interval between the Osborne ligament and the epitrochlear tissue (**red arrow**). The elastosonographic image reveals the firm consistency of the scar tissue, comparable to that of the underlying Osborne ligament (**yellow arrow**). The thickness of the Osborne ligament is 0.50 mm, measured above the ulnar nerve.*

During dynamic maneuvers of forearm supination and elbow flexion at approximately 1 week post-treatment, a tendency for ulnar nerve subluxation was observed beyond 80° of elbow flexion, accompanied by the onset of a "discomfort" sensation from the patient, measured as 3/10 on the visual analog scale (VAS).

- **Two weeks post-treatment:** the ultrasound showed improvement in the position of the ulnar nerve and progressive absorption of the edema. The Osborne ligament demonstrated significant improvement, with a reduction in swelling and increased stability (Fig. 4-5).

Fig. 4. *Patient with elbow extended and forearm supinated at approximately 2 weeks post-treatment. The thickness of the Osborne ligament (**red arrow**) is 0.50 mm measured above the ulnar nerve (**yellow arrow**).*

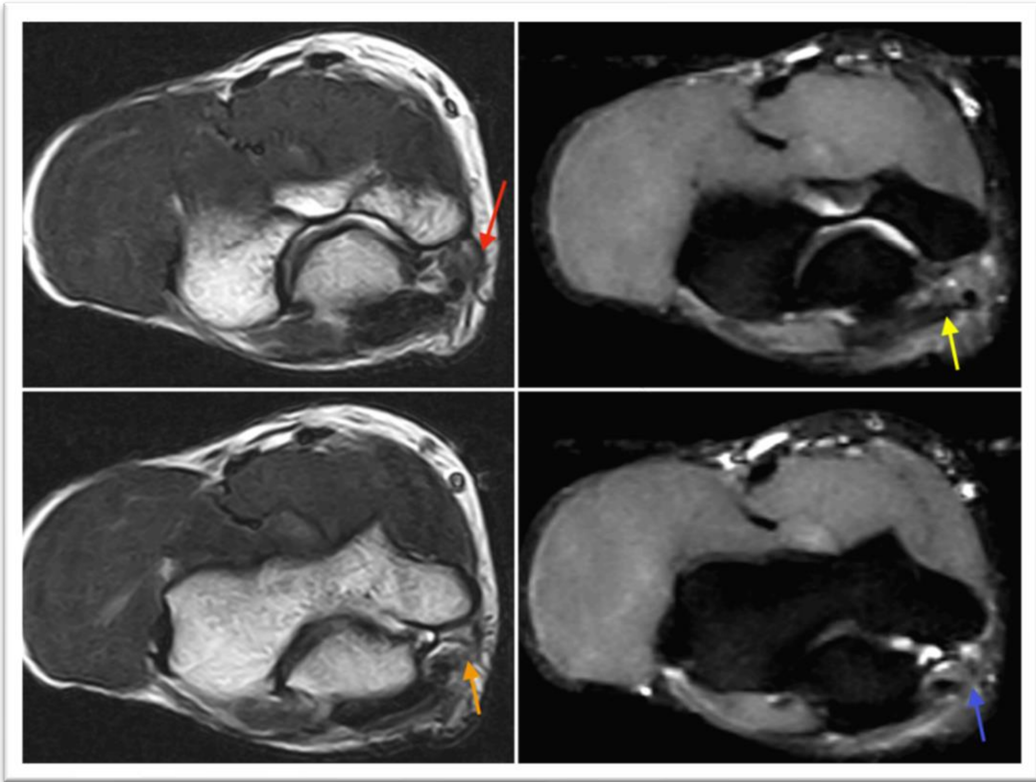

Fig. 5. *Patient with forearm supinated and elbow extended at approximately 2 weeks post-treatment. In the upper portion of the section, the T2 sequence shows the presence of a hypointense scar tissue in a linear shape, surrounding the ulnar nerve from the epicondyle and extending superficially into the subcutaneous tissue towards the olecranon (**red arrow**). In contrast, the STIR sequence shows that this structure is not fibrous compared to the underlying Osborne ligament, which is discontinuous and retracted (**yellow arrow**). In the lower portion of the section, the T2 sequence shows the presence of a thickened, retracted Osborne ligament connected to the ulnar nerve through heterogeneous scar tissue (**orange arrow**), not visualized in the STIR sequence (**blue arrow**).*

During dynamic maneuvers of forearm supination and elbow flexion at approximately 2 weeks post-treatment, a tendency for ulnar nerve subluxation was observed beyond 100° of elbow flexion, accompanied by a reduction in patient discomfort, measured as 1/10 on the visual analog scale (VAS).

- **One month post-treatment**: after one month, ultrasound confirmed continued positive evolution, showing the Osborne ligament becoming tighter and connected to the ulnar nerve via homogeneous scar tissue. The dynamic subluxation persisted, but the nerve demonstrated greater stability during ultrasound maneuvers (Fig. 7-8).

During dynamic maneuvers of forearm supination and elbow flexion at approximately 1 month post-treatment, and after the removal of the brace (Fig. 6), a tendency for ulnar nerve dislocation was observed at the final degrees of forearm supination and elbow flexion, similar to the pre-treatment condition, with the reappearance of "elbow snapping" but without any "discomfort" from the patient, measured as 0/10 on the visual analog scale (VAS).

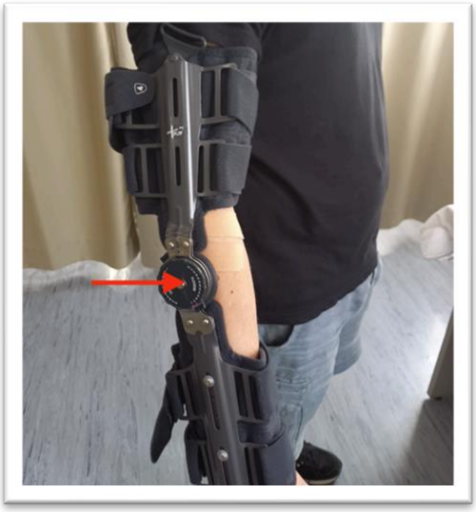

Fig. 6. *Elbow articulated brace (**right side**).*

Fig. 7. *Patient with supinated forearm and extended elbow at approximately 1 month post-treatment. The Osborne ligament is more taut and thinned (**red arrow**). The thickness of the Osborne ligament is 0.46 mm measured above the ulnar nerve.*

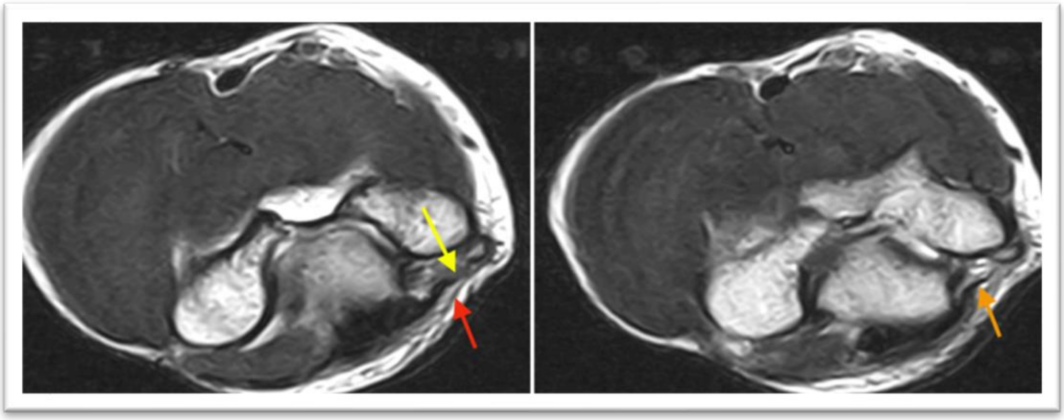

Fig. 8. *Patient with supinated forearm and extended elbow at approximately 1 month post-treatment. In the upper portion of the section, the T2 sequence shows the resorption of the hypointense linear scar (**red arrow**), while the Osborne ligament appears less deflected and partially connected to the ulnar nerve through an area of heterogeneous scar tissue (**yellow arrow**). In the lower portion of the section, the Osborne ligament appears discontinuous, thinned, and retracted (**orange arrow**).*

- **Three months post-treatment:** at three months, the ultrasound confirmed the complete repair of the Osborne ligament, with denser scar tissue and the disappearance of the ulnar nerve subluxation. The ultrasound also highlighted a thickened and tense Osborne ligament, with no signs of discontinuity (Fig. 9-10).

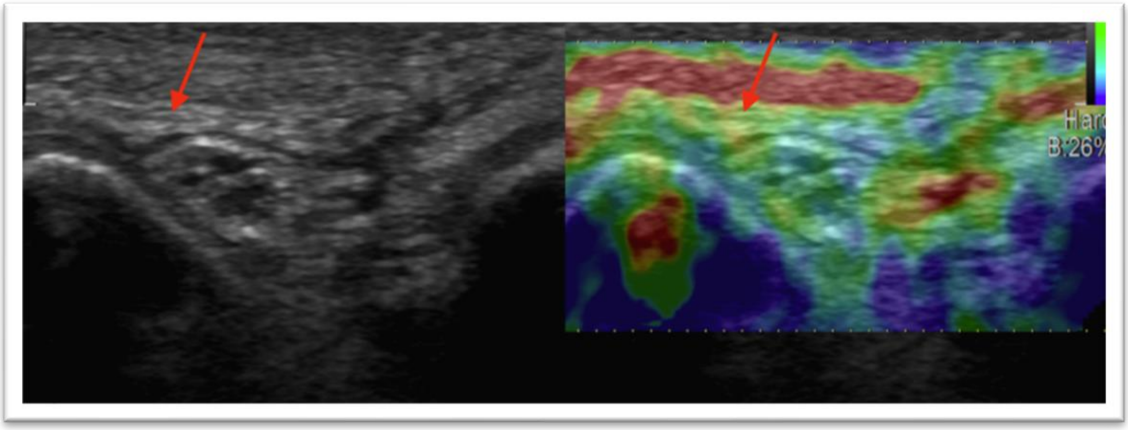

Fig. 9. *Patient with the forearm supinated and the elbow extended at approximately 3 months post-treatment. The B-mode and elastosonography images show thickening and expansion of the scar tissue (**red arrow**). The thickness of the Osborne ligament and scar tissue is 0.67 mm, measured above the ulnar nerve.*

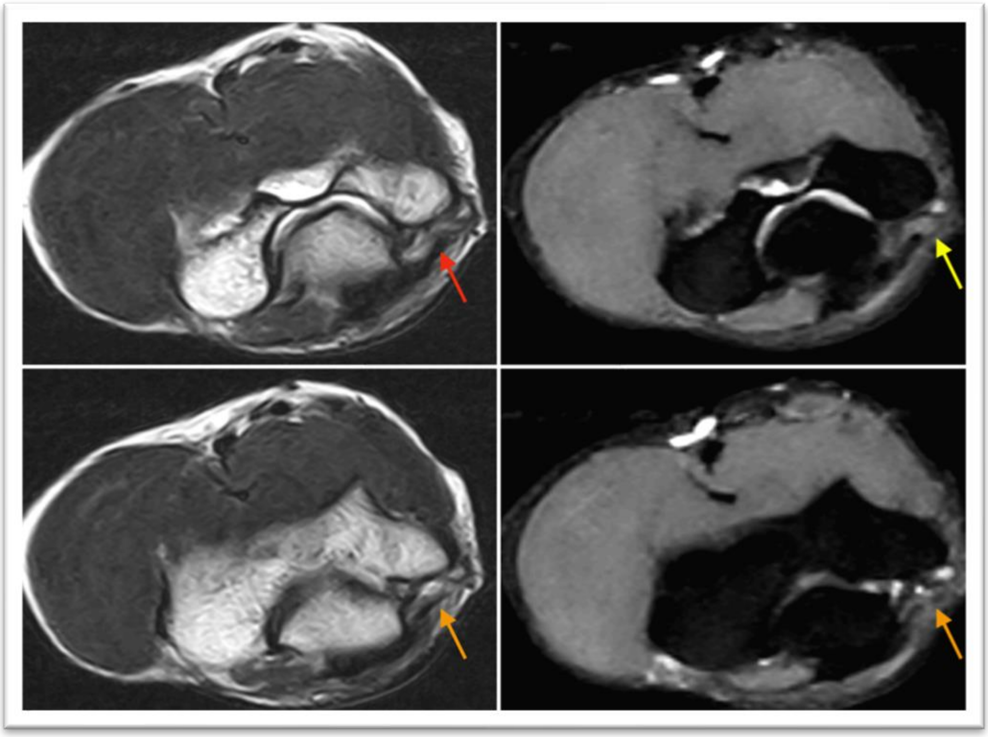

Fig. 10. *Patient with elbow extended and forearm supinated at approximately 3 months post-treatment. In the upper portion of the section, the T2 sequence shows the presence of a very thickened, tense Osborne ligament in continuity with soft scar tissue (**red arrow**), while the STIR sequence demonstrates the fibrous nature of the thin scar tissue (**yellow arrow**). In the lower portion of the section, the Osborne ligament remains discontinuous but is now more tense and thickened (**orange arrow**).*

Clinical and functional evaluation

- **VAS Score (Visual Analog Scale):** before the treatment, the patient reported intense pain (VAS 8/10). One week after treatment, the pain significantly decreased (VAS 3/10), and after two weeks, the score dropped further to 1/10. By the one-month mark, the patient reported no pain (VAS 0/10).
- **Muscle Strength (MRC):** the MRC score for muscle strength increased from 3/5 before treatment to 4/5 two weeks after the infiltration. By one month, muscle strength returned to normal, with a score of 5/5.
- **MRI Imaging:** three months post-treatment, MRI confirmed significant repair of the Osborne ligament, which appeared thickened and tense, with evident fibrous scar tissue in continuity with the ulnar nerve. The initial discontinuity of the ligament was fully resolved, with complete absence of nerve dislocation.

Functional conclusions

The patient reported resuming normal daily activities without limitations one month after infiltration, although a slight dynamic subluxation persisted, which did not significantly affect function. After three months, no signs of residual subluxation were observed, and the patient achieved full muscle strength, with a complete recovery of the motor functions of the arm and hand.

In summary, treatment with ozonized whole blood and procaine resulted in a significant recovery of the ulnar nerve dislocation, with tangible clinical and instrumental improvements within the first week and a full functional recovery at three months.

DISCUSSION

The treatment of ulnar nerve dislocation at the elbow is a complex therapeutic challenge, and despite advances in the medical field, treatment options remain limited. Platelet-rich plasma (PRP) has gained attention as a regenerative approach, utilizing the properties of platelets to stimulate tissue healing and enhance nerve stability. However, its high cost and limited availability make PRP a treatment that is not always accessible to all patients. As a result, alternatives, such as ozonized whole blood combined with procaine, have been explored.

In our study, the infiltration of ozonized whole blood with procaine showed positive clinical and ultrasound results as early as the first week, with a significant reduction in pain (measured as 3/10 on the Visual Analog Scale, VAS) and a trend toward resolution of ulnar nerve subluxation during dynamic ultrasound maneuvers. These results suggest that the proposed approach could be a valid alternative to PRP, with the advantage of being more accessible and potentially less costly, while maintaining similar therapeutic efficacy. However, a single infiltration was not sufficient to ensure complete healing of the dislocation, indicating the need for repeated therapy to achieve optimal results, as is also the case with PRP.

The use of ultrasound guidance for the infiltration could further enhance the treatment's effectiveness by optimizing the distribution of ozonized whole blood and procaine in the lesion areas. The absence of ultrasound guidance in our case represented a limitation, as it may have affected the accuracy of the infiltration, compromising the quality of the restored ligament and the overall effectiveness of the treatment. Post-treatment ultrasound observations, however, highlighted thickening of the Osborne ligament and formation of scar tissue, suggesting that while complete healing was not achieved, signs of tissue damage repair had emerged.

It should also be considered that the healing of a lesion such as ulnar nerve dislocation follows a complex process, involving phases of inflammation, granulation tissue formation, and tissue remodeling. Therefore, the combination of ozonized whole blood and procaine, while effective, cannot be considered a quick solution; the treatment may require a second infiltration after approximately 2-3 months, as recommended to optimize results and promote complete regeneration.

CONCLUSIONS

Platelet-rich plasma (PRP) is a promising treatment for ulnar nerve dislocations, but its high cost limits accessibility for many patients. In this context, the use of ozonized whole blood combined with procaine emerges as an interesting alternative, with the potential to offer a more affordable yet effective solution. The treatment has shown significant benefits as early as the first week, with pain reduction and clinical improvement. However, a second infiltration will be necessary to achieve complete healing of the ulnar nerve dislocation, especially in the absence of ultrasound guidance.

Recommendations derived from the results of this study include the use of ultrasound guidance to improve infiltration accuracy and the possibility of a second treatment administration at 2-3 months for more complex cases. It is essential that the removal of the brace is gradual and based on clinical signals to avoid muscle atrophy due to disuse.

In conclusion, ozonized whole blood with procaine represents a viable alternative to PRP for ulnar nerve dislocation; however, further studies are necessary to confirm the effectiveness of this combination and optimize therapeutic protocols, including the integration of ultrasound guidance and long-term treatment management. This approach may also be applicable to other tendon or ligament injuries, providing new therapeutic opportunities in the regenerative field.

REFERENCES

1. Thompson RG, Bradley K, Lourie GM. Ulnar Nerve Dysfunction at the Elbow Following Platelet-Rich Plasma Treatment for Partial Ulnar Collateral Ligament Injuries. *JSES Reviews, Reports, and Techniques*. 2020;1(1). doi:https://doi.org/10.1016/j.xrrt.2020.11.006
2. Smith P, et al. Efficacy of platelet-rich plasma in reducing pain in patients with ulnar nerve dislocation. *Journal of Clinical Orthopaedics*. 2017;25(3):145-152.
3. Johnson L, et al. unctional improvement following platelet-rich plasma therapy in patients with ulnar nerve dislocation. *Orthopaedic Journal of Sports Medicine*. 2018;6(4):289-296.
4. Martinez H, et al. Accelerated nerve regeneration with platelet-rich plasma in patients with ulnar nerve injuries. *Journal of Neurosurgical Research*. 2019;35(5):134-140.
5. Mautner K. Cost Analysis of Platelet-Rich Plasma (PRP) Injections. *Journal of Clinical Orthopedics and Trauma*. 2015;6(2):103-110.
6. Sanchez M, et. al. Financial Implications of Platelet-Rich Plasma in Musculoskeletal Injuries. *Journal of Orthopaedic Surgery and Research*. 2017;12.
7. Foster TE, Puskas BL, Mandelbaum BR, Gerhardt MB, Rodeo SA. Platelet-Rich Plasma. *The American Journal of Sports Medicine*. 2009;37(11):2259-2272. doi:https://doi.org/10.1177/0363546509349921
8. Rajan PV, Ng MK, Klika A, et al. The Cost-Effectiveness of Platelet-Rich Plasma Injections for Knee Osteoarthritis. *Journal of Bone and Joint Surgery*. 2020;102(18):e104. doi:https://doi.org/10.2106/jbjs.19.01446
9. Klifto KM, Colbert SH, Richard MJ, Anakwenze OA, Ruch DS, Klifto CS. Platelet-rich plasma vs. corticosteroid injections for the treatment of recalcitrant lateral epicondylitis: a cost-effectiveness Markov decision analysis. *Journal of Shoulder and Elbow Surgery*. 2022;31(5):991-1004. doi:https://doi.org/10.1016/j.jse.2021.12.010
10. Ahmad RS, Rahimi M, Mansoor RS, Moradi N. Costutility analysis and net monetary benefit of Platelet Rich Plasma (PRP), intraarticular injections in compared to Plasma Rich in Growth Factors (PRGF), Hyaluronic Acid (HA) and ozone in knee osteoarthritis in Iran. *BMC Musculoskeletal Disorders*. 2023;24(1):22. doi:https://doi.org/10.1186/s1289102206114x
11. Steenvoorde P, van Doorn LP, Naves C, Oskam J. Use of autologous platelet-rich fibrin on hard-to-heal wounds. *Journal of Wound Care*. 2008;17(2):60-63. doi:https://doi.org/10.12968/jowc.2008.17.2.28179
12. Sampson S, Reed M, Silvers H, Meng M, Mandelbaum B. Injection of Platelet-Rich Plasma in Patients with Primary and Secondary Knee Osteoarthritis. *American Journal of Physical Medicine & Rehabilitation*. 2010;89(12):961-969. doi:https://doi.org/10.1097/phm.0b013e3181fc7edf
13. de Vos RJ, van Veldhoven PLJ, Moen MH, Weir A, Tol JL, Maffulli N. Autologous growth factor injections in chronic tendinopathy: a systematic review. *British Medical Bulletin*. 2010;95(1):63-77. doi:https://doi.org/10.1093/bmb/ldq006
14. Lee JS, Guo P, Klett K, et al. VEGF-attenuated platelet-rich plasma improves therapeutic effect on cartilage repair. *Biomaterials Science*. 2022;10(9):2172-2181. doi:https://doi.org/10.1039/d1bm01873f
15. Di Paolo N, Bocci V, Salvo DP, et al. Extracorporeal Blood Oxygenation and Ozonation (EBOO): A Controlled Trial in Patients with Peripheral Artery Disease. *The International Journal of Artificial Organs*. 2005;28(10):1039-1050. doi:https://doi.org/10.1177/039139880502801012
16. Cuccio G, Franzini M. Oxygen-ozone therapy in the treatment of adipose tissue diseases. *Ozone Therapy*. 2016;1(2):25. doi:https://doi.org/10.4081/ozone.2016.6270
17. Elvis AM, Ekta JS. Ozone therapy: A clinical review. *Journal of Natural Science, Biology, and Medicine*. 2011;2(1):66-70. doi:https://doi.org/10.4103/0976-9668.82319
18. Huang P, Wang R, Pang X, Yang Y, Guan Y, Zhang D. Platelet-rich plasma combined with ozone prevents cartilage destruction and improves weight-bearing asymmetry in a surgery-induced osteoarthritis rabbit model. *Annals of Palliative Medicine*. 2021;11(2):442-451. doi:https://doi.org/10.21037/apm-21-1510
19. Gristina AG, Pace NA, Kantor TG, Thompson WA. Intra-articular thio-tepa compared with depomedrol and procaine in the treatment of arthritis. *The Journal of bone and joint surgery American volume*. 1970;52(8):1603-1610.
20. Culafic S, Stefanovic D, Dulovic D, Minic L, Culafic A. Treatment of degenerative chronic low back pain with fluoroscopically guided epidural procaine-corticosteroid injection. *Vojnosanitetski pregled*. 2008;65(7):507-511.

doi:https://doi.org/10.2298/vsp0807507c

21. Minwegen P, Friede RL. A correlative study of internode proportions and sensitivity to procaine in regenerated frog sciatic nerves. *Experimental Neurology*. 1985;87(1):147-164. doi:https://doi.org/10.1016/0014-4886(85)90141-4
22. Morris T, Appleby R. Retardation of wound healing by procaine. *British Journal of Surgery*. 1980;67(6):391-392. doi:https://doi.org/10.1002/bjs.1800670603

LAB PUBLISHER RESEARCH IN SCIENCE

Journal of Orthopedics

Review

A NARRATIVE REVIEW ON TENNIS-RELATED UPPER LIMB PATHOLOGIES

B. Bauchiero[1], S. Spadafora[1], S. Legrenzi[2], V. Salini[1], G. Placella[1]

[1]University Vita-Salute San Raffaele Milano, Italy;
[2]Department of Orthopedic Surgery and Traumatology, ASST Grand Metropolitan Hospital, Niguarda, Milan, Italy

**Correspondence to:*
Giacomo Placella, MD
Vita-Salute University,
IRCCS San Raffaele Hospital,
Milan, Italy
e-mail: placella.giacomo@hsr.it

ABSTRACT

Tennis players are frequently affected by musculoskeletal injuries due to the repetitive nature of the sport, improper technique, and physical stress. The shoulder is one of the most commonly injured areas, particularly in non-professional players, where rotator cuff tendinopathy, impingement, and labral tears are prevalent. These injuries are often linked to faulty stroke mechanics, especially in overhead shots. The elbow is another critical area, with conditions such as tennis elbow (lateral epicondylitis) affecting non-professional players aged 30 to 50, primarily due to poor backhand technique and incorrect racket grip. This condition arises from microtrauma to the extensor carpi radialis brevis and extensor digitorum tendons. In contrast, epitrochleitis (medial epicondylitis) occurs more commonly in professional players and results from stress on the forearm flexors during forehand strokes and serves. Pathologies of the wrist and hand, including tenosynovitis of the extensor carpi ulnaris, De Quervain's disease, and triangular fibrocartilage complex (TFCC) injuries, are also prevalent, often caused by excessive wrist rotation, improper grip, and overuse of topspin strokes. De Quervain’s disease affects the tendons at the radial styloid and is characterized by swelling and restricted movement of the thumb and wrist. TFCC injuries associated with wrist rotation are often caused by combined impacts and loading. Additionally, fractures of the hook of the hamate, though rare, are seen in players who relax their grip during powerful strokes. Early diagnosis, based on clinical tests such as Cozen’s, Maudsley’s, and Finkelstein’s tests, as well as imaging modalities like ultrasound and MRI, is crucial. Conservative treatments, including rest, physical therapy, anti-inflammatory medications, and technique adjustments, are effective in most cases. Surgical intervention is rarely necessary but may be required for persistent or severe injuries. Preventative strategies, such as using proper equipment, and technique, and maintaining physical conditioning, are key to reducing the risk of common tennis injuries.

KEYWORDS: *tennis elbow, upper limb, tennis injuries, tendon, muscle*

INTRODUCTION

Traumatology of the locomotor system in tennis

In Italy, tennis has always been a widely practiced sport. According to estimates by CONI and ISTAT, it ranked second in 2022 in terms of the number of registered players, with growing participation, and reached the top position in regions such as Piedmont and Sicily (1). With over 1 million registered players and approximately 3 million recreational

Received: 2 March 2025
Accepted: 11 April 2025

and casual players, tennis is one of the most popular sports in Italy, followed by more than 24 million sports enthusiasts. The number of senior players is also steadily increasing (2).

This growing interest in tennis underscores the importance of addressing the impact of tennis-related injuries in clinical practice for physicians and athletic trainers. The incidence of acute traumatic events in tennis is low, accounting for about 0.12% of all injuries. However, the incidence of conditions related to functional overuse is significantly higher (3).

For all age groups, the most common injuries are those related to tendons or muscles. In players over the age of 25, overuse injuries are the most prevalent. Among younger players, lower limb injuries are twice as common as upper limb and spinal injuries, with a high incidence of ankle sprains (4). Although the number of female players is increasing, there are no substantial gender-based differences in injury incidence, particularly in players over 25. For adolescent athletes, however, statistics indicate a 0.6% incidence per 1,000 hours of play among females, with a prevalence of patellar conditions and lower back pain. In contrast, males show an incidence of 1.7% per 1,000 hours, with a marked prevalence of contusions, abrasions, lacerations, ankle injuries, and lumbar spine pain (5).

Despite being an asymmetrical sport, tennis is a relatively comprehensive activity that features a variety of athletic movements that engage the entire musculoskeletal system (6). Tennis-related injuries include both acute traumatic injuries specific to the sport and more general injuries common to other sports.

Acute injuries caused by trauma that exceeds the mechanical resistance of anatomical structures are relatively rare. Tennis players are often exposed to forces they generate endogenously rather than exogenous forces, as there is no physical contact with opponents, and the game equipment poses minimal risk (7).

Chronic injuries, on the other hand, are linked to functional overuse and can be influenced by both predisposing and determining factors:

- predisposing factors can be exogenous, such as the playing surface, footwear, equipment, or environmental conditions, or endogenous, related to the athlete’s congenital or acquired abnormalities, such as asymmetries or myotendinous imbalances;
- determining factors are represented by repeated and abnormal functional stresses due to specific athletic gestures (8).

Tennis involves rapid player movements on the court, including sudden changes of direction, sprints, jumps, stops, and dives, which exert considerable stress not only on the spine but also on the upper and lower limbs. Additionally, the specific movements of the dominant upper limb, particularly during serves and smashes (overhead movements), involve significant exertion. If not performed correctly with proper technique, these movements can cause injuries that compromise not only athletic performance but also daily life activities (9). Such injuries, especially those due to poor execution of movements, initially manifest as reactive inflammatory phenomena, followed by regressive and degenerative changes (2).

The following sections describe the most common trauma-based conditions affecting tennis players, with a focus on the upper limb. Emphasis will be placed on the causes, clinical manifestations, diagnostic possibilities, treatment methods, and, most importantly, prevention strategies.

Traumatology of the upper limb in tennis

All sports are influenced by external factors that alter the dynamics of joint forces. Surfaces and shoes play a crucial role in determining directional changes, biomechanical responses to sprints, and landing after jumps. In tennis, the racket is the medium for transmitting forces between the body and the ball. The impact between the racket and the ball generates translational, rotational, and elastic forces in the upper limb, creating a specific type of stress in this part of the body.

Over the past forty years, tennis rackets have undergone a significant evolution in manufacturing, radically changing the way the game is played. The transition from wood to graphite enabled the creation of more efficient rackets, which are lighter, more maneuverable, and allow for increased shot speed, thereby fostering a style of play that emphasizes players' physical power. However, this has also led to greater stress on the upper limb joints (6).

New materials have also enabled an increase in racket size, making the sport more accessible to less experienced athletes who are consequently less skilled in their movements. The structure of modern rackets is characterized by greater stiffness compared to the wooden ones previously used; this ensures better performance in terms of ball rebound speed but also increases the vibrations transmitted to the upper limb (7).

In fact, the vibration frequency has shifted from 90 Hz with wooden rackets to 166–200 Hz with modern ones. The forces transmitted from the ball to the body depend not only on the materials but are also closely linked to stroke technique.

Within the racket head's ellipse, three specific "sweet spots" can be identified, each with distinct mechanical properties (8) (Fig. 1):

1. the center of percussion, which, when struck, neutralizes rotational and translational forces, reducing the stress transmitted to the grip;
2. the point of maximum rebound velocity, which imparts the highest ball speed;
3. the point of the first harmonic oscillation, which minimizes vibration transmission to the grip.

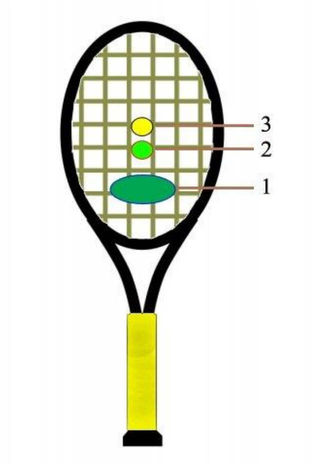

Fig. 1. *The sweet spots of the racket.*

An experienced player, thanks to their acquired sensitivity, can identify the racket area closest to these three points and use it for the majority of their strokes. Conversely, inexperienced players tend to strike random points farther from the sweet spots, generating significantly more stress on the upper limb, up to three times as much. Studies have shown that in terms of vibrations absorbed by the athlete, experienced players absorb approximately 80%, while beginners absorb about 93%. A high grip level on the handle provides greater comfort and security during strokes but also increases the transmission of vibrations. It is, therefore, preferable to choose lower grip levels, especially since these do not influence the ball's rebound speed or shot velocity. It has been observed that experienced players exert maximum grip force on the handle moments before the ball contacts the racket, then slightly reduce it during the strike. This is likely an unconscious protective mechanism against vibrations. However, this adjustment does not occur in beginners (8).

Repetitive rotational, translational, and vibratory forces create mechanical stress on the player's upper limb, increasing the likelihood of developing certain pathologies. This risk is particularly high for inexperienced athletes who, due to incorrect technique, significantly amplify the forces involved.

THE SHOULDER

In 1976, Priest and Nagel introduced the term “Tennis Shoulder,” highlighting specific morphological and functional alterations in the shoulder caused by the repetitive and sudden demands placed on the dominant upper limb in tennis players (9). According to these authors, increased muscle mass and elongation of suspensory muscles lead to a lowering of the dominant shoulder, resulting in an apparent elongation of the limb. This induces a compensatory scoliotic posture of the spine, promoting the onset of subacromial impingement syndrome. Additionally, tennis movements can cause posterior capsular stiffness, resulting in a deficit in internal rotation and an increase in external rotation of the dominant arm compared to the contralateral side.

Scientific interest in the tennis player’s shoulder and the entire upper limb is justified by biomechanical studies showing the complex muscle activity involved during tennis-specific movements (10). The serve, similar to a throwing motion, can be divided into four phases: preparation, loading, acceleration, and deceleration. The entire execution takes approximately 1.56 seconds, with the acceleration phase being the fastest. In contrast, the loading phase recruits the most muscle activity, involving the deltoid, biceps brachii, triceps brachii, supraspinatus, infraspinatus, and latissimus dorsi (11). During the loading phase, the shoulder experiences the highest muscular workload, with a compression force equivalent to approximately 80% of body weight, ensuring humeral centering. In the acceleration phase, primarily driven by the pectoralis major, latissimus dorsi, and subscapularis, the angular velocity of the arm can exceed 2500°/sec, comparable to a washing machine during a spin cycle (10).

These characteristics make shoulder injuries the most common upper limb injuries in tennis players, from young athletes to all levels of competition (12). Such rapid and repeated forces, especially without a well-structured training program, lead to structural and functional alterations in the musculoskeletal and articular structures, including subacromial impingement syndrome, rotator cuff tears, glenoid labrum lesions, acromioclavicular microtrauma, long head of biceps tendon injuries, and shoulder instability.

Subacromial impingement syndrome

Impingement refers to the increased friction of soft tissues resulting from a discrepancy between the space and the structures it contains (12). In this case, the space "défilé" is defined superiorly by the acromion and coracoacromial ligament, and inferiorly by the humeral head and glenoid; the contents are the rotator cuff and subdeltoid bursa, which slide between these structures. Increased friction occurs when the space narrows or the contents expand. Subacromial impingement syndrome is rarely observed in individuals under 40; however, repetitive overhead movements, such as those involved in tennis, predispose athletes to its development (13).

Friction forces cause pathophysiological changes in the subacromial space, classified into three evolutionary stages by Neer (1972; 1983):

1. **Stage 1**: edema and microhemorrhages in the subacromial bursa and rotator cuff tendons, generally found in athletes under 25 years old;
2. **Stage 2**: development of fibrosis and scarring in the subacromial bursa, tendinitis predominantly affecting the supraspinatus and long head of the biceps, typically observed in athletes over 25 years old;
3. **Stage 3**: bone changes and tendon degeneration, potentially progressing to tendon rupture, frequently seen in individuals over 40 years old (Neer, 1983).

Shoulder impingement is classified into two main categories: internal and external. Internal impingement involves the rotator cuff structures and the glenohumeral joint, often due to skeletal abnormalities, extreme repetitive movements, or instability that alters biomechanics and causes excessive contact even at moderate joint angles (14). External impingement arises from excessive friction between the rotator cuff and the inferior margin of the acromion or the coracoacromial ligament, often due to skeletal deformities or inadequate centering of the humeral head on the glenoid (15).

In the early stages, subacromial impingement presents as pain that appears after sports activity, often at night, and disappears with rest. In more advanced stages, pain becomes persistent, worsening with movement and at night. Diagnosis is aided by clinical tests such as Neer, Hawkins, and Yocum tests, which are based on compressing the cuff between the humeral trochite and the acromial roof (12). Radiological imaging, such as standard radiographs, is essential for detecting osseous abnormalities, calcifications, or subacromial space narrowing (16).

Conservative treatment involves functional rest, analgesics, anti-inflammatory medication, and personalized rehabilitation protocols focusing on restoring normal shoulder biomechanics and strengthening the internal and external rotators (17). Approximately 60% of cases improve with conservative management. For cases unresponsive to conservative treatment or presenting with advanced-stage pathology, surgical intervention is recommended in about 30% of cases (18).

Internal impingement

Internal impingement occurs when extreme shoulder movements, characteristic of specific overhead sports gestures, result in repeated and unnatural contact between the internal surface of the rotator cuff and the glenoid joint. This condition affects athletes under 40 years old engaged in overhead sports and is characterized by vague but progressively worsening symptoms. Athletes often report a gradual loss of speed and control during athletic movements, described in the 1980s as "dead arm syndrome", typically associated with glenoid labral lesions (9, 10).

The condition gained attention through arthroscopic studies by Walch (1992) and cadaveric studies by Jobe (1993), which highlighted the interaction between the rotator cuff and the articular margin of the glenohumeral joint. During hyperabduction and external rotation, the articular margin of the cuff and posterior capsule are compressed against the joint, potentially pinched between the humerus and glenoid, causing mechanical injury to the labrum. Similarly, hyperadduction and internal rotation produce a comparable mechanism involving the anterior portion of the cuff, leading to posterosuperior impingement (PSI) in the former case and anterosuperior impingement (ASI) in the latter.

Imaging and cadaveric studies have shown that contact between the rotator cuff and the joint in these positions is physiological; however, the repetitive nature of overhead athletic movements, as seen in tennis, baseball, or volleyball, leads to overstress on the cuff, capsule, and glenoid labrum, eventually resulting in a pathological condition (11-21). Recurrent mechanical insults induce a posterior capsular contracture, initially involving the inferior glenohumeral ligament and posteroinferior capsule, clinically manifesting as a deficit in internal rotation (glenohumeral internal rotation deficit, GIRD) (14). This shifts the articular contact point posteriorly, allowing a greater range of external rotation, increasing stress on the long head of the biceps tendon, and predisposing the shoulder to SLAP lesions (22).

The classical presentation includes partial rotator cuff tears on the articular side of the supraspinatus and glenoid labrum tears in the posterior or posterosuperior region. The rarer anterosuperior internal impingement is based on similar mechanical concepts but involves reversed movements, affecting the anterosuperior structures of the cuff and capsule. In adduction and internal rotation, the subscapularis, pulley, and long head of the biceps tendon come into contact with the glenohumeral joint, leading to partial cuff tears in the anterior region and potential subluxation of the biceps tendon due to pulley damage (2).

Symptoms are typically diffuse, with posterior shoulder pain localized near the joint line. Pain may also be felt anteriorly in the coracoid region and may be associated with symptoms of concurrent lesions, such as cuff, labral, or biceps tendon injuries. Clinical examination often reveals a discrepancy of at least 30°-40° between internal or external rotation compared to the non-dominant arm, depending on whether the impingement is primarily anterior or posterior. Specific tests for associated lesions may be positive, but subacromial impingement tests are usually negative (12). Scapulothoracic dyskinesia, often present in this pathology, should also be investigated; it manifests as an asymmetry relative to the contralateral scapula and increased prominence of the scapular inferior margin (13).

Conservative treatment involves an initial phase of absolute rest from overhead activities, potentially combined with anti-inflammatory medications. In the second phase, muscle strength, flexibility, neuromuscular proprioceptive control, and scapulothoracic biomechanics should be restored and reinforced. Arthroscopic surgical intervention is considered only after the failure of conservative treatment (14). Return to sport is permitted only after complete resolution of pain and satisfactory muscle recovery (15).

Rotator cuff injuries

The rotator cuff is a musculotendinous structure responsible for centering the humeral head in the glenoid cavity during shoulder movements. It consists of four muscles: the supraspinatus, infraspinatus, subscapularis, and teres minor, whose tendons almost entirely encase the humeral head, forming a sort of "cuff" (1-3).

Rotator cuff tears may result from acute trauma or progressive tendon degeneration, eventually leading to rupture. An acute injury may occur due to a sudden movement involving abduction and external rotation (such as a poorly executed smash or backhand) or a fall on the shoulder, elbow, or extended limb. This trauma is typically followed by sharp, intense pain accompanied by a tearing sensation, significant functional impairment initially, and gradually reduced mobility. It primarily limits abduction and external rotation, particularly when resistance is applied (4, 5).

Degenerative tears are commonly observed in athletes over 50, typically affecting an anatomically hypovascular region of the supraspinatus tendon, located about 1 cm from its insertion on the humerus (6-8). Passive abduction evokes pain between 70° and 110° due to the injured area passing under the acromiocoracoid arch. Specific tests reveal pain during targeted muscle activation, and a strength deficit may also be present (9, 10). Imaging studies such as ultrasound, MRI, and arthrography are valuable for diagnosis (2, 11).

Complete tears are often preceded by tendinous degeneration, which can be classified using Zlatkin's MRI-based grading system (12, 13):

- **stage 0**: normal morphology and signal intensity;
- **stage 1**: increased signal intensity without thinning, irregularity, or discontinuity;
- **stage 2**: increased signal intensity with tendon thinning or irregularity;
- **stage 3**: supraspinatus tendon rupture.

Once confirmed, tears are categorized using various schemes considering location, partial or full-thickness nature, shape, size, affected tendon(s), muscle trophism, the state of the long head of the biceps, and associated ligamentous injuries (14-16).

Initial treatment is conservative, involving functional rest, cryotherapy, and possibly anti-inflammatory medications. After the acute phase, functional and motor recovery programs begin (17-19). Surgical intervention targets the cause of the rupture: acute traumatic tears in young or athletic individuals warrant immediate repair. In contrast, degenerative tears often stem from subacromial impingement, necessitating a subacromial decompression procedure based on symptoms and functional limitations (20-22). Notably, as Codman proposed in 1934 and Fukuda confirmed histologically in 1994, cuff tears are progressive and do not heal spontaneously; only symptoms may regress (23-25).

Glenoid labrum injuries

The Glenoid labrum is a fibrocartilaginous structure encircling the articular surface of the glenoid cavity, aiding in the centering of the humeral head within the glenoid concavity. A labral tear decreases shoulder stability, causes pain (due to nociceptive fibers within the labrum and at the insertion of the long head of the biceps tendon), and may produce mechanical sensations such as clicks, intra-articular noises, or functional limitations (26, 27).

Sports like tennis and other overhead disciplines impose repeated stress on the labrum, structurally weakening it and predisposing it to injury (28, 29). Depending on the location, these injuries are classified into different categories: considering the glenoid from a lateral perspective, it can be visualized as a clock. Tears between 9 and 3 (the superior margin) are classified as SLAP lesions involving the superior anterior and posterior labrum. Tears in the inferior portion, from 3 to 9, are called Bankart lesions (30, 31).

SLAP lesions are most frequently observed in tennis players. The acronym SLAP was introduced in 1985 by Andrews and later developed by Snyder in the 1990s; these injuries are closely related to anatomy. The long head of the biceps tendon inserts at the superior glenoid margin, where part of its fibers connect to the apical region of the labrum. Violent trauma or repetitive actions may lead to tears in this area due to reflexive transmission of biceps contractions to the superior labrum. During the deceleration phase (after hitting the ball during a serve or volley), the biceps undergo eccentric contraction to prevent elbow hyperextension, transmitting force to the labrum. Additionally, the labrum's superior portion may be torn during abrupt abduction and external rotation in the loading phase, during which the biceps tendon is pulled posteriorly (32-36).

Diagnostic clinical tests simulate the traumatic mechanism and reproduce pain (37):

- **modified Dynamic Labral Shear test (mDLS)**: elbow at 90°, shoulder abducted beyond 120° and maximally externally rotated. The examiner abducts the arm in the horizontal plane, exerting shear force on the joint, then adducts the arm from 120° to 60°. The test is positive if pain is elicited, particularly in the posterior region;
- **O'Brien test**: elbow extended, shoulder elevated anteriorly to 90° and adducted, with the arm fully internally rotated. The examiner applies downward pressure while the patient resists. The test is positive if pain or intra-articular noises are noted. It may also be positive for acromioclavicular joint issues;
- **Biceps Load test II**: the patient is supine with the arm abducted to 120°, externally rotated, elbow flexed at 90°, and forearm supinated. The patient flexes the elbow against the examiner's resistance. The test is positive if elbow flexion exacerbates pain;
- **Passive Distraction test (PDT)**: the patient is supine with the shoulder at the table's edge, the arm elevated to 150°, the elbow extended, and the forearm supinated. The examiner pronates the forearm. The test is positive if pain occurs in the anterior or posterior shoulder region.

Imaging studies, including MRI or contrast-enhanced CT, are about 90% sensitive and specific, but the gold standard for diagnosis and treatment remains arthroscopic surgery (38, 39).

Tendinopathies of the Biceps Brachii

The long head of the biceps brachii (LHB) is an intra-articular tendon that passes through the bicipital groove of the humerus and inserts on the supraglenoid tubercle of the scapula. Over the years, its function has been significantly reconsidered: it was previously thought to play an important role in actively stabilizing the glenohumeral joint by compressing the humeral head against the glenoid, thereby preventing upward and anterior displacement. However, studies, including cadaveric analyses, have shown that tenotomy of the LHB does not cause upward displacement of the humeral head, suggesting that the LHB likely serves as a passive stabilizer of the joint (9, 10).

LHB pathologies can be categorized into three types: inflammatory, degenerative, and instability. All three commonly present with diffuse shoulder pain. Since the LHB sheath communicates with the joint space and is connected to the rotator cuff, inflammatory changes in these structures often affect the LHB, which may exhibit early symptomatic signals (4). Tendinous degenerative changes can be secondary to subacromial impingement or primary in origin, presenting as tendon thickening, surface irregularities, and scar-like lesions (Neer, as cited in (15). Contrary to earlier beliefs linking degeneration with aging, cadaveric studies have found a low prevalence of tendinopathy in older anatomical specimens, while overhead athletes demonstrate higher rates of LHB tendinopathy due to anterior subluxation of the humeral head during the loading phase of a stroke (5).

Instability of the LHB arises from laxity or rupture of the pulley system that holds the tendon within the bicipital groove. This can lead to medial displacement during contraction, especially in abducted and externally rotated positions.

Although rare in isolation, LHB instability is more frequently associated with rotator cuff injuries and is often observed in overhead athletes (3).

Clinically, pain is exacerbated by both external and internal rotation and by palpation of the bicipital groove. The Yergason and Speed tests are sensitive but lack specificity, while instability may be detected through a palpable click during intra-to-extra rotation with the shoulder abducted to 90° (12). Imaging modalities such as radiography help exclude other conditions, while ultrasound and MRI provide more detailed assessments of the tendon.

Treatment typically begins with conservative management, focusing on functional rest, pain control, and maintaining passive shoulder mobility. Gradual progression includes strengthening the rotator cuff and periscapular muscles, ultimately advancing to sport-specific exercises (14). Surgical intervention, such as arthroscopic debridement, decompression, or tenotomy, may be required if symptoms persist despite conservative treatment (24).

Acromioclavicular joint micro traumatic arthropathy

This degenerative condition affects the acromioclavicular joint and results from repeated microtrauma that damages cartilage and subchondral bone. The acromioclavicular joint, along with the sternoclavicular joint, connects the arm to the trunk and serves as a fulcrum for scapular movement during deceleration in serves and acceleration in backhand strokes (6, 7) (Fig. 2).

Fig. 2. *Backhand stroke.*

Symptoms include activity-related pain, initially sporadic but becoming more frequent over time, tenderness upon palpation of the joint, and pain during forced horizontal abduction with posterior shoulder displacement and internal rotation of the arm. Radiographic findings may reveal bone changes, such as subchondral cysts, typically on the acromial side, without joint space narrowing (4).

Conservative treatment is preferred, but in some cases, resection of the lateral clavicle's end may be necessary surgically (17).

Shoulder instability

Shoulder instability is classified based on pathogenic mechanisms and anatomopathological criteria into three categories: TUBS (Traumatic Unilateral Bankart Surgery), AMBRI (Atraumatic Multidirectional Bilateral Rehabilitation Inferior capsular shift), and AIOS (Acquired Instability Overstressed Surgery).

The first group includes acute traumas that cause damage to the labrum, capsuloligamentous complex, and possibly the bone. The second group includes instabilities without evident traumatic events, likely associated with the constitutional laxity of stabilizing structures. The third group (AIOS) involves microinstabilities resulting from repetitive microtraumas associated with overhead sports, leading to supraequatorial labral lesions, damage to the long head of the biceps (LHB) insertion, and rotator cuff injuries (1, 27).

An unstable shoulder requires assessment of anterior-posterior laxity compared to the contralateral shoulder, sulcus sign for longitudinal laxity, and anterior and posterior apprehension tests to evoke dislocating movements, triggering involuntary protective muscle contractions (21) (Fig. 3, 4). Signs and symptoms of secondary lesions must also be evaluated. A standard radiographic exam is essential, complemented by MR arthrography or CT arthrography where necessary (22).

Treatment involves at least six months of conservative management before considering surgery. Arthroscopic intervention is preferred, involving multiple capsular plications, SLAP repair, debridement, and repair of any rotator cuff injuries (25).

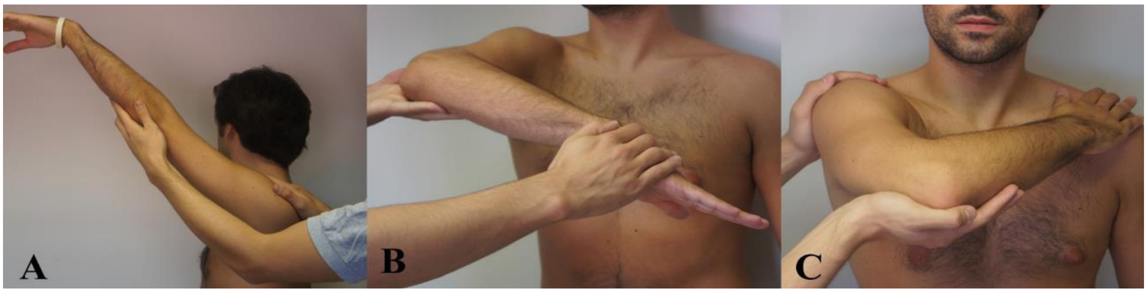

Fig. 3. ***A****): Neer test: the examiner performs passive arm elevation while maintaining scapular depression;* ***B****): Hawkins test: the shoulder and elbow are flexed at 90°, followed by internal rotation leveraging the elbow and dorsal wrist;* ***C****): the patient places the hand of the affected arm on the opposite shoulder, followed by passive elbow elevation and resistance testing.*

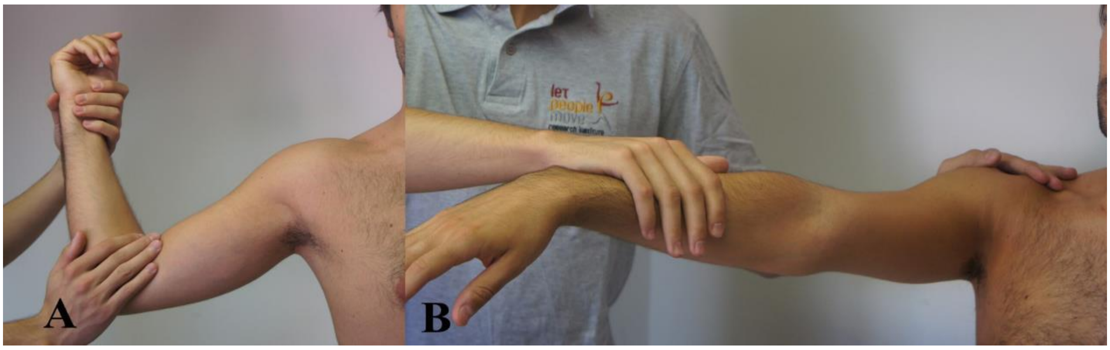

Fig. 3. ***A****): Modified Dynamic Labral Shear test (mDLS);* ***B****): O'Brien's test.*

THE ELBOW

The elbow is among the most affected body regions in microtraumatic pathologies of tennis players, to the extent that the term "tennis elbow" was coined to describe the insertional pathology of tendons on the radial condyle (31, 26).

"Tennis Elbow": epicondylitis in non-professional tennis players

This condition primarily affects tennis players aged 30 to 50, with an incidence of 50% among non-professional players who play more than three times a week (27, 2). It is mainly caused by technical errors, insufficient physical preparation, poor coordination, or an inadequate grip on the racket (30, 3).

The primary movements that favor epicondylitis are characteristic of non-professional players, particularly during incorrect backhand strokes. While professional or experienced players combine proper elbow flexion and trunk rotation with wrist hyperextension to mitigate impact force during the backhand, inexperienced players prematurely rotate their trunk, lead with their elbow, and flex their wrist (on average 13°) during impact (28;7). This results in eccentric contraction of the epicondylar muscles before the stroke and subsequent concentric contraction, causing excessive strain and tension on tendinous structures and muscle bellies (5).

A heavy racket, an inadequately short grip, deflated or heavy balls, excessive string tension, and playing on fast surfaces exacerbate the condition, contributing to the pathology's development (6, 8).

The pathophysiology is linked to the overuse of microlesions of the extensor carpi radialis brevis and sometimes the common extensor digitorum tendon. Chronic inflammation leads to the formation of granulation tissue and adhesions, resulting in painful symptoms when the tendons are under tension (26, 31).

Clinical examination reveals localized tension and pain on palpation of the humeral condyle or during certain diagnostic movements, such as:

- **Cozen's test**: pain during resisted extension of the wrist and fingers with the elbow flexed;

- **Maudsley's test**: pain during resisted extension of the middle finger (Fig. 5);
- **Mills' maneuver**: pain during forced pronation with the wrist flexed and the elbow extended;
- **Solveborn's test**: pain while lifting a chair by its backrest with the elbow extended, forearm pronated, and wrist dorsiflexed.

Radiographic imaging may reveal small calcified zones associated with chronic inflammation or osteophyte formation on the epicondyle (29). In rare cases, fractures may also occur. Ultrasound can demonstrate degenerative tendon thickening, vascular proliferation, and mucoid degeneration (38).

Pain occurs during sports activities and rarely persists at night (1). Before establishing a definitive diagnosis, it is necessary to exclude articular pathologies of the elbow and radicular pathologies of the radial nerve (32). Treatment is primarily conservative, including rest, ice, deep massage, physical therapy with TENS, ultrasound, and orthoses such as dynamic braces (31). After the acute phase, sport-specific training sessions, including stretching of the flexor and extensor muscles, are essential (2).

Surgical treatment is rarely necessary and is indicated only after failure of a conservative program lasting at least six months. Surgical techniques involve releasing the extensor carpi radialis brevis from the lateral condyle and removing degenerated tissue. This procedure can also be performed arthroscopically. Return to sport typically occurs 4–6 months post-surgery (26, 29).

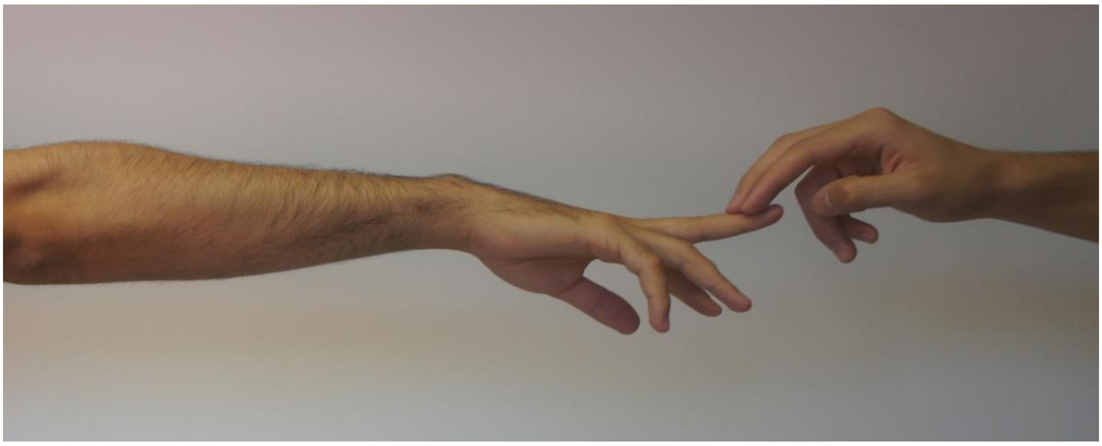

Fig. 5. *Maudsley's test: pain during resisted extension of the middle finger.*

Epitrochleitis: tennis elbow in professional players

Also referred to as "golfer's elbow" or "professional tennis elbow," this condition is associated with forehand strokes rather than backhands, even when executed with proper technique. It is caused by microtrauma to the finger flexor tendons and forearm pronators, which are heavily strained during serves, smashes, and forehand strokes (4, 5).

Typical degenerative anatomopathological alterations are observed in the pronator teres, flexor carpi radialis, and sometimes the palmaris longus, flexor digitorum superficialis, and flexor carpi ulnaris (27, 32).

Differential diagnosis is performed through clinical, radiographic, and electromyographic examinations to distinguish it from articular lesions such as the medial collateral ligament of the elbow, ulnar nerve entrapment, and medial elbow instability (30, 29).

Clinically, pain is associated with palpation of the medial elbow, specifically in the trochlear region, and exacerbated by resisted wrist flexion or forearm pronation (26, 32). Radiography may reveal small calcified zones associated with chronic inflammation, osteophyte formation in the humeral trochlea, or fractures (6, 29).

Treatment is similar to that for epicondylitis and includes rest, ice, orthoses, correction of equipment, and proper training with stretching of the flexor muscles (3, 5). Surgical treatment is rare and should only be considered after the failure of at least three months of conservative therapy. However, arthroscopic treatment is not recommended due to the proximity of the ulnar nerve and medial collateral ligament (27).

THE WRIST AND HAND

Wrist and hand pathologies in tennis are common, as these areas are the link between the body, where force is generated, and the racket, through which this force is transmitted to the ball. Similar to other anatomical regions, the main conditions involve overuse, microtrauma, and movement during strokes, although direct and acute injuries are also possible. These can be caused by excessive wrist rotations during off-center ball impacts on the racket, as well as subsequent counter-shocks (2, 5).

Frequent stress on the wrist and hand is often exacerbated by the overuse of topspin strokes, excessive wrist movement, incorrect grip, and unsuitable string tension (6, 7). Among the most common pathologies related to the functional overload of tendon and muscle structures are tenosynovitis and tenovaginitis, which are chronic, painful inflammations of the sheaths that cover the tendons. These issues are more prevalent in players over 30, with a higher occurrence in women (1).

Tenosynovitis of the extensor carpi ulnaris

The most common wrist issue among tennis players affects the ulnar side and is often attributable to tenosynovitis of the extensor carpi ulnaris (ECU) muscle. It is characterized by the gradual onset of pain during play, especially in top-spin-based games, due to the rapid wrist pronation required for effective strokes. Pain symptoms tend to worsen progressively but improve with rest (33). Swelling in the posteromedial region may sometimes appear, with palpation exacerbating the pain. The clinical examination revealed that resisted ulnar extension of the hand elicits pain. Ultrasound imaging can confirm tenosynovitis, while X-rays rule out stress fractures (38).

Treatment is primarily conservative, involving rest, ice, non-steroidal anti-inflammatory drugs (NSAIDs), stretching, iontophoresis, and ultrasound therapy for the extensor carpi ulnaris (ECU). In some cases, surgical intervention, such as tenolysis or the removal of degenerated tissue, is necessary. In severe cases, tendon instability may require reconstruction of the sixth extensor compartment (34, 35).

Tenosynovitis of the finger extensors and the long extensor of the thumb

Tenosynovitis of the finger extensors and the long extensor of the thumb is less common among tennis players than among instructors. These conditions are associated with the repetitive use of "wrist shots," typically slower and more frequent balls used in teaching beginners (5). Pain is localized to the dorsal mid-third of the forearm for finger extensors and to the anatomical snuffbox for the long extensor of the thumb. Pain is triggered by local palpation and resisted extension of the fingers and thumb. Diagnosis is primarily clinical and anamnesis-based, supported by ultrasound and X-rays to exclude fractures (38).

Conservative treatment includes rest, ice, NSAIDs, and, if necessary, immobilization using a splint. Physical therapy, including iontophoresis and ultrasound, may also be employed, followed by proper physiokinesitherapy after the acute pain phase subsides (34).

De Quervain's disease

De Quervain’s disease is one of the most frequent tendon problems among tennis players. It is caused by irritation of the extensor pollicis brevis and abductor pollicis longus tendons as they pass through the osteotendinous pulley of the radial styloid (5). Chronic inflammation of the tendon sheath leads to swelling that hampers tendon gliding, creating a vicious cycle of increased irritation.

The condition arises from microtrauma and repetitive movements of thumb flexion and extension. Pain, typically radial-side wrist pain, has a progressive onset and may radiate to the forearm. Swelling at the thumb-wrist junction and firm-elastic formations may be evident. Movements of the thumb and wrist are limited by pain, and an audible clicking sensation may occur with thumb extension. Finkelstein's test is consistently positive (2, 33) (Fig. 6).

Fig. 6. *Finkelstein’s test: severe tenderness and pain on the radial aspect of the wrist is caused when the thumb is flexed into the palm and the wrist is ulnar deviated.*

Initial treatment is conservative, involving rest, ice, NSAIDs, and thumb splints. Infiltration therapy may be added. Conservative management resolves symptoms in 80% of cases, restoring functionality without residual effects. Surgical pulley release may be required for persistent or recurrent symptoms. Return to sport after surgery usually occurs around 8 weeks (35).

Triangular fibrocartilage complex (TFCC) injury

The TFCC comprises structures between the ulnar head and the ulnar carpus, including:

- fibrocartilage proper, with limited reparative ability due to poor vascularization;
- radioulnar ligaments, stabilizing the distal forearm during pronation and supination;
- ulnocarpal ligaments, reinforcing the anterior carpus;
- ECU tendon sheath, strengthening the dorsal carpus and absorbing approximately 20% of impact forces transmitted from the carpus to the forearm (36).

Tennis's combination of wrist impacts and rotation predisposes players to TFCC lesions. Clinically, pain occurs at the ulnar styloid, worsening with ulnocarpal loading. X-rays exclude carpal fractures, while MRI helps confirm the diagnosis (38). Conservative management involves immobilization, rest, and NSAIDs, but surgical repair, often arthroscopic, may be needed for persistent symptoms or central fibrocartilage injuries (37).

Fracture of the hook of the hamate

Fractures of the hamate hook, though rare, are typical tennis injuries. They may result from a relaxed racket grip during powerful responses or from centrifugal force overpowering the grip. These fractures are classified as stress or acute injuries based on patient history (39).

Pain, which renders racket use nearly impossible, is exacerbated by resisted abduction/adduction of the fifth finger and palpation of the ulnar carpal side. Standard X-rays often miss this injury, requiring specialized carpal tunnel projections or CT scans for confirmation. Initial treatment includes immobilization with a cast including the fifth finger, but high rates of pseudoarthrosis necessitate surgical removal of the fragment in many cases (39).

DISCUSSION

Upper limb injuries in tennis are predominantly caused by repetitive and high-intensity movements, particularly those involving the shoulder, elbow, wrist, and hand. Overhead strokes, such as serves and smashes, impose substantial mechanical stress on the rotator cuff, biceps tendon, and glenoid labrum, frequently leading to impingement syndromes, tendinopathies, and joint instability. Additionally, chronic conditions such as lateral and medial epicondylitis are prevalent, often attributed to excessive load, inadequate technique, and improper equipment.

Technological advancements in racket design have significantly influenced the biomechanics of tennis. While modern rackets enhance power and maneuverability, they also increase vibratory forces transmitted to the upper limb, thereby exacerbating the risk of overuse injuries. Other contributing factors include training intensity, playing surfaces, and individual anatomical predispositions, all of which may modulate injury susceptibility.

A comprehensive approach to injury management emphasizes early diagnosis, conservative treatment, and preventive strategies. Biomechanical optimization, structured strengthening programs, and adequate recovery periods are fundamental in mitigating injury risk. In cases where conservative management fails, surgical intervention - ranging from arthroscopic procedures to decompressive techniques - may be required to restore function and alleviate symptoms.

CONCLUSIONS

Chronic overuse injuries represent a significant concern in tennis, surpassing the incidence of acute traumatic events. Understanding the biomechanical and physiological demands of the sport is crucial for developing effective prevention and management strategies. Proper technique, optimized equipment, and structured training regimens can significantly reduce the incidence of injuries. While conservative treatment remains the primary therapeutic approach, surgical intervention may be necessary in refractory cases. Future research should focus on refining injury prevention strategies, optimizing rehabilitation protocols, and evaluating the long-term musculoskeletal impact of repetitive tennis-related movements.

REFERENCES

1. Leach RE, Abramowitz A. The senior tennis player. *Clinics in sports medicine*. 1991;10(2):283-290.
2. Perkins RH, Davis D. Musculoskeletal Injuries in Tennis. *Physical Medicine and Rehabilitation Clinics of North America*. 2006;17(3):609-631. doi:https://doi.org/10.1016/j.pmr.2006.05.005
3. Bylak J, Hutchinson MR. Common Sports Injuries in Young Tennis Players. *Sports Medicine*. 1998;26(2):119-132. doi:https://doi.org/10.2165/00007256-199826020-00005
4. Ben Kibler W, Safran MR. Musculoskeletal injuries in the young tennis player. *Clinics in Sports Medicine*. 2000;19(4):781-792. doi:https://doi.org/10.1016/s0278-5919(05)70237-4
5. Cross R. The sweet spots of a tennis racquet. *Sports Engineering*. 1999;1(2):63-78. doi:https://doi.org/10.1046/j.1460-2687.1999.00011.x
6. Hennig EM. Influence of Racket Properties on Injuries and Performance in Tennis. *Exercise and Sport Sciences Reviews*. 2007;35(2):62-66. doi:https://doi.org/10.1249/jes.0b013e31803ec43e
7. Hjelm N, Werner S, Renstrom P. Injury profile in junior tennis players: a prospective two year study. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2010;18(6):845-850. doi:https://doi.org/10.1007/s00167-010-1094-4
8. Abrams GD, Harris AH, Andriacchi TP, Safran MR. Biomechanical analysis of three tennis serve types using a markerless system. *British Journal of Sports Medicine*. 2012;48(4):339-342. doi:https://doi.org/10.1136/bjsports-2012-091371
9. Miller S. Modern tennis rackets, balls, and surfaces. *British Journal of Sports Medicine*. 2006;40(5):401-405. doi:https://doi.org/10.1136/bjsm.2005.023283
10. Priest JD, Nagel DA. Tennis shoulder. *The American journal of sports medicine*. 1976;4(1):28-42.
11. Ryu RKN, McCormick J, Jobe FW, Moynes DR, Antonelli DJ. An electromyographic analysis of shoulder function in tennis players. *The American Journal of Sports Medicine*. 1988;16(5):481-485. doi:https://doi.org/10.1177/036354658801600509
12. Calis M. Diagnostic values of clinical diagnostic tests in subacromial impingement syndrome. *Annals of the Rheumatic Diseases*. 2000;59(1):44-47. doi:https://doi.org/10.1136/ard.59.1.44
13. Lewis JS. Rotator cuff tendinopathy/subacromial impingement syndrome: is it time for a new method of assessment? *British Journal of Sports Medicine*. 2009;43(4):259-264. doi:https://doi.org/10.1136/bjsm.2008.052183
14. Kirchhoff C, Imhoff AB. Posterosuperior and anterosuperior impingement of the shoulder in overhead athletes—evolving concepts. *International Orthopaedics*. 2010;34(7):1049-1058. doi:https://doi.org/10.1007/s00264-010-1038-0
15. Holmgren T, Bjornsson Hallgren H, Oberg B, Adolfsson L, Johansson K. Effect of specific exercise strategy on need for surgery in patients with subacromial impingement syndrome: randomised controlled study. *BMJ*. 2012;344(feb20 1):e787-e787. doi:https://doi.org/10.1136/bmj.e787
16. Halbrecht JL, Tirman P, Atkin D. Internal Impingement of the Shoulder: Comparison of Findings Between the Throwing and Nonthrowing Shoulders of College Baseball Players. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*. 1999;15(3):253-258. doi:https://doi.org/10.1016/s0749-8063(99)70030-7
17. Taverna E, Battistella F. La sindrome da conflitto sottoacromiale. *Lo scalpellooto di Educational*. 2008;22:8-12. doi:https://doi.org/10.1007/s1163900800827
18. Mithofer K, Fealy S, Altchek DW. Arthroscopic Treatment of Internal Impingement of the Shoulder. *Techniques in Shoulder and Elbow Surgery*. 2004;5(2):66-75. doi:https://doi.org/10.1097/01.bte.0000126189.02023.be
19. Russo R, Visconti V, Ciccarelli M. Anatomia patologica e classificazione delle rotture di cuffia. *Lo scalpellootodi Educational*. 2008;22(1):26-31. doi:https://doi.org/10.1007/s1163900800854
20. Li X, Lin TJ, Jager M, et al. Management of type II superior labrum anterior posterior lesions: a review of the literature. *Orthopedic Reviews*. 2010;2(1). doi:https://doi.org/10.4081/or.2010.e6
21. Schlechter JA, Summa S, Rubin BD. The Passive Distraction Test: A New Diagnostic Aid for Clinically Significant Superior Labral Pathology. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*. 2009;25(12):1374-1379. doi:https://doi.org/10.1016/j.arthro.2009.04.070
22. Kim YJ, Choi JA, Oh JH, Hwang SI, Hong SH, Kang HS. Superior Labral Anteroposterior Tears: Accuracy and Interobserver Reliability of Multidetector CT Arthrography for Diagnosis. *Radiology*. 2011;260(1):207-215. doi:https://doi.org/10.1148/radiol.11101176
23. Hegedus EJ, Goode AP, Cook CE, et al. Which physical examination tests provide clinicians with the most value when examining the shoulder? Update of a systematic review with meta-analysis of individual tests. *British Journal of Sports Medicine*. 2012;46(14):964-978. doi:https://doi.org/10.1136/bjsports-2012-091066
24. Krupp RJ, Kevern MA, Gaines MD, Kotara S, Singleton SB. Long Head of the Biceps Tendon Pain: Differential Diagnosis and Treatment. *Journal of Orthopaedic & Sports Physical Therapy*. 2009;39(2):55-70. doi:https://doi.org/10.2519/jospt.2009.2802
25. Porcellini G, Cesari E, Campi F, Paladini P. Il trattamento artroscopico dell'instabilità anteriore di spalla. *LO SCALPELLOOTODI Educational*. 2011;25(2):110-119. doi:https://doi.org/10.1007/s1163901101084
26. Peters T, Baker CL. Lateral epicondylitis. *Clinics in Sports Medicine*. 2001;20(3):549-563.

doi:https://doi.org/10.1016/s0278-5919(05)70269-6

27. Marx RG, Sperling JW, Cordasco FA. Overuse injuries of the upper extremity in tennis players. *Clinics in Sports Medicine*. 2001;20(3):439-451. doi:https://doi.org/10.1016/s0278-5919(05)70261-1
28. Elliott B. Biomechanics and tennis. *British Journal of Sports Medicine*. 2006;40(5):392-396. doi:https://doi.org/10.1136/bjsm.2005.023150
29. Kandemir U, Fu FH, McMahon PJ. Elbow injuries. *Current Opinion in Rheumatology*. 2002;14(2):160-167. doi:https://doi.org/10.1097/00002281-200203000-00013
30. Ciccotti MC, Schwartz MA, Ciccotti MG. Diagnosis and treatment of medial epicondylitis of the elbow. *Clinics in Sports Medicine*. 2004;23(4):693-705. doi:https://doi.org/10.1016/j.csm.2004.04.011
31. Nirschl RP, Ashman ES. Elbow tendinopathy: tennis elbow. *Clinics in Sports Medicine*. 2003;22(4):813-836. doi:https://doi.org/10.1016/s0278-5919(03)00051-6
32. Ciccotti MG. Epicondylitis in the athlete. *Instructional course lectures*. 1999;48:375-381.
33. Rettig AC. Wrist problems in the tennis player. *Medicine and Science in Sports and Exercise*. 1994;26(10):1207-1212.
34. Osterman L, Moskow L, Low CDW. Soft-Tissue Injuries of the Hand and Wrist in Racquet Sports. *Clinics in Sports Medicine*. 1988;7(2):329-348. doi:https://doi.org/10.1016/S0278-5919(20)30938-8
35. Inoue G, Tamura Y. Surgical Treatment for Recurrent Dislocation of the Extensor Carpi Ulnaris Tendon. *Journal of Hand Surgery*. 2001;26(6):556-559. doi:https://doi.org/10.1054/jhsb.2001.0615
36. Palmer AK, Werner FW. The triangular fibrocartilage complex of the wrist—Anatomy and function. *The Journal of Hand Surgery*. 1981;6(2):153-162. doi:https://doi.org/10.1016/s0363-5023(81)80170-0
37. Schädel-Höpfner M, Müller K, Gehrmann S, Lögters TT, Windolf J. [Therapy of triangular fibrocartilage complex lesions] [Article in German]. *Der Unfallchirurg*. 2012;115(7):582-588. doi:https://doi.org/10.1007/s00113-012-2176-1
38. Jacobson JA, Miller BS, Morag Y. Golf and Racquet Sports Injuries. *Seminars in Musculoskeletal Radiology*. 2005;09(04):346-359. doi:https://doi.org/10.1055/s-2005-923379
39. Guha AR. Stress fracture of the hook of the hamate. *British Journal of Sports Medicine*. 2002;36(3):224-225. doi:https://doi.org/10.1136/bjsm.36.3.224