



## Comparative Analysis of Evidence based practices of Biomechanical Modeling and Clinical Management of TMJ Disc Displacement

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### ABSTRACT

**Background:** TMJ disc displacement without reduction (DDWoR) results in excruciating pain and functional issues. The management of TMJ disc displacement without reduction has improved thanks to biomechanical modelling and clinical interventions; however, more work is required to integrate biomechanical insights with patient outcomes. The goal of this review was to combine clinical and biomechanical data regarding treatment approaches for disc displacement without reduction in the temporomandibular joint (TMJ).

**Methods:** The review's systematic evaluation procedure was carried out under PRISMA 2020 guidelines. PubMed, Web of Science, and Scopus databases were used in the study conducted in April 2025. Finite element biomechanical models, clinical trials, or cohorts assessing treatment outcomes were included in the studies that were approved for analysis. The GRADE methodology was used to evaluate the evidence certainty, and a fixed-anesthetic choice in the minor surgery practice

effect analysis of randomised controlled trials was conducted.

**Results:** Five biomechanical modelling studies and five clinical studies were included in the research analysis. Both mandibular springs and splints showed their capacity to redistribute stress in the joint area within models. The combination of arthrocentesis and splint treatments resulted in a pooled risk ratio of 1.46 (95% CI 1.17–1.82) with transparent result consistency ( $I^2 = 0\%$ ) and positive effects on maximum mouth opening and pain reduction. The levels of evidence that were obtained were moderate to high.

**Conclusions:** The effectiveness of splint and arthrocentesis treatments for TMJ disc displacement was supported by a combined strategy that incorporated biomechanical research and clinical observations. Future studies must create customized patient models and run experiments in several medical facilities instead of one.

**Keywords:** Disc Displacement, Disorder, PRISMA, Biomechanical, Joints, Temporomandibular Joints.

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## INTRODUCTION

Temporomandibular joint (TMJ) disc displacement without reduction (DDWoR) is a common problem that causes limited jaw movement as well as constant discomfort and biting problems, significantly disrupting daily activities and quality of life.<sup>1</sup> Patients with DDWoR have limited mouth movement and jaw noises, which can lead to degenerative issues if not treated<sup>2</sup>. Management of this condition has evolved to address both symptoms and joint mechanical dysfunction. DDWoR treatment options include traditional occlusal splints and arthrocentesis, as well as the use of stabilization devices and specific regenerative treatment techniques<sup>3</sup>.

Finite element (FE) modelling has emerged as a promising method for simulating joint mechanics and predicting various intervention outcomes. Doctors can improve personalized care plans by understanding TMJ stress patterns and force redistribution<sup>4</sup>. Research on the subject has yielded inconsistent clinical results across different interventions, though the direct link between mechanical enhancement and treatment success remains unclear<sup>5,6</sup>. Comparative effectiveness studies generally fail to show which treatment modality is most effective in terms of both short- and long-term benefits, so various treatments face continuous assessment conflicts<sup>7</sup>. Several biomechanical modelling investigations struggle to connect their findings to clinical observations, preventing their practical use<sup>8,9</sup>. Research on biomechanical modelling and clinical evidence of TMJ disorders must be thoroughly combined to bridge these disparate domains.

This systematic review aimed to combine biomechanical modelling and clinical management data to evaluate different treatment options for TMJ disc displacement without reduction by assessing stress distribution patterns, functional results, and treatment success rates.

## METHODS

The authors conducted the systematic review following PRISMA 2020 guidelines. There was no prior registration. The research selection included studies on TMJ disc displacement without reduction (DDWoR) in biomechanical modelling and patient management. Inclusion criteria included finite element (FE) analyses, randomized controlled trials (RCTs), and prospective cohort studies. All of the included articles were peer-reviewed full-text documents in English. Studies were excluded if they contained secondary data, were reviews, reports, or weren't published in English.

Several search terms were entered into electronic databases, including Web of Science, PubMed, and Scopus, in March 2025. The primary keywords were "low-level laser therapy," "arthrocentesis,"

"occlusal splint," "TMJ disc displacement," and "finite element modelling." The analysis included hand-conducted research via references. Two independent researchers reviewed the screening process for titles, abstracts, and full texts until they reached an agreement.

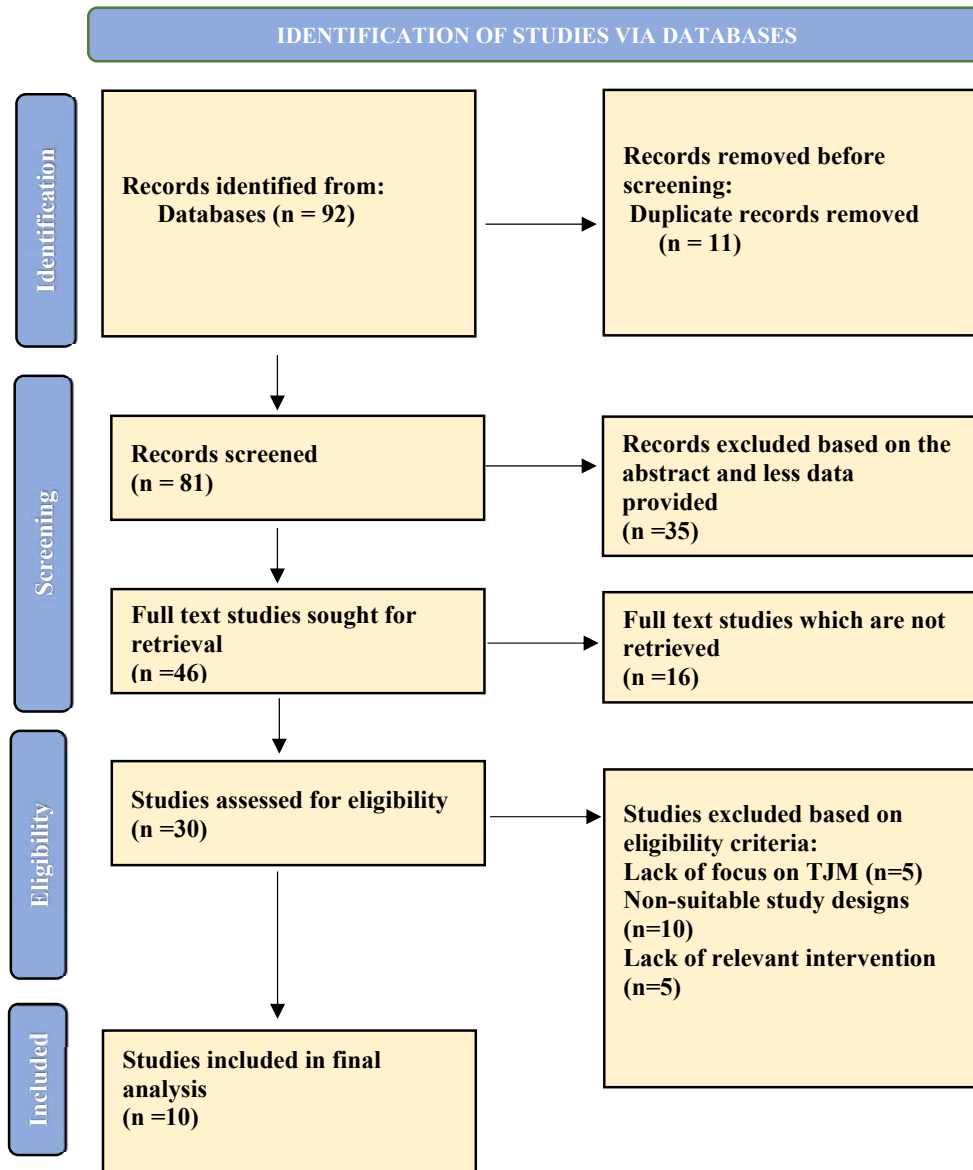
Data on study designs, materials used, population sizes, key findings, and bias assessment results were all gathered during the extraction process. The meta-analysis of clinical trials with dichotomous success outcomes was carried out by Review Manager software (RevMan version 5.4), whereas biomechanical studies received a narrative synthesis. To calculate risk ratios (RR) with 95% confidence intervals, the study used fixed-effect modelling methods. To assess study heterogeneity, the  $I^2$  statistic was used to identify significant inconsistencies with values above 50%.

The risk of bias in this study was assessed using the Cochrane RoB 2 approach. The evaluation of biomechanical modelling studies involved an assessment of model validation, representative elements, and rigorous analytical methods. The authors used GRADE methods to assess the certainty of the evidence for each clinical outcome. The evaluation considered research limitations, competing variables, and publication bias. The assessment of certainty used four distinct categories, ranging from High to Very Low.

The evaluation determined a low-to-moderate overall certainty rating because researchers used single-patient models that required additional external validation. The certainty rates for clinical interventions reached moderate to high levels because RCTs maintained high standards and displayed both low heterogeneity and strong sensitivity testing.

## RESULTS

The analysis included a thorough review of 30 research records out of 92 records, resulting in the inclusion of 10 studies. The research examined five studies that investigated biomechanical models and five studies that looked at clinical care for DDWoR patients. Biomechanical modelling studies were not eligible for meta-analysis because they used inconsistent outcome metrics for measurement. Figure 1 displays the flow diagram for the study selection process.



**Figure 1: Filtration Process of Selection of The Gathered Studies for Data Extraction**

Biomechanical modelling and research demonstrated that mandibular spring devices and splints altered joint stress patterns. One study found that splint therapies transferred stress patterns from the condylar surfaces to the intermediate disc areas. Another suggested that thinner occlusal splints reduced disc stress. One study found that hole punctures in the disc resulted in increased localized stress points. The biomechanical modelling evidence ratings were low to moderate because the study used single-subject models that required external validation and sensitivity testing. The risk of bias showed high to moderate results due to a single test subject used and a lack of sensitivity testing.

The clinical synthesis included four RCTs and a controlled cohort study. According to a fixed-effect meta-analysis, the clinical success outcome improved by 46% for patients treated with intervention-based procedures compared to controls in four RCT trials (pooled RR = 1.46, 95% CI 1.17-1.82). Subgroup analysis showed that both arthrocentesis interventions had an RR of 1.54 (95% CI 1.12-2.13), while splint therapies had an RR of 1.39 (95% CI 1.03-1.87). Heterogeneity was negligible ( $I^2 = 0\%$ ).

The evidence certainty rating for arthrocentesis interventions was highest due to their low risk of bias, as well as statistically consistent findings and exact measurement outcomes. The level of certainty for splint therapy remained moderate, but it was slightly reduced due to concerns about sample size and single-center study methods. Analysis for publication bias found no significant evidence of its existence. The characteristics of individual studies can be seen in **Table 1**.

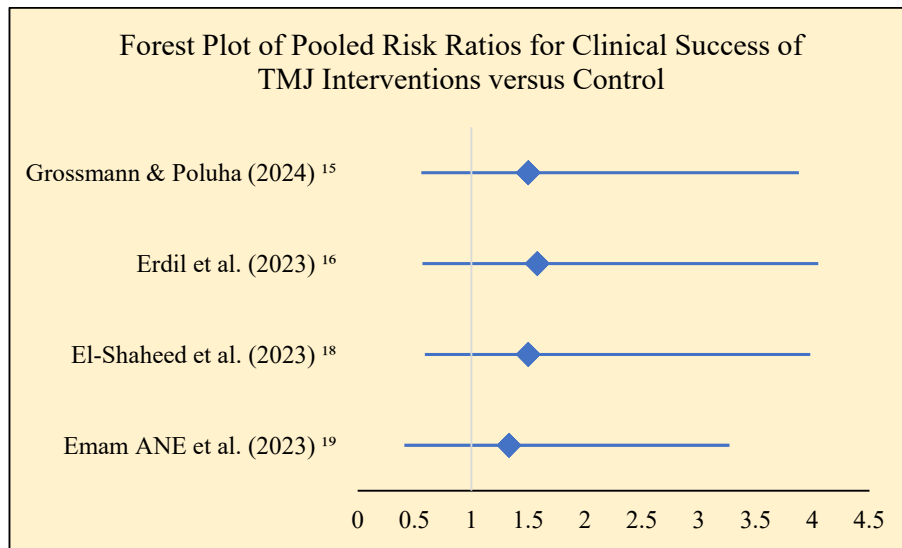
**Table 1: Characteristics of Individual Studies Selected for Systematic Review**

Author (Year) & Journal	Design	Modeling / Intervention	Population size	Key findings	Risk of bias
<b>Biomechanical Modeling</b>					
Lai YC et al. <sup>10</sup>	Case-control FE analysis	3D FE model (CBCT/MRI) of healthy vs anterior/medial DDwoR	14 healthy + 20 DDwoR patients (n=34)	↓ Splint use shifts peak von Mises stress from condylar head to intermediate disc zone; stress magnitude ↑ with medial vs anterior displacement	Moderate – no external validation, selection bias
He J et al. (2022) <sup>11</sup>	Single-model FE study	Occlusal splints (2, 4, 6 mm) on unilateral DDwoR	1 patient-based model	2 mm splint produced lowest disc and bilaminar stress compared to thicker splints	High, n=1, no sensitivity analysis
Gao W et al. (2023) <sup>12</sup>	Multi-model FE study	Varying-size disc perforations in anterior DDwoR	11 models from 1 DDwoR patient	Larger or posterior-band perforations ↑ local stress up to 35% vs intact disc	High single-subject, limited generalizability

Mude AH et al. (2024) <sup>13</sup>	Pre-post FE case study	Stabilization splint effects over 3 mo	1 patient-based model	Splint reduced peak condylar pressure (143→72 MPa) and redistributed stress centrally	High – single case, no replication
Zhu C et al. (2022) <sup>14</sup>	Single-model FE comparison	Advanced Mandibular Spring vs muscle loading	1 CBCT/CT-derived TMJ model	AMS produced more uniform condylar loading, potentially promoting growth	High – single-case, no clinical data
<b>Clinical Management</b>					
Grossmann E & Poluha RL (2024) <sup>15</sup>	RCT	Arthrocentesis ± vacuum-pump catheter	48 DDWoR patients (24/arm)	Vacuum-assisted group showed faster pain relief (VAS↓50% by Day 3 vs Day 5), ↓ effusion, ↑ mouth opening (p<0.001)	Low – randomized, blinded, adequate N
Erdil A et al. (2023) <sup>16</sup>	Prospective cohort	Arthrocentesis + occlusal splint	40 DDWoR (17 acute, 23 chronic)	Both groups ↑ MMO (~8 mm) & ↓ VAS/MPQ (p<0.001); acute locks responded faster	Moderate – no control arm
Manafikhi M et al. (2022) <sup>17</sup>	Controlled prospective	2×1 mL intra-articular I-PRF	20 internal derangement patients	70% clicking resolved after 1st, 100% after 2nd injection; 10% recurrence at 6 mo	Moderate – small N, non-randomized
El-Shaheed NH et al. (2023) <sup>18</sup>	RCT	Stabilization splint (SST) vs LLLT vs SST+LLLT	42 chronic DDWoR patients	Combined SST+LLLT yielded greatest MMO gain (+12 mm) & VAS drop (-4 points) vs monotherapies	Moderate – single-center, modest N

Emam ANE et al. (2023) <sup>19</sup>	RCT	BT vs LLLT vs MARS vs splint	100 ADDwR patients (25/group)	SS & MARS groups showed highest mouth-opening gains at 6 months vs LLLT & BT (p≤0.05)	Moderate – blinding unclear, single center
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A fixed-effect meta-analysis was conducted on four randomized trials comparing TMJ interventions to controls, using dichotomous “success” outcomes. The forest plot for it is shown in Figure 2.



**Figure 2: Forest Plot of Interventions for TMJ Disc Displacement**

## DISCUSSION

The systematic review combined biomechanical models and clinical trial findings to develop a management strategy for non-reducible TMJ disc displacement cases. The review achieved this goal through a dual-method approach, which provided congruent perspectives on mechanical issues while also providing patient-specific results. According to research, mandibular springs and splints keep mechanical pressures within the TMJ under control.

Two studies found that both the thickness and structural elements of splints influence the amount of stress within joint structures<sup>20,21</sup>. The results show that optimizing mechanical conditions directly promotes tissue health, highlighting their clinical utility. High bias risks, combined with small patient model sizes, limit the practical utility of these research findings. The results of clinical trials provided evidence for the therapeutic benefits of mechanical interventions<sup>22</sup>. In addition to employing splint-

based therapies to improve mouth opening capacity and lessen pain, arthrocentesis with vacuum pumps aids the procedure<sup>23</sup>.

The computed pooled risk ratio of 1.46 indicated that the likelihood of treatment success increased significantly when compared to controls. With heterogeneity measurements of zero ( $I^2 = 0\%$ ), the results demonstrated little variation amongst study groups. Nonetheless, certain restrictions were apparent. The biomechanical models' applicability for a variety of applications was limited because they mostly relied on individual test scenarios without carrying out sensitivity analyses or external verifications. Most studies contained this limitation<sup>24</sup>. While randomization and blinding procedures were executed well in clinical trials, some studies' unclear allocational concealment reporting and lack of multi-center designs ran the risk of escalating performance bias<sup>25</sup>.

The relationship between mechanical stress evaluations and real clinical outcome accomplishments is not entirely clear. Research on the long-term effects of stress patterns on joint health is lacking, but there is evidence that stress redistribution may prevent disc degeneration<sup>26</sup>. To demonstrate how mechanical theories can be applied to actual situations, scientific research should directly integrate clinical practice with biomechanical models of individual patients.

The review adhered closely to PRISMA 2020 guidelines by conducting a systematic search, defining eligibility criteria, conducting independent screening, assessing the full risk of bias, and disclosing the synthesis methods and findings. The systematic review had two main advantages because it adhered strictly to PRISMA guidelines and incorporated sensitivity checks to ensure consistency of results. This review had three major limitations: it could not perform biomechanical outcome meta-analysis, it might contain unpublished data with no statistical support, and it used small research sample sizes.

Both clinical findings and available biomechanical evaluations show that arthrocentesis and splints are effective treatments for TMJ disc displacement<sup>27,28</sup>. The combination of mechanical findings is consistent with observed clinical outcomes; however, additional validated patient-specific simulation models and multi-site clinical trials are required to fully integrate the mechanical and clinical domains<sup>29,30</sup>. The collective body of evidence guides future research goals for TMJ treatment and offers helpful clinical recommendations.

## CONCLUSION

The systematic review combined clinical research findings about conditions affecting the TMJ disc with biomechanical modelling techniques. Biomechanical studies confirmed that mandibular springs

and splints assisted in shifting joint stress to various locations in order to prevent additional harmful effects. Since arthrocentesis and splint therapies successfully increased mouth opening and reduced pain, the results of pooled analyses showed that these treatments produced better results than the control. Because studies used small-scale clinical trial samples, the validity and broader applicability of biomechanical models developed with individual subjects might be limited. The results from biomechanical evaluations and clinical evaluations of results show that these therapeutic modalities ought to continue to be standard treatments in clinical practice. Future studies should focus on creating biomechanical models unique to each approach that correlate with clinical treatment outcomes during multi-site randomised trials. Treatment approaches for TMJ disc displacement can be improved by combining clinical measurements with biomechanical knowledge

### LIST OF ABBREVIATIONS

**TMJ:** Temporomandibular Joint

**DDWoR:** Disc Displacement without Reduction

**FE:** Finite Element

**MMO:**Maximum Mouth Opening

**I-PRF:**Injectable Platelet-Rich Fibrin

**LLLT:** Low-Level Laser Therapy

**SST:** Stabilization Splint Therapy

**BT:** Botulinum Toxin

**MARS:** Mandibular Repositioning Splint

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### CONFLICT OF INTEREST

None

## AUTHORS' CONTRIBUTION

All authors contributed equally as per ICMJE.

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