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Dentistry Section

Mandibular Flexure and its Impact on the Biomechanics of Implant-supported Prostheses: A Systematic Review

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ABSTRACT

Introduction: Mandibular flexure, a biomechanical phenomenon that occurs during functional mandibular movements, greatly influences the biomechanics of implant-supported prostheses. The rigid connection between implants and prosthetic frameworks affects stress distribution and may increase peri-implant bone stress, as well as impact the stability of the prostheses.

Aim: To integrate the literature on the current research regarding the impact of mandibular flexure on the biomechanics of implant-supported prostheses.

Materials and Methods: The present review assessed studies investigating mandibular flexure and its impact on implant-supported prostheses using the following keywords: "mandibular flexure," "implant-supported prostheses," "Finite Element Analysis (FEA)," "Cone Beam Computed Tomography (CBCT)," and "peri-implant bone loss." Data were extracted from clinical, radiographic, in-vivo, and FEA studies. Outcomes included stress distribution, peri-implant bone loss, prosthetic failure, and material performance. A structured analysis was performed to identify patterns across variables such as framework design, implant placement, loading conditions, and biomechanical methods. Nine studies were included in the review.

Results: Across the nine studies included in the review, mandibular flexure significantly impacted the distribution of stress around the implant, with magnitudes of stress ranging from 0.073 mm deformation in brachyfacial types to 300 N in specific loading scenarios. Segmented frameworks reduced stress by up to 20% compared to non segmented designs. Bone loss was most pronounced in distal implants, with rates exceeding 15% in high-stress regions. Material performance varied, with titanium and cobalt-chromium frameworks showing superior biomechanical stability compared to polymeric alternatives. Dynamic and oblique loading conditions caused higher stress concentrations than static loading.

Conclusion: Mandibular flexure affected implant-supported prostheses by altering stress distribution and increasing bone loss around the implants, especially in distal areas. Framework segmentation and material optimisation proved to be effective in mitigating these effects. These results highlight the importance of individualised biomechanical solutions to improve the longevity of prostheses and clinical outcomes.

Keywords: Flexure, Brachyfacial, Distal implants, Finite element analysis, Peri-implant

INTRODUCTION

Mandibular flexure is a complex biomechanical phenomenon described as the deformation of the mandible during functional movements such as mastication, opening, protrusion, and clenching [1]. Consequently, dental and prosthodontic research has focused significant interest on this issue. It primarily depends on the contraction of the masticatory muscles, where the lateral pterygoid and other associated muscles exert forces against the mandible during mandibular movements [2]. Flexure presents as alterations in the dimensions of the mandible, including medial convergence, dorsoventral shear, corporal rotation, and anteroposterior displacement. Although these physiological changes are well tolerated in patients with natural dentition, the lack of periodontal ligaments and tooth mobility in edentulous patients treated with implant-supported prosthetic rehabilitation may increase the biomechanical effects of mandibular flexure [3,4].

The biomechanical scenario in implant prosthodontics differs from that of natural dentition because of the rigid connection between osseointegrated implants and their supporting prostheses. Splinting implants in a fixed prosthetic framework eliminates the mobility present with natural teeth and thus alters the distribution of stresses in the mandibular arch [5,6]. This rigidity affects not only the peri-implant bone stress but also increases the likelihood of prosthetic complications, such as screw loosening, framework fractures, and stress-induced bone resorption [7]. The magnitude of these effects depends on several factors, including framework design, material properties, the number and distribution of implants, and occlusal loading patterns [8].

Greater influence has been shown for mandibular flexure in full-arch fixed prostheses. There are other designs for the framework, which include one-piece versus segmented two- or three-piece frameworks that have been introduced to address issues of flexure [5,7]. One-piece frameworks, by promoting uniform stress distribution across implants, may magnify the stress experienced by distal implants on the flexure-induced stress side [9]. Segmented frameworks aim to reduce these stresses by allowing individual movement of mandibular segments while introducing challenges regarding prosthetic fit and stability [10]. The material properties of the prosthetic framework also play a critical role, although rigid materials such as titanium and cobalt-chromium demonstrate superior biomechanical performance compared to polymeric material alternatives, such as polyetheretherketone and polymethyl methacrylate, which exhibit deformation under applied load [11].

Moreover, the problem of biomechanics will be compounded during implant placement along with occlusal loading dynamics. This approach has often been favored to distribute occlusal forces symmetrically. However, it has been shown that implant placement distal to the mental foramen leads to increased bone loss due to high-stress concentrations [12]. The loading conditions—static, dynamic, or oblique—determine the magnitudes of stress. Generally, dynamic and oblique loads lead to higher peri-implant stress compared to static conditions. The interplay of these variables underscores the importance of biomechanical optimisation in implant-supported prosthetic designs to reduce the undesirable consequences of mandibular flexure [8,12,13].

The present systematic review aimed to evaluate the biomechanical effects of mandibular flexure on implant-supported prostheses, focusing on stress distribution and peri-implant bone loss. The objectives included analysing the impact of flexure on stress patterns in different prosthetic frameworks, assessing the role of implant design in mitigating flexure-related stresses, comparing methodologies such as FEA and cone beam computed tomography, and identifying clinical implications for optimising prosthetic rehabilitation. This review sought to determine how mandibular flexure influenced biomechanical performance, stress distribution, and peri-implant bone loss, while also exploring prosthetic design considerations to minimise these effects.

MATERIALS AND METHODS

PECOS Protocol: The primary research question for present review was: "How does mandibular flexure affect the stress distribution and peri-implant bone loss in patients with implant-supported prostheses, and what are the roles of prosthetic framework design, material selection, and implant positioning in mitigating these effects?"

The PECOS protocol for the review was constructed to systematically find and analyze studies addressing mandibular flexure with its biomechanical implications in mind. The protocol followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) 2020 guidelines [14] for adequate reporting and proper methodological clarity. The criteria were as follows:

- P- Population: Edentulous patients or partially edentulous patients who are rehabilitated with an implant-supported prosthesis within the mandible.
- E- Exposure: FEA of mandibular flexure, CBCT, radiographic analysis, or other biomechanical studies.
- C- Comparator: Prosthetic designs showing one-piece and segmented frameworks with varying implants and their setups.
- O- Outcomes: Distribution of biomechanical stress, peri-implant bone loss, implant stability, prosthetic failure, and ways to mitigate stress.
- S- Study Design: In-vitro, in-vivo, retrospective, or prospective observational studies.

Inclusion and Exclusion criteria: The inclusion criteria encompassed studies focusing on mandibular flexure in patients rehabilitated with implant-supported prostheses. The included studies utilised biomechanical methods such as FEA, CBCT, or radiographic analysis and reported outcomes including stress distribution, bone loss, or implant stability. In-vitro and in-vivo studies, along with retrospective analyses, were included. Studies were excluded if they focused purely on non implant-supported prostheses and did not provide information about the degree of mandibular flexure or if they lacked relevant biomechanical analysis. Additionally, reviews, editorials, case reports, and studies not available in English were also excluded.

Database Search Protocol

Database searching was conducted across seven databases: PubMed (60), Scopus (72), Web of Science (65), Embase (58), Cochrane Library (50), IEEE Xplore (57), and Google Scholar (55). Boolean operators and MeSH terms were employed in retrieving studies, including original research studies. Keywords such as "mandibular flexure," "implant-supported prostheses," "FEA," "CBCT," "peri-implant bone loss," "clinical study," "retrospective study," "in-vivo study," "radiographic analysis," and "biomechanical study" were utilized. Sensitivity was maximised using synonyms and alternative keywords while maintaining truncation and wildcards for maximum coverage [Table/Fig-1]. Only publications available in the English language were considered, and only those classified as "original research studies" were included.

Database	Search string
PubMed	("Mandibular Flexure"(Mesh) OR "mandibular deformation" OR "jaw flexion") AND ("Dental Implants"(Mesh) OR "implant-supported prostheses" OR "implant-borne restorations") AND ("Finite Element Analysis"(Mesh) OR "FEA" OR "biomechanical simulation") AND ("Cone-Beam Computed Tomography"(Mesh) OR "CBCT" OR "3D imaging") AND ("Peri-Implantitis"(Mesh) OR "peri-implant bone loss" OR "marginal bone level") AND ("Clinical Study"(ptyp) OR "Retrospective Study"(ptyp) OR "In Vivo Study") AND (english(lang))
Scopus	TITLE-ABS-KEY("mandibular flexure" OR "jaw deformation" OR "mandibular strain") AND TITLE-ABS-KEY("implant-supported prosthesis" OR "implant restoration" OR "implant overdenture") AND TITLE-ABS-KEY("finite element analysis" OR "FEA" OR "stress simulation") AND TITLE-ABS-KEY("CBCT" OR "cone beam CT" OR "3D imaging") AND TITLE-ABS-KEY("peri-implant bone loss" OR "bone resorption around implant") AND TITLE-ABS-KEY("clinical study" OR "retrospective study" OR "biomechanical analysis") AND (LIMIT-TO(DOCTYPE, "ar")) AND (LIMIT-TO(LANGUAGE, "English"))
Web of Science	TS=("mandibular flexure" OR "jaw bending" OR "mandibular displacement") AND TS=("implant-supported prostheses" OR "implant-retained denture") AND TS=("finite element modeling" OR "biomechanical modeling" OR "stress analysis") AND TS=("CBCT" OR "cone-beam computed tomography" OR "volumetric tomography") AND TS=("peri-implant bone loss" OR "marginal bone change") AND TS=("clinical study" OR "retrospective cohort" OR "radiographic analysis") AND LA=(English) AND DT=(Article)
Embase	('mandibular flexure'/exp OR 'jaw distortion' OR 'mandibular torsion') AND ('dental implant'/exp OR 'implant-supported prosthesis' OR 'implant denture') AND ('finite element analysis'/exp OR 'stress modeling' OR 'biomechanics simulation') AND ('cone beam computed tomography'/exp OR 'CBCT') AND ('periimplantitis'/exp OR 'peri-implant bone loss') AND ('clinical study'/exp OR 'retrospective study'/exp OR 'radiographic study') AND (english)/lim AND (article)/lim
Cochrane Library	("mandibular flexure" OR "jaw deformation" OR "mandibular bending") AND ("implant-supported prosthesis" OR "implant-fixed restoration") AND ("finite element analysis" OR "biomechanical modeling") AND ("CBCT" OR "cone beam computed tomography") AND ("peri-implant bone loss" OR "marginal bone change") AND ("clinical trial" OR "retrospective study" OR "in-vivo study")) in Trials
IEEE Xplore	("mandibular flexure" OR "jaw motion analysis" OR "mandibular biomechanics") AND ("implant-supported prosthesis" OR "dental implant modeling") AND ("finite element method" OR "stress analysis" OR "structural simulation") AND ("CBCT imaging" OR "cone beam CT") AND ("peri-implant bone loss" OR "osseous deterioration") AND ("clinical evaluation" OR "experimental validation") AND (Document type: Journals and Conferences) AND (Language: English)
Google Scholar	All in title: ("mandibular flexure" OR "jaw deformation") AND ("implant-supported prosthesis" OR "implant fixed denture") AND ("finite element analysis" OR "biomechanical study") AND ("CBCT" OR "cone beam imaging") AND ("peri-implant bone loss") AND ("clinical study" OR "in-vivo analysis") site:.edu OR site:.org OR site:.gov

[Table/Fig-1]: Search strings utilised across the databases add a foot note of IEEE; Institute of electrical and electronics engineers

Data Extraction Protocol

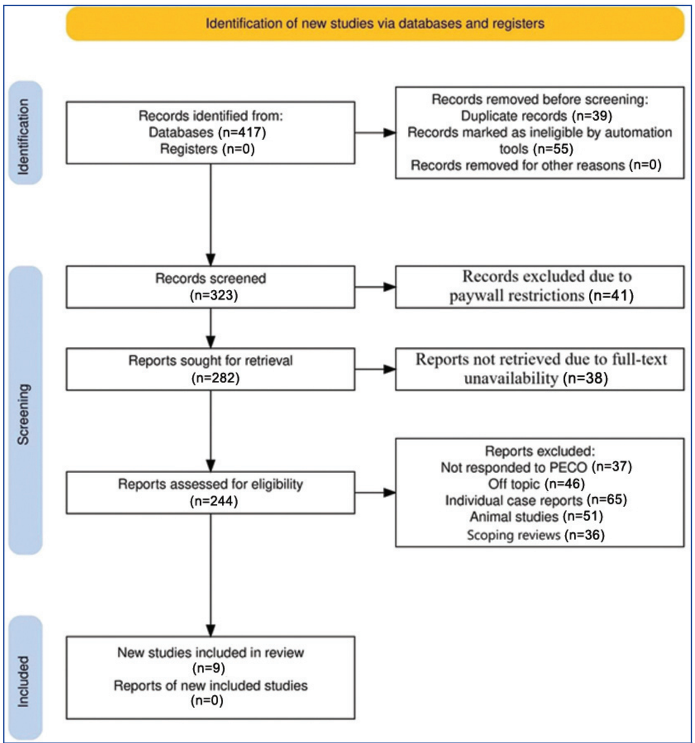
A standardised data extraction form was utilised to ensure consistency and accuracy in collecting relevant information from the included studies. Two independent reviewers extracted data, including study identifiers (author, year, location), study design, population characteristics, intervention details such as implant type and prosthesis design, biomechanical evaluation methods, primary outcomes related to stress distribution and peri-implant bone loss, and study conclusions. Any discrepancies in data extraction were resolved through consensus; if disagreements persisted, a third reviewer was consulted. Extracted data were systematically entered into a structured database for synthesis and analysis. No automation tools were employed in the data collection process, and no direct contact was made with study investigators for additional data confirmation.

Bias Assessment Protocol

For present review, tailored tools for each study design were used for bias assessment. For clinical studies and retrospective/prospective radiographic analyses, ROBINS-I [15] was utilized, focusing on confounding, participant selection, and intervention classification. A modified QUADAS-2 tool [16] was employed for assessing in-vivo CBCT studies and 3D FEA studies, focusing on patient selection, index tests, and reference standards.

RESULTS

A total of 417 records were identified in the database search, with no further records from registers [Table/Fig-2]. After the automated removal of 39 duplicates and 55 ineligible records, screening was conducted for 323 records. Of those, 41 records were excluded because they were restricted due to a paywall. Subsequently, 282 reports were requested for retrieval, but 38 reports were not retrieved due to unavailability of the full text. A total of 244 records were screened for eligibility, and 235 were excluded for reasons such as not meeting PECO criteria (37), being off-topic (46), being case reports (65), involving animal studies (51), or being scoping reviews (36). Finally, nine studies were included in the final review [17-25].



[Table/Fig-2]: Study selection process

Study Design and Groups Included

The review aggregated studies with widely varying study designs [Table/Fig-3] [17-25]. The overwhelming majority were based on 3D FEA [17-20,23-25]. Additionally, there was a clinical study [17], a retrospective radiographic analysis [21], and an in-vivo CBCT-based study [22]. The groups studied were diverse across the research works, ranging from splinted versus non splinted frameworks [18,19] to comparisons of one-piece, two-piece, and three-piece frameworks [24]. Facial type variations (brachyfacial, mesofacial, and dolichofacial) [21] and different implant-supported designs such as three-implant versus four-implant-supported prostheses [20] were also considered. These groups were chosen specifically to investigate biomechanical performance under mandibular flexure, with computational simulations providing quantitative insight into stress distributions and deformations in these configurations.

Measurement Techniques and Magnitude of Mandibular Flexure

Advanced 3D FEA techniques were used to measure mandibular flexure in most studies [17-20,23-25], supplemented by radiographic analysis [22] and measurements based on CBCT [23]. The magnitude of flexure was quantified using various parameters, including von Mises stress values and deformation. The highest reported stress occurred in polymeric frameworks such as Polyether Ether Ketone (PEEK), which showed significant deformation under dynamic loading conditions [25]. In contrast, some frameworks, such as titanium, performed better and had a stress magnitude of 300 N for three-implant-supported designs compared to four-implant-supported ones [20]. One study reported that mandibular deformation during jaw opening was 27 mm [24], while another calculated tightening in the molar region to be -0.81 mm during mandibular movements [23]. The brachyfacial type exhibited the highest average flexure of 0.073 mm, indicating that facial morphology has a significant impact on biomechanical results [21].

Type of Prosthesis and Implant Materials

All studies included in this review evaluated fixed prostheses, except for one that assessed both fixed and removable designs [19]. Titanium was the most commonly used implant material due to its excellent strength and biocompatibility [17,21,24]. Zirconia revealed more stress compared to titanium, while other materials, including cobalt-chromium, were also used [21]. Polymethyl Methacrylate (PMMA) and Polyether Ether Ketone (PEEK) frameworks demonstrated higher deformation under load compared to the rest, with the most deformation observed in PEEK across all the different materials tested [25].

Different placements of the implant included symmetrical placement [24] and inter-foraminal [18], in addition to placements at the back of the jaw close to the mental foramen [22]. Experiments revealed that implant location was significantly important in affecting stress distribution. Distal locations were sensitive and showed increased bone loss compared to mesial sites [22]. The type of occlusal loading was categorized into dynamic (50-150 N) [17,24], oblique and vertical forces (300 N) [20], and static during CBCT-based analyses [23]. Dynamic loading conditions exhibited more pronounced stress concentrations, with marked differences between splinted and unsplinted configurations [19].

Prosthetic Materials and Biomechanical Stress Analysis Methods

Prosthetic materials included metal alloys like titanium and cobalt-chromium, zirconia, and polymeric materials such as PMMA and PEEK. The values of stress and deformation for metal alloys were generally lower; however, titanium frameworks demonstrated the most stability in the presence of biomechanical loads [25]. The biomechanical stress analyses were carried out using software such as ANSYS [17], Mimics [21], and CBCT-based tools [23], providing high precision in simulating the distribution of stress. One study reported stress reductions in unsplinted designs, where bar-clip systems showed

Study	Year	Study design	Groups assessed	Mandibular flexure measurement technique	Flexure magnitude (in mm or degrees)	Type of prosthesis (fixed/removable)	Implant material	Implant location (mandibular quadrant or arch region)	Occlusal loading type (dynamic/static)	Prosthetic material	Biomechanical stress analysis method	Clinical outcomes assessed	Flexure mitigation strategies employed	Conclusion assessed
Ahmed M et al., [17]	2018	Clinical study	4 implant-retained frameworks	3D FEA	Von Mises stress; deformation	Fixed	Titanium	6 implants symmetrically	Dynamic (50-150N)	Co-Cr frameworks	ANSYS	Bone stress and deformation	Segmented frameworks	Segmented frameworks reduce stress
Barão VA et al., [18]	2013	3D FEA	Splinted vs non splinted frameworks	Clinical observation	Not significant	Fixed	Titanium	Inter-foraminal	Immediate functional loading	Not specified	Clinical and radiographic	Bone density	Segmented designs	Segmented frameworks superior

Elsayyad AA et al., [19]	2020	3D FEA	Unsplinted vs splinted over-dentures	3D FEA	Highest in BC-C (39.8 MPa)	Fixed/ remov-able	Not specified	4 implants inter-foraminal	Oblique (100N)	O-ring/ bar-clip systems	Finite Element Method	Stress reduction in unsplinted	Use of unsplinted implants	Unsplinted designs beneficial
Gao J et al., [20]	2022	3D FEA	3-implant vs 4-implant-supported designs	3D FEA	300 N stress higher in 3-implant design	Fixed	PMMA	Midline and second premolars	Oblique and vertical	PMMA	FEA	Stress levels in implant configur-ations	Reduced cantilever designs	3-implant acceptable under certain loads
Giordano F et al., [21]	2024	Retro-spective radio-graphic analysis	Brachy-facial, mesofacial, dolicho-facial	3D FEA	0.073 mm (average)	Fixed	Titanium	Symmetric for facial types	Dynamic	Zirconia, Titanium	Mimics software	Stress in facial types	Optimised for facial types	Brachy-facial highest stress
Londono J et al., [22]	2023	In-vivo CBCT study	Different implant positioning patterns	Radio-graphic analysis	Bone loss significant distally	Fixed	Not specified	Distal to mental foramen	Static	Not specified	SPSS analysis	Bone resorption	Optimised implant placement	Distal implants at risk
Martin-Fernandez E et al., [23]	2018	3D FEA	Max opening vs inter-cuspation	CBCT	-0.81 mm molar tightening	Fixed	Not specified	Canines and molars	Static CBCT analysis	Not specified	CBCT-based	Di-mensional changes	Radio-graphic stent evaluations	Mandibular changes significant
Sharma S et al., [24]	2023	3D FEA	1-piece, 2-piece, 3-piece frame-works	3D FEA	27 mm jaw opening	Fixed	Titanium	Symmetrical placements	Dynamic	Metal alloy	FEA software	Bone stress in frame-works	Undivided frame-works optimal	Undivided frame-works optimal
Sirandoni D et al., [25]	2019	3D FEA	Frame-works: Ti, Co-Cr, ZrO2, PEEK	3D FEA	PEEK showed highest deforma-tion	Fixed	Ti, Co-Cr, ZrO2	Distributed across mandible	Dynamic loading	Ti, Co-Cr, ZrO2	3D simula-tion	Stress distribution differences	Non polymeric frame-works optimal	Ti frame-works best for stress

[Table/Fig-3]: Studies included in the review and their observed inferences [17-25].

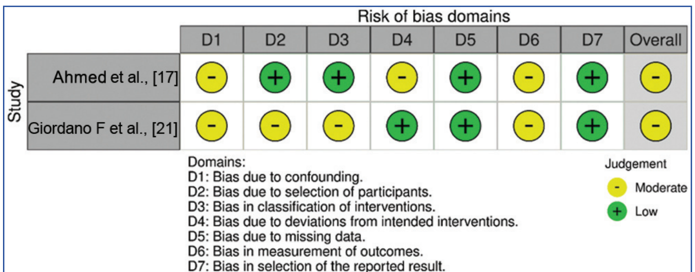
stress magnitudes of 39.8 MPa, which was lower than that of splinted designs [19]. Another study highlighted stress differentials between one-piece and three-piece frameworks, with segmented designs showing increased stress around distal implants [24].

Clinical Outcomes and Flexure Mitigation Strategies

Clinical outcomes included bone stress, peri-implant bone loss, dimensional changes, and prosthetic stability. Segmented frameworks effectively mitigated stress, with one study reporting that unsplinted designs reduced peri-implant stress by up to 20% compared to splinted designs [19]. Another study demonstrated that optimized implant placements reduced distal bone loss rates by over 15% in cases with distal-to-mental-foramen implant configurations [22]. Framework designs have been critical since, non divided frameworks exhibit better strength and stress distribution when subjected to dynamic loading [24]. Radiographic analysis of stents also quantitatively measured some of the mandibular bending dimensional changes, resulting in significant reductions of up to -0.87 mm on one side [23].

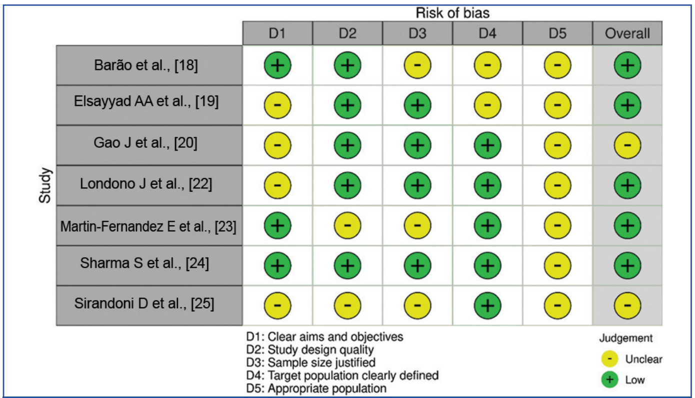
Quality Levels Assessed

Across the clinical studies both Ahmed M et al., and Giordano F et al., showed moderate bias in domains related to study design quality (D2) and sample size justification (D3), while other domains, including target population definition and appropriateness (D4-D7), were rated as low [Table/Fig-4]. The overall risk of bias for these studies was categorised as moderate.



[Table/Fig-4]: Bias levels assessed across retrospective/prospective studies included in the review [17,21].

Variability in bias levels was more pronounced for studies that used FEA and in-vivo methodologies [Table/Fig-5] [18-20, 22-25]. Barão VA et al., and Sharma S et al., reported low bias in most domains, including well-defined aims (D1) and quality of study design (D2), but showed unclear bias concerning the justification of sample size and appropriateness of the population [18,24]. In contrast, studies like Elsayyad AA et al., Gao J et al., and Sirandoni D et al., appeared to have uncertain or low scores in several of the domains, particularly in sample size justification and population clarity, which together resulted in a low or unclear risk of bias for those studies [19,20,25].



[Table/Fig-5]: Bias levels assessed across FEA and in-vivo studies [18-20, 22-25].

DISCUSSION

It has been established that the contraction of the lateral pterygoid muscles, especially their lower heads, is one of the main causes of mandibular flexure. The contraction of these muscles pushes the condyles and condylar necks medially and anteriorly, thus rotating the mandibular arch in a buccolingual direction [11]. However, direct measurements of the forces generated by the lateral pterygoid muscles are difficult due to anatomical complexity and the location of these muscles [26]. Additionally, other muscles such as the mylohyoid, platysma, and superior pharyngeal constrictor also contribute in a secondary way to mandibular flexure [11].

On the frontal plane, mandibular flexure produces a narrowing of the distance between the mandibular rami due to the elastic deformation of the mandible, which reduces the width of the mandibular arch [6-8]. Static analyses have demonstrated a progressive reduction in the medial-lateral diameter of the mandibular arch as the degree of jaw opening increases [10,27,28]. Dynamic assessments further showed that this diameter decreased during mandibular protrusion and increased during retraction, due to muscular activity without tooth contact [1,29,30].

Mandibular deformation has been categorised during flexion into four patterns: symphyseal flexion, dorsoventral shear, corporal rotation, and anteroposterior shear [30]. These deformation patterns are associated with compressive, tensile, or shear forces. Among these, the highest symphyseal tension, leading to bending, was attributed to the contraction of the medial component of the Lateral Pterygoid Muscles (LPMs). The shape of the jaw changes, and the arch width also reduces. In reported cases, reductions range from a few microns to 1 mm, with an average of 0.073 mm. Lingual tipping of the teeth in the mandibular arch can be caused by this phenomenon as well [10,11,31-33]. Mandibular deformation has been categorised during flexion into four patterns: symphyseal flexion, dorsoventral shear, corporal rotation, and anteroposterior shear [30]. These deformation patterns are associated with compressive, tensile, or shear forces. Among these, the highest symphyseal tension, leading to bending, was attributed to the contraction of the medial component of the LPMs. The shape of the jaw changes, and the arch width also reduces. In reported cases, reductions range from a few microns to 1 mm, with an average of 0.073 mm. Lingual tipping of the teeth in the mandibular arch can be caused by this phenomenon as well [10,11,31-33].

A protective mechanism against bone loss exists in natural dentition, allowing physiological movement of the tooth in the case of mandibular flexion, provided by the periodontal ligament [18,19]. According to Frost's mechanostat theory, the bone's stress/strain levels are maintained within a physiological range, minimising excessive stress accumulation [20,21]. However, in edentulous jaws rehabilitated with implant-supported full-arch prostheses, the absence of periodontal ligament function and the rigid connection of implants within a single framework exacerbate flexural forces. These forces increase bone stress around implants, potentially leading to resorption [34,35].

Mandibular flexure has been considered a contributing factor to posterior implant failure in mandibular full-arch fixed prostheses with interconnected implants [25]. Such restorations might provoke crestal bone loss around implant heads due to functional mandibular flexibility. In addition, experimental and clinical evidence indicates that mandibular flexure compromises the fit of both fixed and removable prostheses, leading to complications such as denture decementation, fractures of prosthetic components (such as porcelain or screws), and even implant fractures [6,17,36]. Moreover, in impression-taking procedures, lingual tipping of teeth can be introduced due to mandibular flexure, which might compromise the final treatment outcome [37,38].

The present review's findings indicate similarities and differences in the analysis of mandibular flexure and its clinical implications compared to reviews conducted with similar objectives [39-41]. the present review extensively utilised advanced 3D FEA techniques, supplemented by CBCT and radiographic analyses, to quantify mandibular flexure and its impact on implant-supported prostheses. Similar to present findings, Caggiano M et al., highlighted the multifactorial etiology of mandibular flexure, with greater deformation observed during protrusive movements and in the posterior regions of the mandible. Both studies acknowledged the significant role of individual anatomical variations, such as facial morphology and bone structure, in influencing mandibular flexure [41].

However, Law C et al., focused more on the effects of mandibular flexure on the implant-framework system and highlighted the importance of dividing prostheses into multiple segments to minimize its effect [39]. This strategy aligns with the segmented framework designs discussed in the present review. In contrast, Law C et al., did not present quantitative measurements of mandibular deformation; thus, their analysis lacked some degree of precision [39]. Mijiritsky E et al., did not aim for direct measurements but stressed the importance of reducing mouth opening and protrusive movements during rehabilitation as much as possible to minimise the effects of mandibular flexure, which aligns with the present conclusion about the relevance of jaw movement control [40].

The present analysis points out that titanium is the most stable material against biomechanical loads, exhibiting reduced stress and deformation compared to polymeric materials like PEEK and PMMA. This agrees with Mijiritsky E et al., who advised the use of stiff materials with low elastic moduli for implant-supported restorations [40]. The two studies concurred on segmenting frameworks into two or three parts to minimize the effects of mandibular flexure. Law C et al., also proposed the division of prostheses, especially at the symphysis region, to reduce the transmission of stress, which is consistent with the present study [39].

In contrast, Caggiano M et al., used more patient-specific variables, such as the gonial angle and jaw length [41]. These aspects have not been taken into consideration within the present work; however, they present an opportunity to complement the understanding of how mandibular anatomy can affect prosthetic stability. Additionally, Mijiritsky E et al., highlighted the potential impact of non rigid connectors on decreasing stress on the prostheses, a fact that was not deeply investigated in the present analysis [40].

Both the present review and the studies by Law C et al., and Mijiritsky E et al., emphasized the use of segmented frameworks to reduce peri-implant stress [39,40]. the present findings demonstrated that unsplinted frameworks could reduce stress by up to 20%, while Law C et al., focused on the unclear effects of mandibular flexure on long-span implant-supported prostheses [39]. Mijiritsky E et al., provided more practical recommendations, including reducing the number of abutments and using non rigid connectors [40]. This somewhat aligns with the present focus on optimising framework design.

The quantitative approaches were utilised including computer-aided stress analyses using ANSYS and Mimics software, which provided very detailed representations of the biomechanical behavior. In contrast, the works of Law C et al., and Mijiritsky E et al., relied mainly on clinical experiences or general guidance to address clinical outcomes [39,40].

The present review highlighted clinical concerns related to mandibular flexure, such as peri-implant bone loss and dimensional changes associated with prosthetic instability. Reducing stress through the use of segmented frameworks, along with optimal implant placement in the lower jaw, aligns with the recommendations of Mijiritsky E et al., who suggested splitting structures in the lower jaw to avoid flexure effects [40]. Law C et al., also recommended dividing prostheses; however, the authors did not report clinical data regarding outcomes [39]. Caggiano M et al., discussed the association of mandibular flexure with greater jaw length, brachyfacial type, and smaller gonial angles, which is in line with the present findings about the influence of facial morphology on the magnitude of flexure [41]. However, while the present study provided quantitative data on stress and deformation, Caggiano M et al., focused on identifying risk factors and suggested further prospective studies to evaluate the long-term consequences of mandibular flexure, a recommendation consistent with the call for more comprehensive clinical research [41].

The variability in study methodologies, including differences in loading conditions, framework designs, and material properties assessed, limited the findings of this review. Most studies utilised computational models with limited clinical validation, thus restricting the generalisability of the results to in-vivo conditions. Moreover, sample sizes and patient demographics varied, making it challenging to systematically compare outcomes across studies. The lack of standardised outcome measures also impeded the synthesis of quantitative data.

Future studies should be conducted with standardized methodologies to enhance comparability across research. Clinical studies with larger sample sizes are highly necessary to validate the biomechanical insights derived from computational models. In implant-supported prostheses, segmented frameworks and rigid materials such as titanium or cobalt-chromium should be considered to optimize stress distribution, thereby reducing peri-implant bone loss. In this respect, placement strategies should aim to reduce distal stress concentrations, with further investigation into dynamic loading cases to define actual clinical recommendations. Additionally, integration of more advanced and high-tech methodologies like CBCT and FEA can enable precise and detailed evaluation procedures in the formulation of improved treatments.

CONCLUSION(S)

The findings highlighted the role of strategic framework design and material selection in mitigating the biomechanical effects of mandibular flexure. Non-segmented frameworks provided optimal stress distribution in some scenarios, while segmented frameworks offered advantages in reducing peri-implant stress in others. Brachyfacial individuals experienced the highest stress levels, necessitating tailored biomechanical solutions for such cases. Overall, the studies emphasised the necessity of individualised approaches based on framework design, material properties, and patient-specific anatomical factors to improve implant stability and reduce prosthetic complications.

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