Mandibular Flexion on Implant-Supported Full-Arch Rehabilitations

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Mandibular flexion (MF) is a complex biomechanical phenomenon, which involves a deformation of the mandible, due mainly to the contraction of the masticatory muscles, and it can have numerous clinical effects. The deformation of the lower jaw caused by mandibular flexion is generally very small, and it is often overlooked and considered irrelevant from a clinical point of view by many authors; however, it should be important to remember that median mandibular flexure (MMF) has a multifactorial aetiology.

mandibular flexure | mandibular deformation | fixed oral rehabilitation | allonfour | AO4 | full-arch | implant dentistry | full-arch rehabilitation

1. Introduction

All long bones in the body exhibit a complex biomechanical behaviour known as elastic-deformation under functional load, and the human mandible is no exception [1]. This is mainly related to two different factors: the intricate structure of the bone, which is an elastic, anisotropic, and non-homogeneous tissue, and its anatomical horseshoe form, which is in close contact with the ligaments and muscles of the head and neck, particularly the masticatory ones [1][2][3][4][5]. The contraction of these structures results in pressure and tractional forces on the mandible, changing its shape. Median mandibular flexure (MMF) is the name for this multifactorial condition, which was first identified around 60 years ago. It more frequently happens when the mouth protrudes or opens, and less frequently when the mouth moves laterally [6][7][8]. Further studies have revealed that it also happens during clenching and bruxism, highlighting that mandibular flexion also occurs with muscular activity alone and not necessarily with jaw movements or when the occlusal load is placed on the jaw itself [9][10][11][12].

The bilateral contraction of the lateral or external pterygoid muscles (LPMs) is the primary source of this phenomenon: when the lower heads contract, they pull the condyles and condylar necks medially, forward and down, producing a buccolingual rotation of the mandibular arch [11]. However, measuring the force generated by the contraction of LPMs to ascertain this is quite difficult due to their size and position [13]. In addition to the lateral pterygoid muscles, the mylohyoid, platysma, superior pharyngeal constrictor, and other jaw depressor muscles provide supplemental aid for its generation [11].

In the frontal plane, the distance between the right and left mandibular ramus narrows due to elastic flexion of the mandible, leading to a reduction in the width of the mandibular arch [6][7][8]. For increasing degrees of jaw opening,

mandibular arch static amplitude analyses showed a gradual decrease in its medial–lateral diameter [10][14][15]. Furthermore, dynamic investigations have demonstrated an increase during mandibular retraction and a decrease during protrusion movements, owing to muscular contraction without tooth contact [1][9][11].

Hylander et al. recognised four mandibular deformation patterns during mandibular flexion: symphysis flexion, dorso-ventral shear, corporal rotation, and antero-posterior shear [7]. From his research, it appeared that any of the postulated mandibular deformation patterns can provide compressive, tensile, or shear pressures, and that the highest symphyseal tension, which causes bending, was produced by the contraction of the medial component of the LPMs.

In addition to causing an alteration in the shape of the jaw with a reduction in the width of the arch from a few microns to 1 mm, with an average of 0.073 mm, MMF also affects the relative position of the teeth on the mandibular arch, producing lingual tipping [10][11][14][16][17]. The periodontal ligament reduces bone loss around teeth due to mandibular flexion in natural dentition by allowing the physiological movement of teeth [18][19]. According to Frost's mechanostatic theory, stress/strain levels are maintained within the bone's physiological adaptation window by avoiding an excessive rise in stress [20][21]. In the case of edentulous jaws restored with implant-supported full-arch prostheses, a rigid structure is created that connects the various implants, forming a single functional unit [22]. By doing this, not only is there no longer the protective effect of the periodontal ligament, but it facilitates the creation of flexural forces that modify and/or increase bone stress around the implants, resulting in resorption [8][23][24]. Mandibular flexion was found to be the main factor contributing to posterior implant failure in mandibular full-arch fixed prostheses with solidarised implants by Miyamoto et al. [25]. In fixed implant restorations, the biomechanical effect of the mandible's functional flexibility might result in crestal bone loss surrounding the implant head. Moreover, several clinical and experimental studies have demonstrated that mandibular bending can negatively impact the proper fit of fixed and removable prostheses; lead to denture decementation; and cause fracture of porcelain, screws, or implants [6][17][26][27][28]. Once more, the accuracy of the impression can be impacted by the lingual tipping of the teeth that happens when the mouth is opened for impression taking, creating a series of flaws that could result in treatment failure [15].

As the deformation of the lower jaw caused by mandibular flexion is generally very small, it is often overlooked and considered irrelevant from a clinical point of view by many authors, especially taking into account the large size of the mandible in relation to the lateral pterygoid muscle [27]. However, it should be important to remember that MMF has a multifactorial aetiology and that there are many variables that can affect it and cause increasing deformity up to non-negligible levels. These parameters include facial type; mandibular structure; and symphysis characteristics of bone density, length, and surface area [29][30][31][32][33][34].

2. Mandibular Flexion on Implant-Supported Full-Arch Rehabilitations

2.1. Measurement of Mandibular Flexion

Due to the wide variability in jaw size and bone density between individuals, the assessment of mandibular biomechanical characteristics is challenging. In addition, the contraction of the masticatory muscles can generate a wide range of mandibular movements and forces that play a key role in the genesis of MMF. It is extremely difficult to measure the force that the superficial muscles of mastication, such as the masseters, exert on the mandible, and even more so regarding the deep muscles, such as the lateral pterygoid muscles, due to their position and size.

The range of mandibular flexure measurements is a few micrometres to around 1 mm, with an average value of 0.073 mm [11][12][14][16][17][35][36][37][38][39][40].

Such a large range can be justified by several factors affecting the measurements:

- Individual factors: facial type, mandibular structure, gonial angle, and symphysis characteristics (density, length, and bone surface). Some authors have also proposed age, gender, maximum occlusal force (MOF), height, weight, BMI, muscle pain, bruxism, and tooth wear as parameters that may influence mandibular flexion values.
- Measurement techniques: in vivo or in vitro.
- Type of movement performed during measurement: protrusion, mouth opening, laterality, and retrusion.
- Area of the mandible where the measurement is performed: incisor-canine, premolar, and molar area.
- Clinical condition of the mandible: jaw with teeth or edentulous.

2.1.1. Individual Factors

There are three different patterns of facial types:

- Brachifacial is characterised by a reduced angle of the mandibular plane, reduced vertical facial height, and a horizontal growth pattern, with maximum muscle anchorage. Brachifacial patients present a short and wide face, a square jaw and strong muscle chains.
- Mesofacial is characterised by a medium mandibular plane angle, medium vertical facial height, and a mixed growth pattern, with medium muscle anchorage. Mesofacial patients are referred to as “neutral subjects” because no skeletal or muscular features prevail in them, showing a harmonious balance of the vertical and horizontal components of the face.
- Dolichofacial is characterised by a high mandibular plane angle, high vertical facial height, and a vertical growth pattern, with minimal muscle anchorage. Dolichofacial patients have a long, narrow face with a convex profile [41].

From an epidemiological point of view, 70% of the population is mesofacial, while the remaining 30% is divided more or less evenly between brachifacial and dolichofacial types [42]. Since the brachifacial patient has stronger

masticatory muscles, it has been hypothesised that they have a higher MMF, followed by the mesofacial and dolichofacial types. This hypothesis has been supported by numerous studies relating facial type to mandibular flexion, all of which were initially conducted on natural dentition [23][26][29][30][34][43]. Nevertheless, Shinkai et al. ruled out a significant influence of facial type on MMF, arguing that, given the small size and not excessive strength of the lateral pterygoid muscle, muscular strength plays a secondary role with respect to the resistance of the bone structure to mandibular deformation [33]. The recent study by Gao, J. et al. evaluated for the first time the morphological-functional response to mandibular flexion of implant-supported prostheses in different facial types, showing that not only is mandibular deformation greater in brachial patients, but that different clinical arrangements are required than in meso and dolicho patients [44].

Mandibular flexion is directly correlated with the length of the mandibular structure: the longer the mandible, the greater the mandibular flexion. Furthermore, it has been shown that the gonial angle, which represents mandibular inclination, when reduced, statistically affects the increase in mandibular flexion, even if to a limited extent [12].

Parameters of considerable influence on MMF are the symphysis characteristics, such as height and length, surface area, and bone density. Several in vivo studies have shown that symphyses with increased length and height, large surface area, and high bone density are more resistant to mandibular deformation, reducing it [7][17][26][30].

On the other hand, older edentulous individuals are more inclined to experience higher mandibular deformation because they have less thick skeletons due to an increased risk of osteoporosis and smaller symphyses as a result of bone resorption after edentulousness [24][36][45][46][47].

2.1.2. Measurement Techniques

In vitro and in vivo intra- and extra-oral measuring techniques were utilised in the various investigations to analyse the degree of mandibular deformation.

Diagnostic models made from imprints obtained at various phases of the mandibular opening were frequently used to make in vivo extra-oral measurements, as were photos that monitored the movement of the mandibles [10][15][30][48].

On the other hand, strain gauges, calipers, and transducers connected to surfaces or implants were used to make in vivo intra-oral measurements [9][10][14][35][36][39][49].

2.1.3. Type of Movement Performed during Measurement

According to Omar and Wise, there is no change in the mandibular arch width up to a mouth opening of 28% [11]; however, after that point, the decrease is proportionate to the degree of mouth opening, with an average loss of 0.093 mm and a range of 0.012–0.164 mm. The results from the study are comparable to those obtained in the research of Goodkind and Heringlake, and Regli and Kelly, where the deformation ranged from 0.0316 mm to 0.0768 mm and 0.03 mm to 0.09 mm, respectively, depending on the degree of mouth opening [9][10].

Gates and Nicholls demonstrated that mandibular flexion was greater during protrusion movements than during mouth opening movements. In their work, the distortion values found during opening ranged from 0 to 0.3 mm, in line with the studies of Osborne et al., Bowman et al., and Goodkind and Heringlake, but lower than the ranges of 0.2–1.4 mm and 0.6–1.5 mm found by McDowell and Regli, and De Marco and Paine, respectively [6][9][14][50][51]. Conversely, strain values during protrusion range from 0.1 to 0.5 mm, in line with the results obtained by Osborne et al., but lower than the 0.2–1.2 and 0.2–1.5 mm ranges of Bowman et al. and of McDowell and Regli, respectively. Several other clinical and biomechanical studies highlighted the increased mandibular deformation and stress/strain during protrusion movements [52][53][54][55][56]. The lack of involvement of the anterior digastric muscles in mandibular flexion during mouth opening may be the cause of this. From a therapeutic perspective, parafunctions such as grinding or incisal–incisal margin contact can greatly be influenced by this, while for mastication, where protrusive motions are uncommon, it is less significant.

As demonstrated by Burch and Borchers, lateral movements can also cause mandibular arch decrease [36]. In the right lateral position, the average amplitude of the reduction was 0.243 mm, and in the left lateral position, it was 0.257 mm. Due to the activation of only one lateral pterygoid muscle rather than both, the mandibular flexion values in lateral motions are lower than protrusion motions (0.61 mm MMF) and than mouth opening (0.438 mm MMF). The same author then conducted research with a larger sample size (25 participants as opposed to 10 in the prior study), and the same results were validated [1].

2.1.4. Area of the Mandible Where the Measurement Is Performed

Asadzadeh et al.'s study was the first to examine the potential for various mandibular deformation levels across different mandibular regions [39]. Prior to this investigation, mandibular bending was usually measured at the level of the first or second molar in the posterior intermolar areas. On 35 female volunteers with teeth, Asadzadeh et al. measured MMF using digital calipers in the canines and second molars. In the molar area (0.1894 mm), the mandibular flexure measured greater values than in the canine region (0.1671 mm). This can be explained by the closer proximity of the posterior sectors to the LPM muscle insertions; as one moves toward the anterior sectors from them, mandibular flexion reduces more and more. The recent study by Gülsoy, Tuna, and Pekkan confirmed this hypothesis by taking measurements in seven different regions, starting from the anterior to the posterior region, in dentate and edentulous individuals [57].

2.1.5. Clinical Condition of the Mandible

Following tooth loss, which frequently is brought on by aging, alveolar bone resorbs, and the mineral content and density of cortical and trabecular bone decrease [58]. Mandibular flexion is typically enhanced in low-bone-density patients. However, due to a loss in collagen fibres with age, bone tissue's elasticity also declines [59]. Considering all of these factors, it follows that mandibular flexion is not significantly different in dentate and edentulous people, nor is it different with age. The study by Gülsoy, Tuna, and Pekkan found no statistically significant difference in the MMF values of the same mandibular areas in dentate and edentulous patients [57].

2.1.6. Potential Recoil of a Mandibular Flexion with a Release of Muscular Tension

A potential recoil of mandibular flexion, accompanied by a release of muscular tension, could lead to several significant effects on the jaw and surrounding structures. As the mandible returns to its original position following flexion, the sudden release of muscular tension may result in a quick and forceful movement. This recoil could potentially cause discomfort or even pain in the temporomandibular joint (TMJ) and surrounding muscles, particularly if the flexion was excessive or performed repetitively.

2.2. Clinical Effects of MMF

2.2.1. MMF and Impression Taking

During mouth opening movements, mandibular flexion results in a reduction of the mandibular arch and a lingual tipping of the teeth. All impression taking methods include a certain amount of mouth opening; hence, it is inevitable that the effects of MMF be taken into consideration while creating an impression. Generally, the imperfect fit of dentures was attributed to the variability of dental procedures, not considering the influence of MMF, which can alter the precision of the master model and compromise the prosthesis [9][15]. The prosthesis created from the impression taken with the mouth open wide may not fit the jaw precisely when it is at rest because it is built on a limited arch and has teeth that are not only more lingual but also rotated lingually. This may lead to pressure on the teeth and surrounding structures, pain, gingival inflammation, tooth mobility, and bone loss. The areas generally subject to most pain are located below the lower denture, at the level of the mylohyoid ridge, where the greatest stress occurs during mandibular flexion [35][60]. In implant-supported full-arch prostheses, it is even more important that impressions are accurate to allow a passive fit of the superstructure on rigidly connected implants [23][61]. Consequently, in order to minimise deformation when taking traditional impressions for the lower jaw, it has been suggested that impressions should be made with a minimum mouth opening, as close to the upper jaw as possible and ideally with no more than 20 mm, so as to involve minimal activation of the masticatory muscles [15].

2.2.2. MMF and Fixed-Teeth-Supported Rehabilitation

By allowing physiological movement of the dental elements, the periodontal ligament (PDL) absorbs most of the stress created by mandibular flexion, preventing bone loss around them [18][19]. However, in fixed-teeth-supported rehabilitations, the use of rigid connectors and long spans limits the movement of the dental components and, as a result, increases stress at the PDL level, which may outcome in bone resorption, as well as at the level of the prosthesis itself, which may end up in porcelain fractures. It is preferable to utilise flexible connections and divide the span into many portions to prevent such unfavourable effects, especially in the case of periodontal patients. Additionally, it is not advised to utilise porcelain for bigger restorations [10][15][62][63].

2.2.3. MMF and Implant-Supported Full-Arch Fixed Rehabilitations

By changing the distribution of stresses at the bone/implant interface and at the level of the prosthetic structure itself, mandibular flexure has the potential to affect the accuracy of several phases of implant rehabilitations,

including osseointegration and the creation of implant-supported prostheses. This can result in peri-implant bone resorption, material fracture, and pain during function.

The main goal of implant-supported fixed restorations is to determine an adequate biomechanical distribution both at the level of the prosthetic superstructure and at the level of the implant [55].

To achieve this, it is necessary to make assessments on three different parameters:

- Type of prosthesis: single or segmented structure.
- Material of the superstructure.
- Number and position of implants.

Type of Prosthesis: Single or Segmented Structure

The results that have emerged from the literature are somewhat contradictory regarding the necessity or not of splitting the superstructure, separating doctors into two separate schools of thinking. For some authors, division of the superstructure at the level of the symphysis is recommended to reduce the increased stresses occurring at that level [64][65][66]. This indication was also supported by Fischman and McCartney, who highlighted how a single, continuous, and rigid structure can subject both the implant/bone interface and the prosthetic structure to dangerous concentrations of stress, increasing the rate of screw loosening and fracture [15][67].

Material of the Superstructure

The material of the superstructure could also influence mandibular bending. Suedam et al. found that materials with a lower modulus of elasticity, and thus that are more flexible, reduce stress to a greater extent, while stiffer materials are more resistant to bending forces [68].

Favot described that the zirconia framework has the highest stresses compared with the NiTi. The highest stresses in the framework were obtained during maximum intercuspation. The highest stresses at the bone–implant interface were recorded on the working axial implant during unilateral molar clench and on tilted implants during maximum intercuspation. The influence of the framework's material stiffness on the stresses at the bone–implant interface was insignificant for axial implants (except the right implant during unilateral molar clench) and slightly more significant for tilted implants.

Number and Position of Implants

Over the years, several protocols have been proposed for implant-supported fixed rehabilitation of mandibular totally edentulous patients. Brånemark's initial technique for the rehabilitation of totally edentulous patients involved the use of five implants for the mandible and six for the maxilla arranged in parallel and distributed in the inter-

foraminal region for anatomical and surgical reasons, such as the location of the alveolar nerve and the quantity and quality of bone [69][70][71][72][73].

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