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Mandibular Flexure and Its Significance on Implant Fixed Prostheses: A Review

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Abstract

Purpose: The aims of this review are to determine the effect of mandibular flexure on the "implant-framework system," and analyze the existing literature on the topic.
Materials and Methods: A MEDLINE and PubMed search was conducted to identify any articles in English related to the topic published up to May 2010 using the search words "mandible," "dental implants," "dental impression technique," "jaw movement," "dental stress analysis," and "mechanical stress."
Results: The search identified 40 and 36 articles from MEDLINE and PubMed, respectively. Twenty articles met the inclusion criteria.
Conclusions: Mandibular flexure is a multifactorial phenomenon, and the effect of the implant-framework system in this is unclear. Studies have focused mainly on the fully edentulous mandible. These have found that mandibular flexure should be taken into consideration when designing a prosthesis and have suggested that dividing the prosthesis at the symphysis region, or into multiple implant fixed dental prostheses, may minimize the effect of mandibular flexure on the implant prosthesis. At this time, no studies have investigated the effect of mandibular flexure on long-span, unilateral, implant fixed prostheses. The clinical significance of mandibular flexure on the success of dental implant treatment is at this time unclear, and further research is needed.

Dental implants are gaining popularity as a preferred treatment option to restore edentulous areas. The effect dental implants and implant prostheses have on quality of life has been measured in various studies. A randomized clinical trial conducted by Awad et al[1] concluded that those who received dental implants perceived greater improvement in their oral health than those who received conventional prosthodontic treatment. A meta-analysis of randomized control trials concluded that although implant prostheses provide patients with more satisfaction than conventional treatment, the magnitude of improvement is uncertain.[2] With regard to stress distribution, osseointegrated implants behave differently than natural teeth, due to the absence of the periodontal ligament, and therefore, strain introduced to an implant is transmitted directly to the body of the mandible.[3-6]

The human mandible, like all long bones in the body, deforms when loaded. Mandibular flexure is defined as "the change in shape of the mandible caused by the pterygoid muscles contracting during opening and protrusion movements."[7] The amount of deformation can be measured by strain, defined as the change in length per unit of length. Hylander[8] hypothesized four patterns of jaw deformation in the primate mandible:

1. Symphyseal bending associated with medial convergence, or corporal approximation: this type of strain is associated with contraction of the laterial pterygoid muscle during jaw opening movements.[9]
2. Dorsoventral shear: this produces a shearing force in the sagittal plane and is a result of the vertical components of muscle forces from the lateral pterygoid muscles and the reaction forces at the condyles. The magnitude of the shear force is dependent on the points of application. During symmetrical loading, the amount of shear force is equal on both sides of the mandible; however, during unilateral loading, the amount of deformation differs between the working and balancing sides.[9]
3. Corporal rotation: this occurs during rotation of the body of the mandible, usually during the lower stroke of mastication. The resultant force causes narrowing of the dental arch.[9]
4. Anteroposterior shear: this occurs as a result of contraction of the lateral components of the jaw-elevating muscles. It occurs late in the power stroke, and the bending moment increases from the posterior to the anterior region.[9]

Data analysis of the mechanical properties of the human mandible is difficult because there is a large variation in mandibular size and bone density in the population. To study the amount of mandibular deformation, in vivo intraoral and extraoral measurements have been used. The extraoral measurements were usually made on diagnostic casts made from impressions taken at different stages of mandibular opening, or by using a series of photographs to trace the movement of the mandible.[10,11] Intraoral measurements have been taken using a transducer and strain gauges.[12-17] In vitro studies on the distribution of strain within the body of the mandible were first undertaken using the photoelastic technique[18-20] and later finite element analysis (FEA) models.[21,22]

Activation of the muscles of mastication can generate a wide range of movement of the mandible. The force exerted by these muscles on the body of the mandible is suggested to play a significant role in mandibular flexure. The effect of the lateral pterygoid muscle on mandibular deformation is controversial. Some authors believe that the location of insertion and action of the inferior head of the lateral pterygoid muscle contributes most to mandibular deformation during opening.[10,11,23] However, some authors have argued that the size of the lateral pterygoid muscle is relatively small compared with that of the mandible; therefore, the force it exerts on the mandible can be considered insignificant.[24] Measuring the force exerted by the superficial muscles of mastication, such as the masseter muscle, on the mandible has been a difficult and complicated task, and measuring the force generated by the lateral pterygoid muscle when it contracts is even more complex due to its location and size.[25]

Intraoral impressions are necessary for rehabilitation procedures, including rehabilitation with implant prostheses. All impression techniques trigger a certain degree of muscle activity that distorts the mandible. Different stages of implant treatment, including the impression technique used, as well as the number of implants placed and the material used for the fabrication of the implant prosthesis, can affect its fit and long-term prognosis.[11,22,26-28] The significance of mandibular flexure in implant dentistry, however, is not clear without a standardized method of measurement for comparison.

Implant prostheses can be divided into screw- and cement-retained. Preloading of the abutment screw is crucial, especially for screw-retained prostheses on external-hexed implants.[29,30] Excessive occlusal loading is believed to be one of the main contributing factors to implant treatment failure as a result of unfavorable leverage and torque on the implant.[31-36] Post-solder joint fracture, veneering material fracture, screw loosening, and pain are other common complications of implant treatment.[37] Whether mandibular flexure contributes to these implant-framework and implant superstructure system complications is unclear.

It is the purpose of this review to investigate the effect of mandibular flexure on the "implant-framework system" and to analyze the existing literature on the topic.

Materials and methods

An electronic search on MEDLINE and PubMed, from 1950 to May 2010, was conducted using the keywords "mandible," "dental implants," "dental impression technique," "jaw movement," "dental stress analysis," and "mechanical stress." Abstracts of articles were examined to determine if they met the following criteria:

1. In vivo or in vitro studies.
2. Related to the topic.
3. English language.

Results

The MEDLINE and PubMed search from 1950 to March 2010 identified 40 and 36 articles, respectively. From these, 22 articles were identified. Of the 22 articles identified, 2 clinical reports were excluded from this review due to their low level of evidence. There were no randomized control trials, nonrandomized control clinical trials, or case-control studies.

The majority of the studies were conducted on individuals with fully edentulous mandibular arches. Of the studies found, bone density, size of the mandible, and symphyseal height were suggested as contributing factors to the amount of mandibular deformation.[10,38-40] The difference between dentate and edentulous mandibles, and between the two sexes could be a compounding variable in mandibular flexure.

Most of the studies focused on measuring the amount of strain that developed in the body of the mandible during different jaw movements. Horiuchi et al[24] used hydroxyapatite-coated implants as reference points to study mandibular deformation; however, this study was potentially flawed because hydroxyapatite-coated implants have a high osseointegration failure rate when in close proximity to natural teeth, possibly affecting the accuracy of the results. Jiang and Ai[41] measured the amount of mandiblular flexure during various clenching movements using a charged-coupled device (CCD). Three points on the mandible were located and photographed during clenching, and it was found that the mandible deformed under unilateral molar clenching.[41] Hylander[8] described three types of mandibular deformation, namely medial convergence, corporal rotation, and dorsoventral shear. These deformations were measured with strain gauges and transducers.[42-45] Anterioposterior shear has been measured using electromyographic activity (EMG).[46,47] It was concluded that the mandible deforms concurrently and immediately following any jaw movement.[42-44]

These studies established that mandibular deformation exists and provided quantitative measurements. Other authors have attempted to transfer this finding to implant dentistry by studying the stress that develops within the "implant-framework system" under occlusal loading.[48-50] An in vitro study by Hobkirk and Havthoulas[51] investigated unilateral loading on implant prostheses and noted extrusion forces on the distal implant. They concluded that mandibular flexure was a significant factor to be considered when designing an implant prosthesis.[51] Restoration of mandibular posterior edentulous areas often involves implant placement in the premolar region due to the limited amount of bone in the molar region that restricts implant placement. Furthermore, in these situations the molars are often cantilevered pontics off an implant placed in the premolar area. Occlusal force placed on these implants will be transferred directly to the surrounding mandibular bone generating shear forces in the distal mandible.[52]

The in vitro study by Hobkirk and Havthoulas[51] examined stress distribution within the implant framework system when using a bench-support and a suspended-support mandible model, and noted higher extrusion forces in the suspended-support model where implants were splinted together. They also found that fewer implants resulted in a more localized stress distribution. Finite element models have been used to analyze the difference in stress distribution between cross-arch prostheses and sectioned unilateral prostheses.[28] It has been suggested that cross-arch prostheses significantly restrict the flexure of the mandible, and sectioning the implant prosthesis will allow the pattern of mandible flexure to be restored to close to its natural state.[28] Nokar and Naini[48] compared the difference in stress distribution within the mandible using a splinted one-piece prosthesis, a two-piece prosthesis that was sectioned along the midline, and a three-piece prosthesis sectioned distal to the canine region. Their results showed that each design performed better under different loading conditions. During unilateral molar clenching, the three-piece sectioned prosthesis was found to distribute stress more evenly, whereas the two-piece sectioned prosthesis generated a more favorable stress distribution during incisal clenching.[48] Their results differ from that of Yokoyama et al,[49] who suggested that a one-piece rigid connection was better at transferring stress within the structure, and therefore generated less stress in the mandible; however, they did not take into consideration mandibular flexure when they formulated their FEA model, and this would have affected the anisotropic/isotropic behavior of the mandible bone used in their FEA model assumption. Indeed, earlier studies often refer to the mandible as one uniform structure, which behaves isotropically under loading that could affect the behavior of the FEA model, and therefore the results, significantly.[50]

Discussion

The high survival rate of implant prostheses in partially edentulous patients has been reported in a retrospective multicenter study[53] and in a meta-analysis.[54] A systematic review by Cordaro et al[55] for the Fourth ITI Consensus Conference in 2008 concluded that conventional loading of fixed implant prostheses in the partially edentulous mandible, that is, loading of implants after 6 to 8 weeks of healing, can be regarded as a routine procedure, due to the high success rate of this loading method. Implant location and number of teeth restored were often not clearly stated in these studies, making the conclusion nonspecific. The influence of mandibular deformation on the success rate of dental implant treatment, especially in the partially dentate mandible, is unclear and requires further study. Mandibular flexure can, however, potentially affect the accuracy of different stages of implant treatment, including implant prosthesis fabrication, that can continue to affect strain distribution within the framework and surrounding bone during mastication.

Implant prostheses fabrication

Impression

Various studies have shown changes in the mandibular arch during various jaw movements.[15-17] All impression techniques involve a certain amount of mouth opening. Contraction of the muscles of mastication in the conventional open-mouth impression technique may induce medial convergence of the mandible, hence compromising the accuracy of the resulting master cast.[11,16] Impressions made using the closed-mouth technique, with minimal activation of the muscles of mastication, could reduce the amount of mandibular flexure. The extent of reduction is uncertain because there is very limited literature comparing the open and closed mouth impression techniques in implant dentistry.

Framework production assessment

Prostheses can be fabricated by the sectioning and soldering technique, or the passive-fit technique.[56] Stress analysis studies have shown that frameworks constructed using the passive-fit method induce significantly smaller amounts of strain in the implant prosthesis compared with the conventional technique.[56] Most of the studies reviewed, particularly the case studies, did not test for initial passive fit of the frameworks. Because of this, the reported decrease in strain may have occurred from sectioning the framework to smaller pieces, thereby improving passive fit of the framework rather than the result of a change in design of the framework to allow for mandibular movement. Clinical methods to evaluate the passivity of implant prostheses have been studied, but none have yet provided useful quantitative measurements.[57] The computer-aided design/computer-aided manufacturing (CAD/CAM) technique has been used to fabricate implant frameworks. It bypasses the casting technique used in the routine framework fabrication procedure, and this technique has been reported to produce frameworks with improved passive fit compared with the casting technique.[58] The accuracy of the master cast has not been taken into consideration in any of the published in vitro stress analysis studies or during clinical evaluation. Should mandibular deformation play a significant role, evaluation of the fit of implant prostheses could be very complicated, as the accuracy of the master cast, a crucial factor to establish passively fitting prostheses, was not taken into account in these studies. The shape of the implant prosthesis has been studied by Korioth and Johann[59] who found that a rectangular-shaped beam with a smaller width generated less stress than other designs such as an I- or L-shaped bar. It has also been suggested that by increasing the number of implants, the bending movement of the implant prosthesis during unilateral clenching can be reduced.[60] Implant configuration can also affect the distribution of stress within a prosthesis. Itoh et al[61] investigated the difference between a straight and an offset configuration using a photoelastic model. They found a change in stress distribution using the offset configuration, but overall there were no distinct advantages. This staggered arrangement reduced the stress on the anterior and posterior implants compared with the straight arrangement; however, the middle implant was subjected to more stress.[61]

Effect of prosthesis material on mandibular movement

Development of zirconia as a biomaterial was started by Helmer and Driskell in the late 1960s.[62] It was described as "ceramic steel" due to its excellent mechanical properties.[63] The use of zirconia in implant prosthesis fabrication has become more popular recently due to its esthetic appearance and mechanical properties. The Young's moduli of elasticity of tetragonal zirconia polycrystals and commercially pure grade IV titanium, used to manufacture implants or implant superstructures, are about 210 and 100 GPa, respectively.[9,64,65] This is five to ten times higher than the Young's modulus of elasticity of cortical bone, which is about 10 to 20 GPa. Skalak[66] stated that the rigidity of the material used for the construction of a prosthesis, or for the splinting of fixtures, was not significant, especially if each fixture was able to carry the full load applied to it. The mechanical properties of the framework material were, however, not considered. Suedam et al[67] compared the use of precious and nonprecious metal alloys for the fabrication of implant frameworks. They found that material of a lower modulus of elasticity, such as palladium–gold alloy, was better at reducing stress while materials with a high modulus of elasticity (cobalt–chromium) were more resistant to bending forces, but generated more intense stress at the terminal abutment.[67] It is believed that stability of implants can be improved by splinting the implants, or by using materials with a high modulus of elasticity as frameworks. It has been shown that splinting natural teeth reduces the amount of mandibular flexure, and the degree of inhibition is proportional to the number of teeth splinted and the rigidity of the splinting material.[68] Natural teeth are surrounded by periodontal ligament, which absorbs some of the displacement transferred to the mandible and reduces the amount of mandibular flexure; however, osseointegrated implants transfer all the stress to the mandible and more bending of the mandible could be expected. When implants are splinted, the restriction in the amount of mandibular flexure can be assumed to be at least equal to, if not more than, that which occurs when the natural dentition is splinted. Because rigid splinting is often required in implant dentistry to better distribute the stress on each fixture, this results in a restriction in the amount of mandibular flexure that can occur during function.[28,66,69] The extent is not known, and further research evaluating how the mandibular flexure can potentially affect the accuracy of the implant fixed prosthesis is needed.

Conclusions

The mandible deforms instantaneously and concurrently with jaw movement.[42,43] Four patterns of mandible deformation have been proposed. They are as follows:[8]

1. symphyseal bending associated with medial convergence or corporal approximation;
2. dorsoventral shear;
3. corporal rotation;
4. anteroposterior shear.

Mandibular flexure is a multifactorial phenomenon, and bone quality and quantity, implant number and location, impression technique, and prosthesis design are contributing factors. Available studies have focused mainly on the fully edentulous mandible. Although the significance of mandibular flexure on the success of implant treatment is unclear at this stage, studies suggest that mandibular flexure should be taken into consideration when designing a prosthesis.[28,44,48] The use of a sectional prosthesis design, such as multiple implant fixed dental prostheses or a prosthesis divided along the symphysis region, can be considered to minimize the effect of mandibular flexure.[48] At this time, no studies have investigated the effect of mandibular flexure on long-span unilateral implant fixed prostheses.

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