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ANALYSIS OF THE DISTRIBUTION OF OCCLUSAL VERTICAL STRESS IN CANTILEVER DENTAL BRIDGES - METHOD OF FINITE ELEMENTS: A LITERATURE REVIEW

АНАЛИЗА НА ДИСТРИБУЦИЈАТА НА ОКЛУЗАЛНИТЕ ВЕРТИКАЛНИ СИЛИ КАЈ ДИСТАЛНО ПРОДОЛЖЕНИ МОСТОВНИ КОНСТРУКЦИИ–МЕТОД НА КОНЕЧНИ ЕЛЕМЕНТИ: РЕВИЈАЛЕН ТРУД

Vujasin S.[1], Bundevska J.[2], Kokalanov V.[3], Vankoski V.[4], Dejanoska T.[5]

[1]Faculty of Dentistry, Department of Prosthodontics, EURM, Skopje, RM, [2]Faculty of Dentistry, Department of Prosthodontics, UKIM, Skopje, RM, [3]Faculty of Computer Science, Numerical Analysis and Applied Mathematics, UGD, Štip, RM, [4]Faculty of Dentistry, Department of Prosthodontics, EURM, Skopje, RM, [5]PZU DENTAL INTERNATIONAL, Skopje

Abstract

Cantilever dental bridges are prosthetic appliances which have abutments and distally positioned pontic. In cantileversdental bridges, occlusal forces which transfer via the distal cantilever cause changes in the dentures and teeth in terms of rotation and bending, depending on the direction and of the stress and the amount of the load. Distribution of occlusal load is an important factor for the treatment's effectiveness and its prophylactic influence on the remaining teeth. In line with this, the present paper will look at various authors who have researched the area of occlusal stress and its distribution in cantilever dental bridges. **Keywords:** Cantilever, Finite element method, Fixed partial denture, Occlusal forces, Prosthetic restoration, Shortened dental arch.

Апстракт

Дистално продолжените мостовни конструкции се протетички изработки кои имаат носачизабии висечки членови кои се поставени дистално од носачите . Кај дистално продолжените мостовни конструкции, оклузалнате сили кои се пренесуваат преку продолжените членови предизвикуваат придвижувања на конструкцијата и забитево смисол на ротација и инклинација зависно од правецот на дејствување и јачината на силата на оптоварување. Дистрибуцијата на оклузалните сили врз забите носачи е значаен фактор за ефектот од третманот и неговото профилактичко делување врз преостанатите заби. Од тој аспект во трудот ќе биде направен преглед од автори кои се бавеле во подрачјето на оклузалните сили и нивна дистрибуцијата кај дистално продолжените мостовни конструкции. **Клучни зборови:** Дисталенчлен, метод на конечни елементи, дентален мост, оклузални сили, протетичка реставрација, скратен дентален низ.

Introduction

Partial tooth loss leads to morphological, functional, and aesthetic disturbance in the functions of the masticatory system. Therapeutic means to compensate for partial tooth loss are mobile appliances, bridges, or a combination of the two. A dental bridge is a fixed prosthetic appliance used for masticatory, phonetic, aesthetic and prophylactic therapy and restoration of the masticatory system.

Planning of dental bridge appliance includes two basic elements: biological and mechanical. The biological aspect refers to the mechanism of transfer of masticatory force that is exclusively dental, regardless of whether the bridges are fixed or mobile. The mechanical aspect refers to the way bridges are connected and fixed to the abutment teeth. The pontics or the body of the bridge may be inserted between the abutment teeth (traditional bridge) or extended distally or mesially (cantilever bridge). Cantilever bridges are defined as fixed restorations that have one or more abutments on one end, while the other end is left unsupported.

The pontics in a cantilever dental bridge may be positioned either mesially of the abutment tooth or distally of the abutment tooth. Distally cantilever dental bridges are indicated for patients with a shortened dental arch.

Aim

The purpose of this paper is to analyse the findings on the distribution of occlusal forces in distally cantilever bridges.

Material and method

The material consists of 315 papers that examine distally cantilever dental bridges. The paper looks at 38 papers where the abutments are natural teeth. The papers were acquired by means of international journals and PubMed and EBSCO database research done from January, 2005 to January, 2016. Research was done using keywords according to the Mesh index.

Discussion

The traditional goal of dental treatments is maintaining dental arches with presence of 28 teeth. According to data gathered from the first phase of the NHANES III research (Third National Health and Nutrition Examination Survey), completed in the USA from 1988-1991, the average number of teeth per capita was 23,5, while the goal set by the WHO is preserving at least 20 teeth until the age of 80.[4]

Distal cantilever dental bridges require more attention compared to conventional ones. However, if the biological and mechanical aspects of the cantilever dental bridge are well balanced, it is very likely that it is going to be successful.[5]

One of the elements that speak of the success rate of this treatment is the life span of these bridge appliances. According to Sailer, the duration of dental bridge prostheses is defined as the time frame of the experiment during which a maximum of two interventions have been made.[6]

The classifications of bilateral and unilateral partial tooth loss do not define the number of lost teeth. This is why Witter and his associates made additional classification of the distal tooth loss by distinguishing four categories of shortened dental arches: 1. Slightly shortened dental arches; 2. Moderately shortened dental arches; 3. Extremely shortened dental arches; and 4. asymmetrical extremely shortened dental arches. According to them, decision-making on extending a shortened dental arch should be based on the principle of: examination of the masticatory system function, treatments value for the patient, oral function and the patient's perceived impact on oral health-related quality of life, as well as on the type of shortened tooth arch. Witter and his associates believe that slightly shortened dental arches should not be extended, while extending moderately shortened dental arches is indicated in exceptional cases, especially for aesthetic reasons. In the case of extremely shortened dental arches and asymmetrical shortened dental arches, they believe that there are sufficient reasons for extension.[7,8]

Anneloes and associates made a clinical trial on patients with shortened tooth arches with 3-4 lateral teeth missing. The patients were monitored for 27,4 (± 7,1) years, and it was found that in 20 out of 23 participants the condition remained unchanged.[9]

The concept of shortened dental arches implies that shortened dental arches with at least 4 occluding pairs, preferably in symmetrical positions, are sufficiently capable to maintain satisfactory oral function.[10]

Wolfart analysed the quality of oral health via the HRQoL index in two separate groups of participants. The first group had shortened dental arches with lost molars and dental bridges that did not replace the lost molars, while the second group had shortened tooth arches and a mobile prosthesis which replaced the lost molars. The values generated with the HRQoL index did not show any significant differences between the groups. This led him to the conclusion that there is no need to replace missing molars.[11]

According to Fueki, the concept of shortened dental arches is based on indirect evidence and it is not in contradiction with current occlusion theories. He claims that this concept is not suitable for patients aging up to 50, those with malocclusion Angle III, Kenedy class III, patients with verified parafunction and symptoms in TMJ and a significantly decreased periodontal support of remaining teeth.[5]

Aras and associates during the 1-year research examined: mastication, occlusal forces, and occlusal contact in patients with shortened dental arches Kennedy I class. The research covered three groups of 10 patients each. The first group included patients with shortened dental arch (natural teeth or bridge appliances), the second group was made up of patients with mobile partial prostheses, while the third group was a control group of patients with fully natural dentition. No significant difference was noticed between the groups with shortened dental arches with or without prostheses in the masticatory effect, however, in patients with shortened dental arches, a significantly lower instance of contact and weaker forces were noticed compared to patients with entirely natural dental arches (P <0,05).[12]

Witter monitored 74 patients with shortened dental arches and 72 with full dental arches. Following a 9-year research, Witter came to a conclusion that there was no difference between the two groups as far as the masticatory system was concerned.[13]

Two independent research studies on accepting the concept of shortened dental arches were carried out in Victoria, Australia and Great Britain. The findings were contradictory. In Victoria, Australia, 61% of the interviewees accepted the concept of a shortened dental arch, while in Great Britain, only 1.4% accepted it.[14, 15]

Prosthetic therapy is often necessary to restore the function and aesthetics in patients with advanced stage of periodontal changes. Remaining teeth are usually mobile and need to be immobilized and periodontally treated. According to the perio-prosthetic treatment first introduced in Sweden in 1970, circular fixed bridges can provide certain rigidity and a more favourable distribution of masticatory forces on all remaining teeth. This concept is in collision with Ante's rule, however, but authors justify their claim by pointing out that Ante's rule is more focused on the number of teeth. Furthermore, several multiyear research studies have shown that circular fixed bridges can be successfully supported by a minimal number of teeth if teeth are well positioned, the condition of the periodontium is under control and has kept 20-30% of the original periodontal supporting tissue.[16, 17]

Maximal force measurement of masticatory pressure is a useful indicator of the functional condition of the masticatory system. The values of this force vary depending on the measuring method, sex, and age. Still, it is of great use that the results can be compared to corresponding referential values. The masticatory force is a result of a combined action of the masticatory muscles, the biodynamics of the lower jaw and the reflex mechanisms.[18]

Bonakdarchian and associates found that the average maximal masticatory forces in adults with normal occlusion are significantly higher in male patients compared to female ones.[19]

Pain is an important factor for controlling the scale of masticatory force. Furthermore, this factor can also be used to treat some irregularities and painful conditions of the masticatory system.[18]

Johnsen and associates looked at the intensity of masticatory forces in each tooth separately in patients when under anesthetics and without. They noticed that the force is higher when teeth are anesthetized, i.e. when the periodontal sensitivity is off. Likewise, they noticed that the masticatory forces are higher distally.[20]

Fratila and associates used photoelastic analysis to look at the distribution of occlusal stress in a conventional bridge with two abutments and a pontic in between, while the other was a mesial cantilever with two units, an abutment, and a pontic. The loading was vertical on the occlusal surface. In a classical bridge, when the distal abutment was loaded, the highest strain was noticed around the connection of the distal abutment and the pontics, as well as on the distal abutment's periodontal tissue. A significantly smaller stress was distributed via the pontic to the mesial abutment. The same, only in the opposite direction, occurred when the mesial abutment was loaded. When the middle part of the pontic was loaded, an approximately symmetrical distribution of stress, however a much smaller stress was registered in the periodontal tissue of the mesial abutment. The authors explain this in relation to the number of roots, since the distal abutment has two roots, while the mesial only one. Almost identical findings on the distribution of stress in conventional bridges were reported by Motta and associates.[21, 22]

In mesial cantilever dental bridges with two units, when the abutment was loaded, most stress was distributed onto the root of the tooth. When loading was on the mesial extended unit, the greatest deforming stress occurred on the connection of the abutment and extended unit and on the apical mesial surface of the root and the mesial wall of the alveolar bone. The distal root recorded low values of distributed stress, with an occurrence of the 'pulling' phenomenon. Overall, there is strong and uneven loading of the abutment and the bone structures, and the restoration has a tendency to tilt mesially. Identical results were obtained by Eraslan and associates.[21,23]

Planning a bridge construction must provide an optimal secure static, stability to withstand masticatory stress and to preserve the integrity of supporting tissue. Crucial to this is familiarity with the features of biological and mechanical elements of a bridge.[24]

The stress forces generated in cantilever dental bridges are generally higher than in conventional dental bridges, due to the physical principles arising from the fact that the pontic is acting as a single lever.[25]

To minimize the risk of a single lever effect, Jeong recommends decreasing the occlusal surface of the extension and the occlusal contacts, as well as remove contact in lateral movements.[26]

According to Fratila, the stress loaded on partial dentures may cause: luxation, inclination, rotation and bending. This may be compensated by static and biodynamic balanced planning of construction. Cantilever dental bridges with one or more pontics have one point of reliance and therefore can be moved in all directions, so they cannot be in dynamic equilibrium. It is therefore necessary for each bridge construction with a distally canivelr to have at least two abutments.[21]

For cantilever dental bridge constructions, Milas recommends a balanced occlusion with absolutely no interferences.[27]

Edward lists three crucial factors in planning distally cantilever bridges: abutments, functional masticatory strain, and connection abutment and extension. The abutments need to have a periodontal surface which is larger than the tooth which is going to be replaced, the ratio of the coronary and radicular part of the abutment should be 2:3, small motility, be vital, and have a healthy periodontium. Occlusal contact should be diminished; occlusal surface of the cantileverpontic should not be in contact with its antagonists.[28]

Eraslan analyzed on models the influence of the length of a distal cantilever of the bridge construction, the strain distribution on bridge constructions made by metal-ceramic and all-ceramic materials. The research showed that by increasing the length of the cantilever,the values of the deformation forces increase proportionally.[23]

Tomás Geremia also got similar results which showed that increasing the length of the cantileverfrom 10 to 20 mm resulted in a rise of the axial force of approximately 50% and about 70% rise of the sagittal force.[29]

The fact that the length of the cantileverplays an important role in the deforming strain distribution is confirmed in the research work of Bevilacqua and Rubo and associates.[30,31]

Using the method of finite elements analysis, Maia Correia and associates looked at the deforming strain distribution on the cantilever and found that if 50N were loaded on an abutment (average value of masticatory stress), deforming strain will decrease and will reach Titanium's elasticity resistance threshold if the connector is made in oval shape with a vertical radius of 1,68 mm and a horizontal radius of 1mm.[32,33]

Manda and associates researched the effect of increasing the vertical dimension on the maximum stress developed within the connector of the cantileverdental bridge during maximal load of a cross-arch dental bridge with a 1- and 2-unit cantilever.The researched connections were of 3, 4, and 5 mm. The increase of the vertical dimension of the distal connection to the retaining abutment, for each FDP, presented a maximum stress value decrease of approximately 25% when the height of the connection was increased from 3 to 4 mm, and 48% when the height of the connector was increased from 3 to 5 mm. For the 2-unit cantilever restoration, the stress decreases were approximately 10% for the 4-mm connector. The highest stress value was measured on the 3-mm connector.[34]

The design of the denture is especially significant for the distribution of masticatory stress on supporting tissues. Designing a connector located in specific conditions must satisfy biological and aesthetic needs, especially in the posterior region where the stress is much higher and clinical crowns shorter.[23,32,35]

Romeed states that a 3-unit denture is a better solution than the 2-unit one.[36]

Guo and associates analysed the stress distribution in the abutment periodontal ligament of posterior cantilever bridge under transient dynamic loads using a three-dimensional finite element model. A cantilever bridge was examined using second premolar and first molar and distally extended second molar. The loads were set as 250 N occlusal forces loaded at different positions on the cantilever. It was found that with the increase of loading, the stress value in the abutment periodontal ligament increased gradually. When the load was on the second molar, tensile forces appeared in the mesial part of the second premolar.[37]

Two types of bridge constructions were researched in Korea: bridge constructions with no extensions and unilateral or bilateral distal cantilevers.

39 Korean patients were provided with 50 bridge constructions that had between 11 and 14 units with an average of 5 to 7 abutments and a total periodontal ligament area of 79% of the total ligament area of the replaced teeth, meaning abutment teeth had average 26% preserved periodont. Inthe 3-year follow-up examination, the bridge constructions were stable in all patients who generally maintained good oral hygiene. The change in the periodontal ligament area over the 3-year observation period was negligible (1 mm2 per dental unit) and showed no statistically significant difference in relation to the three types of bridge constructions.[38]

There are many more data in the relevant literature, however, the greatest challenge is the different methodology of research used which makes results difficult to compare. There are very few clinical trials, and the ones published mostly refer to periodical analyses.

Conclusion

Most research papers recommend that cantilevers should have at least two abutments, while the extension should have smaller occlusal surface compared to the replaced tooth and a minimal number of occlusal contacts.

Results on the masticatory stress distribution show that strongest strain occurs on the connectors of the distal cantilever and the mesial abutments.

The largest part of relevant research was performed on models, however, clinical trials with periodical patient monitoring complementthem, in most cases, and help provide useful recommendations for the clinical practice.

References

1. Ćatović A. Klinička fiksna protetika. Zagreb: Sveučilište u Zagrebu, Stomatološki fakultet; 1999.
2. Капушевска Б. Технологија на фиксни протези (мостови). Скопје:УКИМ, Стоматолошкифакултет; 2013.
3. The Glossary of Prosthodontic Terms. J Prosthet Dent 2005;94:2. 10-92.
4. Marcus S.E., Drury T.F., Brown L.J., Zion G.R.Tooth retention and tooth loss in the permanent dentition of adults: United States, 1988-1991.J Dent Res. 1996;75: 684-95.
5. Kenji Fueki, Eiko Yoshida, Yoshimasa Igarashi A systematic review of prosthetic restoration in patients with shortened dental arches. Japanese Dental Science Review. 2011;47(2): 167–174
6. Sailer I., Pjetrusson B.E., Hämmerle C.H., A systematicreview of the survival and complication rates of allceramic and metalce-ramic reconstructions afteran observation period of at least 3 years. Part II:Fixed dental prostheses.Clin Oral Implants Res. 2008; 19(3):326-8
7. Witter D.J., Hoefnagel R.A., Snoek P.A., Creugers N.H.Extension of (extremely) shortened dental arches by fixed or removable par-tial dentures. Ned Tijdschr Tandheelkd. 2009;116(11):609-14.
8. Witter D.J., Kreulen C.M., Mulder J., Creugers N.H.Signs and symptoms related to temporomandibular disorders-Follow-up of subjects with shortened and complete dental arches. J Dent. 2007; 35(6):521-7
9. Anneloes E. Gerritsen , Dick J. Witter, Ewald M. Bronkhorst, Nico H. J. Creugers, An observational cohort study on shortened dental arches - clinical course during a period of 27–35 years., Clinical Oral Investigations., 2013; 17 (pp): 859-866
10. Käyser A.F. Shortened dental arches and oral function.J Oral Rehabil. 1981 Sep;8(5):457-62.
11. Wolfart S. The randomized shortened dental arch study: oral health-related quality of life.Clinical Oral InvestigationsMarch 2014; 18 (20): 525-533
12. Aras K., Hasanreisoğlu U., Shinogaya T.Masticatory performance, maximum occlusal force, and occlusal contact area in patients with bilaterally missing molars and distal extension removable partial dentures. Int J Prosthodont. 2009; 22(2): 204-9.
13. Witter D.J., Kreulen C.M., Mulder J., Creugers N.H.Signs and symptoms related to temporomandibular disorders--Follow-up of subjects with shortened and complete dental arches. J Dent. 2007; 35(6):521-7
14. Abuzar M.A., Humplik A.J., Shahim N. The shortened dental arch concept: awareness and opinion of dentists in Victoria, Australia. Aust Dent J. 2015; 60(3): 294-30
15. Nassani M.Z, Devlin H., Tarakji B., McCord J.F., A survey of den-tists' practice in the restoration of the shortened dental arch. Med Oral Patol Oral Cir Bucal. 2010;15(1): 85-9.
16. Laurell L., Lundgren D., Falk H., Hugoson A. Long-term progno-sis of extensive polyunit cantilevered fixed partial dentures. J Prosthet Dent. 1991 Oct;66(4):545-52.
17. Kourkouta S., Hemmings K.W. & Laurell L. Restoration of peri-odontally compromised dentitions using cross-arch bridges. Principles of perio-prosthetic patient management. British Dental Journal 203, 189 - 195 (2007)
18. Merete Bakke, Bite Force and Occlusion. Seminars in Orthodontics, 2006; 12 (2): 120-126
19. Bonakdarchian M., Askari N., Askari M. Effect of face form on maximal molar bite force with natural dentition. Arch Oral Biol. 2009;54(3):201-4.
20. Johnsen S.E., Svensson K.G., Trulsson M., Forces applied by ante-rior and posterior teeth and roles of periodontal afferents during hold-and-split tasks in human subjects. Exp Brain Res. 2007;178(1):126-34.
21. Fratila C., Vasiloaica S., Silivasan S., Sebesan V.,Boitor V. , Stef L.Analysis of stress within the bridge and dental periodontalag-gregate with one and two teeth support usingphotoelasticity . Digest Journal of Nanomaterials and Biostructures. 2012; 3(7): 1149 – 1155
22. Motta, Andréa Barreira, Pereira, Luiz Carlos. Da Cunha, Andréia R.C.C., Duda, Fernando Pereira. The Influence of the Loading Mode on the Stress Distribution on the Connector Region of Metal-ceramic and All-ceramic Fixed Partial Denture.Artificial Organs. 2008; 32 (4):283-291
23. Eraslan O., Sevimay M., Usumez A., Eskitascioglu G. Effects of cantilever design and material on stress distribution in fixed par-tial dentures: A finite element analysis. J Oral Rehabil 2005; 32:273-78.
24. Ashu Sharma, G. R. Rahul, Soorya T. Poduval, and Karunakar Shetty. Assessment of Various Factors for Feasibility of Fixed Cantilever Bridge: A Review Study.ISRN Dent. Mar 1. 2012;
25. André Ricardo Maia Correia a João Carlos Sampaio Fernandes b José Carlos Reis Campos c Mário Auguso Pires Vaz d Nuno Viriato Marques Ramos d. Stress analysis of cantilever-fixed par-tial denture connector design using the finite element method. Rev. odonto ciênc. 2009;24(4):420-425.
26. Jeong C.M., Caputo A.A., Wylie R.S., Son S.C., Jeon Y.C. Bicortically stabilized implant load transfer. Int J Oral Maxillofac Implants 2003;18:59-65
27. Milas I., Fiksnoprotetska terapija mostovima., diplomski rad., Sveučilište u Zagrebu, Stomatološki fakultet Zagreb, svibanj 2012.
28. Edward E. Hill, DDS.,Decision-Making for Treatment Planning a Cantilevered Fixed Partial Denture. November/December 2009 Issue - Expires December 31st, 2012
29. Tomás Geremia, Marcos Michelon Naconecy, Luis André Mezzomo, André Cervieri, Rosemary Sadami Arai Shinkai c., Effect of cantilever length and inclined implants on axial force and bending moment inimplant-supported fixed prostheses Rev. odon-to ciênc. 2009;24(2):145-150
30. Bevilacqua M., Tealdo T., Pera F, Menini M., Mossolov A., Drago C. et al. Three-dimensional finite element analysis of load trans-mission using different implant inclinations and cantilever lengths. Int J Prosthodont 2008;21:539-42.
31. Rubo J.H., Capello Souza E.A. Finite-element analysis of stress on dental implant prosthesis. Clin Implant Dent Relat Res 2010;12:105-13.
32. Correia A.R., Sampaio Fernandes J.C., Reis Campos J.C., Pires Vaz M.A.; Ramos N.V.M.Stress analysis of cantilever-fixed partial denture connector design using the finite element method.RevOdonto Ciencia 2009; 24(4): 420-425. (6p)
33. Correia A.R., Fernandes J.S., Campos J.R., Vaz M.A., Ramos N.V., Martins da Silva J.P. Effect of connector design on the stress distribution of a cantilever fixed partial denture. J Indian Prosthodont Soc 2009;9:13-7
34. Manda M., Galanis C., Georgiopoulos V., Provatidis C., Koidis P., Effect of varying the vertical dimension of connectors of can-tilever cross-arch fixed dental prostheses in patients with severely reduced osseous support: a three-dimensional finite element analysis. J Prosthet Dent. 2010 Feb;103(2):91-100.
35. Goodacre C.J., Campagni W.V., Aquilino S.A. Tooth preparations for complete crowns: An art form based on scientific principles. J Prosthet Dent 2001;85:363-76

36. Romeed S.A., Fok S.L., Wilson N.H. The mechanical behaviour of cantilever fixed partial dentures in shortened dental arch therapy: a 2-D finite element analysis. Eur J Prosthodont Restor Dent. 2004;12(1):21-7.
37. Guo Y., Tang L., Pan Y.H., [Three-dimensional finite element analysis of the stress in abutment periodontal ligament of cantilever fixed bridge under dynamic loads]. Zhonghua Kou Qiang Yi Xue Za Zhi. 2009;44(9):553-7.
38. Seung-Won Yi, Gunnar E. Carlsson, Ingvar Ericsson,Prospective 3-year study of cross-arch fixed partial dentures in patients with advanced periodontal disease. J Prosthet Dent 2001;86:489-94