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THE DISTRIBUTION OF OCCLUSAL VERTICAL STRESS IN SHORTENED DENTAL ARCHS WITH CROSS-ARCH DENTAL BRIDGES

ДИСТРИБУЦИЈА НА ОКЛУЗАЛНИ ВЕРТИКАЛНИ СИЛИ КАЈ МАЛКУ СКРАТЕНИ ЗАБНИ НИЗИ СО МОСТОВНИ КОНСТРУКЦИИ

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Abstract

The **aim** of the research is to analyze the distribution of occlusal vertical forces of the abutment teeth in bridge constructions with slightly shortened dental arches. **Material and method.** Subject of research are bridge constructions in slightly shortened dental arches in the mandibula. The Finite Element Method (FEM) was applied, and the analysis was made with simultaneous both-sided loading on the distal three abutment teeth. The simulated loading forces are with strength between 0.5 to 512N. Distributed occlusal vertical forces are measured at the level of the periodontal ligament (PDL). **Results.** The results show a symmetrical distribution of forces on both sides of the bridge structure. The largest forces are distributed on teeth with applied force. The smallest forces are distributed in the apical part of PDL. There was no difference between the total distributed forces on teeth and the distributed forces on the lateral part of the PDL. The measured strength of the forces and the percentage are within the known values in the literature. **Conclusion.** The obtained results of the research are within the level of known functional values of the mastication forces. This means that the biomechanical aspect for bridge constructions with slightly shortened dental arches is not disputable, but the decision to make it should also be based on other individual and clinical conditions. **Keywords:** Occlusal vertical forces, bridge construction, shortened dental arches, finite elements method (FEM), periodontal ligament (PDL).

Апстракт

Цел на трудот е да се направи анализа на дистрибуцијата на оклузални вертикални сили на забите носачи кај мостовни конструкции кај малку скратени забни низи. **Материјал и метод.** Предмет на истражување е мостовна конструкција кај малку скратен забен низ во долна вилица. Применет е метод на конечни елементи (МКЕ) а анализата е направена со симетрично оптоварување на дисталните три заби носачи. Симулираните сили на оптоварување се со јачина од 0.5 до 512N. Дистрибуираните сили се мерени на ниво на перодонталниот лигамент (ПДЛ). **Резултати.** Резултатите покажуваат симетрична дистрибуција на силите и на двете страни на мостовната конструкција. Најголеми сили се дистрибуираат на забите на кои делува аплицираната сила. Најмали сили се дистрибуираат во апикалниот дел на ПДЛ. Не е најдена разлика помеѓу вкупно дистрибуираните сили на забот и дистрибуираните сили на страничниот дел на ПДЛ. Измерените сили по јачина и процент се во рамките на познатите вредности во литературата. **Заклучок.** Добиените резултатите од истражувањето се во ниво на познатите функционални вредности на џвакалните сили. Ова значи дека од биомеханички аспект изработка на мостовни конструкции кај малку скратени забни низи не е спорна, но одлуката за изработка треба да се донесе и врз база на другите индивидуални и клинички услови. **Клучни зборови:** Оклузални вертикални сили, мостовни конструкции, скратени забни низи, метод на конечни елементи (МКЕ), периодонтален лигамент (ПДЛ).

Introduction

Until the seventies of the twentieth century, the goal of dental treatment was the maintenance of complete dental arches with 28 teeth. In 1981, the concept of the shortened dental arch (SDA) promoted by Käyser, suggesting that shortened dental arches with at least four occlusal units, preferably in a symmetrical position, have sufficient capacity to maintain an adequate oral function[1].

This claim caused a series of researches in which the concept of shortened dental arch was studied from all aspects, the functions of the masticatory system, the effect of dental treatment, the quality of life, as well as the economic and social aspects[2, 3, 4, 5, 6].

Based on the results of extensive surveys, the World Health Organization WHO in 1992 set the new goal of dental treatment, which is a healthy, natural, and functional dental arch with at least 20 teeth without the need for prosthesis[7, 8].

Anneloes and associates found that shortened dental arches can stay stable for more than 27 years, which justifies the dental concept for shortened dental arches[9].

However, certain teeth changes can disrupt the stability of the shortened dental arches and in that case, a prosthetic treatment would be needed. The most frequent changes are the migration of teeth by separation, aesthetical and functional needs, and especially the loss of bone support.

According to De Oliveira and associates, teeth in shortened arches show greater movement than teeth in intact dental arches[10].

According to Kourkout and associates, bridge constructions can provide a certain degree of rigidity and enable a more favorable distribution of the masticatory forces of all remaining cases in patients with an advanced degree of progressive changes in the periodont[11].

Measuring the the masticatory forces is important in order to assess the functional state of the masticatory system, but it is a complex problem. The values obtained depend on many factors in the masticatory system, in the body, as well as of the measurement methods. Therefore, we find differences in the values obtained in literature.

In the published results, prevailing data suggest that the occlusal forces in static occlusion range from 100 to 1000N, while the data of the functional masticatory forces range from 3.5 to 350N[12].

According to Waltimo and Kononen, the maximal occlusal forces between Europeans and Americas range from 600 to 750N, while the functional mastication forces are much smaller, around 60-100 N[13].

Veleski measured the maximal masticatory forces in intact dental arches in the lower jaw from 176.8 N to 380.9 N in women and from 193.7 N to 506.9 N in men[14].

Himmlová measured the approximate value of 135 N in masticatory forces in subjects with natural intact dental arches[15].

Laurell L. measured maximal masticatory forces of 320 N in circular dental bridge constructions with a healthy periodont and 264 N with weakened paradont[16].

In his research, Biswas found the mean values of the maximal masticatory forces for the front teeth to be 193N, for the canines 223 N, for the premolars 280 N and for the molars 350 N[17].

The mean value of the occlusal force is between 39-66 N for the premolars and 11-33 N for the front teeth[18].

According to Lundgren and Laurell, the maximal force that occurs during the chewing act is 280 N and the medium functional force is about 100 N. He thinks that, on average, about 37% of the total maximal occlusal force is used in chewing[19].

Sato too believes that the dynamic functional momentum is 35-45% of the measured static forces[20].

By electromyographic analysis of the masticatory muscles, Prochechel and Morneburg found a mean functional masticatory force of 220N[21].

Several authors noted that the strength of the masticatory forces increases in the distal direction of dental arches[16, 22, 23, 24, 25, 26, 27, 28].

Kondo measured higher values of the maximal masticatory force in slightly shortened dental arches and pressure on PDL on second premolars[29].

Guo and associates and André and associates proved that the deformation forces of the periodontal ligament increase in proportion to the increase of the loading[30,31].

According to Apostolov, there are no distinctive differences in the values of the maximal masticatory forces on the left and on the right side of the dental arches[32, 33].

Cai and associates and Zhou Shu-min and associates found out that in the initial teeth loading, a larger amount of the masticatory forces are distributed on the cervical and lateral parts of the periodontal ligament[34, 35, 36].

In Jayam's research, during vestibular, lingual and incisal loading, the distribution of force in the apical zone is from 0.75 to 0.80N[37].

Fratila, Oruć and Je J discovered that the greatest concentration of the forces is distributed at the site of force action[18, 38, 39].

Al-Zarea measured higher values of force on the side of the natural teeth in comparison to the bridge structure side, in same subjects, the difference was statistically significant ($p < 0.05$)[40].

According to literature data, the highest influence on teeth is inflicted by the occlusal vertical forces which are the largest and the base of mastication. They are one of the most important conditions for physiologically optimal occlusion, especially in prosthetic constructions where the tendency during modeling is to reduce the impact of side forces[24].

From this aspect, the interest of this research is the distribution of the occlusal vertical forces of bridge constructions made in small shortened sequences.

Aim of the research

The aim of this research is to analyze the distribution of occlusal vertical dental forces of bridge constructions in slightly shortened dental arches.

Material and methods

The analysis of the distribution of occlusal vertical forces is made by using the finite element method. The research was done on a three-dimensional computer model, the computer analysis and the generation of the finite element network were done with SOFISTIK software package.

The basic model is Kenedy class I edentulous in the mandibula with end teeth 45 and 35, a slightly shortened dental arch (Figure 1.).

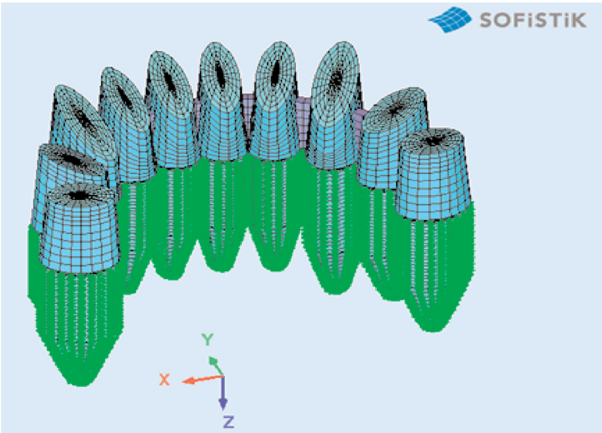

Figure 1. Model of bridge construction in slightly shortened dental arch

The discretization of the model is on finite elements with six sides and eight nodes.

The values needed for modeling teeth, periodontal ligament, component materials for bridge structures were taken from literature data.

The analysis was performed by symmetrical loading on the three distal abutment teeth of the bridge construction 45, 44, 43, 42, 41, 31, 32, 33, 34, 35 (Figure 2).

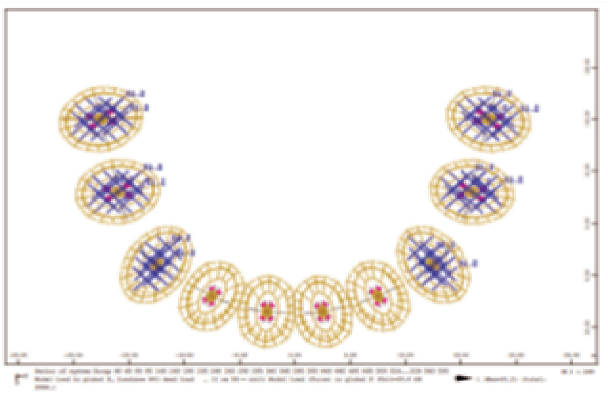

Figure 2. Symmetrical loading of the three distal teeth

Simulated vertical occlusal forces with a magnitude of 0.5N to 512N were applied in the research, respectively to the literature data for maximal and minimal masticatory forces.

The duration of the load force is not taken as a factor for the analysis.

The applied finite element method is a recognized and used method in dental researches, especially in dental biomechanics.

In this research, a three-dimensional (3D) finite element method (FME) is applied, based on the deformation method.

It is a numerical method that performs physical discretization of space. The continium (independent of its shape, shape, size) is divided into elements with finite dimensions. These elements are connected to each other in discrete points marked as nodes, and that way, a finite element network is formed. By analyzing the finite elements, actually the analysis of the continuum as a whole is carried out.

The data for teeth, periodontal ligament, materials used for bridge structures are taken from literature[41.42].

The problem being analyzed in this research is nonlinear. Nonlinearity is due to the anisotropic properties of the periodontal ligament. According to Kojima, PDL should be modeled as nonlinear[43].

By using the nonlinear analysis, a real response is obtained for the behavior of bridge structures and the distribution of forces.

Results

By carrying out the foreseen examinations in the research, we obtained the following results:

Table 1 shows the obtained values of the distributed occlusal vertical forces on the abutment teeth during simultaneous both-sided load of the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction at 45 44 43 42 41 31 32 33 34 35 with the slightly shortened dental arch.

Table 2 shows the percentage distribution of occlusal vertical forces on the abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction 45 44 43 42 41 31 32 33 34 35 with the slightly shortened dental arch.

Table 3 shows the obtained values of the distributed occlusal vertical forces in the apical part of PDL of abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction 45 44 43 42 41 31 32 33 34 35 with a slightly shortened dental arch.

Table 4 shows the percentage distribution of occlusal vertical forces in the apical part of PDL of abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction 45 44 43 42 41 31 32 33 34 35 with a slightly shortened dental arch.

Table 1. Values of the distributed occlusal vertical forces on the abutment teeth during simultaneous both-sided load of the three distal abutment teeth 45 44 43 and 33 34 35

Tooth \ F	0.5 N	1 N	2 N	4 N	8 N	1 6N	32 N	64 N	128 N	256 N	512 N
45	-0..17	-0..35	-0..69	-1.39	-2.92	-5.89	-13.58	-24.85	-49.91	-94.30	-186.09
44	-0..13	-0..26	-0..52	-1.05	-1.96	-4.24	-7.20	-18.52	-35.54	-79.09	-160.03
43	-0..10	-0..20	-0..40	-0.80	-1.56	-2.97	-5.53	-t1.27	-25.92	-52.13	-113.78
42	-0.05	-0..11	-0..21	-0.42	-0.84	-1.55	-3.05	-4.74	-10.24	-18.44	-31.18
41	-0.04	-0.08	-0..17	-0.34	-0.70	-1.32	-2.56	-4.09	-6.78	-11.80	-16.31
31	-0.04	-0.08	-0..17	-0.34	-0.69	-1.32	-2.56	-4.09	-6.74	-11.76	-16.28
32	-0.05	-0..11	-0..21	-0.42	-0.84	-1.54	-3.06	-4.74	-10.28	-18.49	-31.33
33	-0..10	-0..20	-0..40	-0.80	-1.56	-2.96	-5.54	-11.18	-25.86	-52.02	-113.56
34	-0..13	-0..26	-0..52	-1.05	-1.96	-4.24	-7.21	-18.49	-35.50	-79.11	-160.04
35	-0..17	-0..35	-0.70	1.39	-2.92	-5.89	-13.60	-24.87	-49.94	-94.37	-186.18
Total	-1.00	-2.00	-3.99	-7.99	-15.98	-31.94	-63.88	-126.83	-256.71	-511.51	-1014.78

Table 2. Percentage distribution of occlusal vertical forces on the abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35

Tooth \ F	0.5 N	1 N	2 N	4 N	8 N	1 6 N	32 N	64 N	128 N	256 N	512 N
45	17.40	17.36	17.40	17.37	18.30	18.44	21.26	19.59	19.44	18.44	18.45
44	13.12	13.10	13.12	13.10	12.29	13.29	11.27	14.6.60	13.84	15.46	15.77
43	10.04	10.04	10.03	10.03	9.79	9.31	8.66	8.88	10.10	10.19	11.21
42	5.25	5.27	5.24	5.26	5.27	4.84	4.78	3.74	3.99	3.61	3.07
41	4.20	4.24	4.21	4.24	4.35	4.15	4.01	3.22	2.64	2.31	1.61
31	4.20	4.24	4.20	4.23	4.35	4.14	4.00	3.22	2.63	2.30	1.60
32	5.24	5.26	5.24	5.25	5.27	4.84	4.79	3.74	4.01	3.61	3.09
33	10.03	10.02	10.03	10.02	9.78	9.27	8.67	8.82	10.07	10.17	11.19
34	13.12	13.09	13.13	13.10	12.30	13.27	11.28	14.58	13.83	15.47	15.77
35	17.42	17.37	17.42	17.38	18.30	18.45	21.29	19.61	19.45	18.45	18.35
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 3. Values of the distributed occlusal vertical forces in the apical part of PDL

Tooth \ F	0.5 N	1 N	2 N	4 N	8 N	1 6N	32 N	64 N	128 N	256 N	512 N
45	-0.001	-0.002	-0.003	-0.006	-0.013	-0.026	-0.079	-0.151	-0.270	-0.443	-0.817
44	-0.001	-0.001	-0.002	-0.005	-0.009	-0.019	-0.031	-0.110	-0.205	-0.383	-0.704
43	0.000	-0.001	-0.001	-0.003	-0.006	-0.011	-0.031	-0.048	-0.126	-0.230	-0.429
42	0.000	0.000	-0.001	-0.002	-0.003	-0.006	-0.011	-0.018	-0.047	-0.091	-0.139
41	0.000	0.000	-0.001	-0.001	-0.003	-0.005	-0.009	-0.015	-0.020	-0.053	-0.074
31	0.000	0.000	-0.001	-0.001	-0.003	-0.005	-0.009	-0.015	-0.020	-0.053	-0.074
32	0.000	0.000	-0.001	-0.002	-0.003	-0.006	-0.012	-0.019	-0.049	-0.095	-0.145
33	0.000	-0.001	-0.001	-0.003	-0.006	-0.011	-0.020	-0.047	-0.125	-0.228	-0.425
34	-0.001	-0.001	-0.002	-0.005	-0.009	-0.019	-0.031	-0.110	-0.205	-0.383	-0.704
35	-0.001	-0.002	-0.003	-0.006	-0.013	-0.027	-0.079	-0.151	-0.270	-0.443	-0.818
Total	0.00	-0.01	-0.02	-0.03	-0.07	-0.13	-0.30	-0.68	-1.34	-2.40	-4.33

Table 4. Percentage distribution of occlusal vertical forces in the apical part of PDL on abutment teeth

Tooth \ F	0.5 N	1 N	2 N	4 N	8 N	16 N	32 N	64 N	128 N	256 N	512 N
45	0.08	0.08	0.08	0.08	0.08	0.08	0.12	0.12	0.11	0.09	0.08
44	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.09	0.08	0.07	0.07
43	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.05	0.04	0.04
42	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.01
41	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
31	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
32	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
33	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.05	0.04	0.04
34	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.09	0.08	0.07	0.07
35	0.08	0.08	0.08	0.08	0.08	0.08	0.12	0.12	0.11	0.09	0.08
Total	0.42	0.42	0.42	0.42	0.42	0.42	0.47	0.54	0.52	0.47	0.43

Table 5. Values of distributed occlusal vertical forces on the lateral parts of PDL of abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35

Tooth \ F	0.5 N	1 N	2 N	4 N	8 N	1 6 N	32 N	64 N	128 N	256 N	512 N
45	-0.17	-0.35	-0.69	-1.38	-2.91	-5.86	-13.50	-24.70	-49.64	-93.86	-185.27
44	-0.13	-0.26	-0.52	-1.04	-1.96	-4.22	-7.17	-18.41	-35.33	-78.70	-159.32
43	-0.10	-0.20	-0.40	-0.80	-1.56	-2.96	-5.51	-11.22	-25.80	-51.90	-113.35
42	-0.05	-0.10	-0.21	-0.42	-0.84	-1.54	-3.04	-4.73	-10.20	-18.35	-31.04
41	-0.04	-0.08	-0.17	-0.34	-0.69	-1.32	-2.55	-4.07	-6.76	-11.74	-16.23
31	-0.04	-0.08	-0.17	-0.34	-0.69	-1.32	-2.55	-4.07	-6.72	-11.71	-16.20
32	-0.05	-0.10	-0.21	-0.42	-0.84	-1.54	-3.05	-4.72	-10.23	-18.39	-31.18
33	-0.10	-0.20	-0.40	-0.80	-1.56	-2.95	-5.52	-11.13	-25.73	-51.80	-113.14
34	-0.13	-0.26	-0.52	-1.04	-1.96	-4.22	-7.18	-18.38	-35.29	-78.73	-159.33
35	-0.17	-0.35	-0.69	-1.38	-2.91	-5.87	-13.53	-24.72	-49.67	-93.93	-185.36
Total	-1.00	-1.99	-3.98	-7.95	-15.91	-31.80	-63.58	-126.15	-255.38	-509.11	-1010.45

Table 6. Percentage distribution of occlusal vertical forces on lateral parts of PDL in abutment teeth

Tooth \ F	0.5 N	1 N	2 N	4 N	8 N	1 6 N	32 N	64 N	128 N	256 N	512 N
45	17.32	17.28	17.32	17.30	18.21	18.36	21.14	19.47	19.34	18.35	18.26
44	13.06	13.04	13.06	13.04	12.24	13.23	11.22	14.51	13.76	15.39	15.70
43	10.00	10.01	9.99	10.00	9.75	9.27	8.63	8.85	10.05	10.15	11.17
42	5.23	5.25	5.22	5.24	5.26	4.82	4.76	3.73	3,97	3.59	3,06
41	4.18	4.23	4.19	4.22	4.34	4.13	3.99	3.21	2.63	2.30	1.60
31	4.18	4.22	4.18	4.22	4.33	4.12	3.99	3.21	2.62	2.29	1.60
32	5.22	5.24	5.22	5.23	5.25	4.82	4.77	3.72	3.99	3.60	3.07
33	9.99	9.98	9.99	9.98	9.74	9.24	8.63	8.78	10.02	10.13	11.15
34	13.06	13.03	13.07	13.04	12.24	13.21	11.23	14.49	13.75	15.39	15.70
35	17.34	17.29	17.34	17.31	18.22	18.37	21.17	19.49	19.35	18.36	18.27
Вкупно	99.58	99.58	99.58	99.58	99.58	99.58	99.53	99.46	99.48	99.53	99.57

Table 5 shows the obtained values of the distributed occlusal vertical forces on the side parts of the PDL on abutment teeth during simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction 45 44 43 42 41 31 32 33 34 35 with a slightly shortened dental arch.

Table 6 shows the percentage distribution of occlusal vertical forces on lateral parts of PDL of abutment teeth during the simultaneous both-sided load on the three distal abutment teeth 45 44 43 and 33 34 35 in bridge construction 45 44 43 42 41 31 32 33 34 35 with a slightly shortened dental arch.

Discussion

OThe obtained results for the distribution of the occlusal vertical forces on the abutment teeth of bridge constructions in slightly shortened dental arches during simultaneous both-sided loading of the three distal abutment teeth 45 44 43 and 33 34 35 (Table 1) have an approximately identical distribution of the applied force to the left and right side. Such results were also obtained by Apostolov[32].

All distributed forces have the same direction of action identical to the direction of action of the loading force.

The distributed force has a tendency to approximately double the rise with the increase in the strength of the applied force. That is in line with the results of Guo and associates and André and associates[30, 31].

For all applied loading forces, the strongest force is distributed to the distal abutment teeth that gradually decrease mesially. Fratila, Oruc and Ye Y. found this kind of force distribution[18, 38, 39].

On teeth not exposed to direct loading forces, smaller forces are distributed that reach values of 31.33 N for the strongest applied force (Table 1).

During the simultaneous both-sided load of the three distal abutment teeth 45, 44, 43 and 33, 34, 35 in bridge structures, there is approximately identical distribution percentage of distributed force on the left and right side. The percentage of distributed forces is approximately identical for small and large forces with a tendency of slight increase by increasing the strength of the applied force. The highest percentage of force is distributed to distal abutment teeth that gradually decrease to the mesial abutment teeth.

On teeth with no force applied, the greatest force is distributed during small loading forces and gradually decreases with the rise of loading force (Table 2).

The strength of the distributed forces on the apical part of the PDL on the abutment teeth is minimal, and is less than 1 N, which is in accordance with Jayam's research.37

The percentage of the distributed forces of the apical parts of the PDL of the teeth carriers is less than 0.5% (Table 4).

Distributed force on the side parts of the PDL on the abutment teeth has the same characteristics as the distributed forces on teeth. This means that the major part of the force is received by the lateral parts of PDL. This is consistent with the results of Cai and Associates and Zhou Shu-min and associates[34, 35, 36].

Over 99.5% of the applied force is distributed to the lateral parts of PDL of the abutment teeth and has the same characteristics as on the entire teeth (Table 6).

The greatest difficulty in this research was that there are many data in the literature, but the results are difficult to compare because different research methods have been used. The published clinical trials are often reduced to periodic analyzes.

Conclusion

Distributed occlusal vertical forces on all abutment teeth have the same direction of action that is identical with the direction of action of the loading force.

For all applied loading forces, the strongest force is distributed to the distal teeth.

The percentage of distributed occlusal vertical forces on teeth is approximately identical for small and large forces.

Distributed occlusal vertical forces on the lateral parts of PDL have the same characteristics as the distributed forces on teeth.

The strength and percentage of the distributed occlusal vertical forces on the apical part of PDL on the abutment teeth is minimal, and is less than 1N or 0.5%.

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