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# Optimisation of the length of posts used in the post and core procedure on the basis of strength tests

## Optymalizacja długości wkładów koronowo-korzeniowych na podstawie badań wytrzymałościowych

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*Summary*

***Introduction.*** *The post and core procedure is used to reconstruct the tooth stroma. Cast posts reflect the configuration of the prepared canal. There are aspects that determine the strength of the tooth restored with a post.*

***Aim of the study.*** *To optimize the length of the radicular part of the posts on the basis of in vitro strength tests.*

***Material and methods.*** *The study material included maxillary incisors extracted due to periodontal and orthodontic indications, which were reinforced with individual posts made of Co-Cr and restored using prosthetic crowns made of Co-Cr alloy. The first experimental test method involved compression tests using the Instron 8520 strength machine. The second study method involved numerical modelling (based on microcomputed tomography) and strength analysis using finite elements method.*

***Results.*** *The test results confirmed that the highest destructive force values were obtained for the teeth restored with the longest posts. In a simulation, the maps of the distribution of stress*

*Streszczenie*

***Wprowadzenie.*** *Zastosowanie wkładów koronowo-korzeniowych ma na celu rekonstrukcję zrębu zęba. Wkłady lane odzwierciedlają konfigurację opracowanego kanału korzeniowego. Istnieją aspekty, które determinują wytrzymałość zęba odbudowanego za pomocą wkładu.*

***Cel pracy.*** *Celem pracy była optymalizacja długości części korzeniowej wkładów koronowo-korzeniowych na podstawie badań wytrzymałościowych in vitro.*

***Materiał i metody.*** *Materiał badań stanowiły siekacze szczęki usunięte ze wskazań periodontologicznych i ortodontycznych, które zostały wzmocnione pojedynczymi wkładami wykonanymi ze stopu Co-Cr i odbudowane koronami protetycznymi również ze stopu Co-Cr. Pierwsza metoda badań eksperymentalnych polegała na przeprowadzeniu prób ściskania na maszynie wytrzymałościowej Instron 8520. Druga metoda badań obejmowała modelowanie numeryczne (na podstawie mikrotomografii komputerowej) oraz analizę wytrzymałościową wykonaną metodą elementów skończonych.*

*reduced under the influence of occlusal forces were determined.*

***Conclusions.*** *The finite element method makes it possible to compare and optimise the length of posts used in the post and core procedure (the optimal length of the post's radicular part is approximately 2/3 of the root's length). Periodontium absorbs the transfers caused by chewing forces, and stress provides a compressive physiological stimulus to the alveolar process.*

***Wyniki.*** *Wyniki badań potwierdziły, że największe wartości sił niszczących osiągnięto dla zębów odbudowanych najdłuższymi wkładami. W symulacji wyznaczono mapy rozkładu naprężeń zredukowanych pod wpływem sił okluzji.*

***Wnioski.*** *Metoda elementów skończonych umożliwia porównanie i optymalizację długości wkładów koronowo-korzeniowych (optymalna długość części korzeniowej wkładu to około 2/3 długości korzenia zęba). Przyzębie amortyzuje przemieszczenia powodowane przez siły żucia, a naprężenia stymulują kompresyjnie wyrostek zębodołowy w zakresie fizjologicznym.*

## Introduction

In prosthetic treatment, great emphasis is placed on retaining residual teeth in the oral cavity. A healthy root of the tooth that has undergone endodontic treatment that involves extensive hard tissue loss may be used to reconstruct its stroma. In such cases, extraction should be a last resort solution only. If well-embedded and healed roots are retained, alveolar bone atrophy may be significantly slowed down.

The entire function and aesthetics of the endodontically treated tooth may be restored, and the tooth may serve as an abutment for fixed or removable partial dentures. To achieve the above goals, a post and core procedure is performed. There are two types of posts used in dental practice: cast (custom) and standard (pre-fabricated) ones. What makes them different, among others, is that cast posts reflect the configuration of the prepared canal, while standard posts already have a certain shape which must be adjusted to the tooth root canal. Depending on the length of the radicular part, cast posts may have different biomechanical properties. Apart from the length of the radicular part of the post, there are other aspects that determine the strength of the tooth restored using a post including the material of the post, its width, the proper bonding between the post and the tissues, the presence of the supragingival structure of the tooth and tooth loading.[1] Some authors also claim that as the value of Young's modulus for the post increases, the stress within the post also increases, while it is reduced for the dentine, the crown, and the cement.[2-5]

The aim of this work was to optimize the length of the root part of posts on the basis of *in vitro* strength tests.

## Materials and methods

The study material included maxillary incisors extracted for periodontal and orthodontic reasons reinforced with individual posts made of Co-Cr (Wironit LA, Bego) and restored using prosthetic crowns made of Co-Cr alloy (Wironit LA, Bego). The prosthetic reconstruction was made with preserved supragingival dentine structure and ferrule effect.

The study material was divided into five groups, depending on the length of the post-root part, each including twenty teeth. To determine the length of the post's root part, the root was divided into six equal sections (Fig. 1). In group 1, the length of the post's root part constituted 5/6 of the length of the tooth root, while in group 5 the length of the post's root part was 1/6 of the root's length.

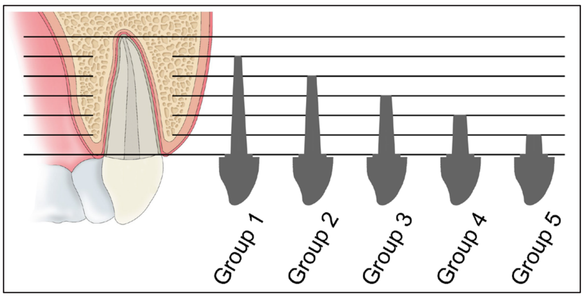


***Fig. 1. The relationship between the length of the post's root parts and the length of the tooth roots in individual study groups.***

In order to perform an individual post and core procedure, the preparation of the tooth root involved: the initial preparation of the root canal using a Radix Anker pilot drill bit nº 2, the preparation of the load-bearing surface using a Radix Anker step drill bit nº 2, widening, and the final preparation of the root canal using milling bur OL508 with a limiter and the preparation of a chamfer in order to install a prosthetic crown in the future.

The posts were modelled using a fast polymerizing material, which was replaced with metal (CoCr – chromium-cobalt alloy) in the centrifugal casting procedure. They were embedded in the teeth using carboxylate cement and the crown stroma was restored using a prosthetic crown. For strength tests, the teeth were stabilized on plates. In order to achieve the real conditions of the complexity of tooth loading, the angle of inclination of the long tooth axis toward the vector of force applied in the test sample was 32°±2°. This angle is determined in the normal plane to the labial surface of the tooth and is a result of the occlusive loading analysis performed. The tested teeth were then embedded in sleeves (20 mm high and 1 inch diameter) filled with acrylic. After hardening, the samples were placed in an environment with humidity of 100% (in physiological saline) for a period of one week before starting the tests.

The experimental test method involved compression tests using the Instron 8520 strength machine. The tests were carried out with the increasing quasi-static load until the moment of crown's disintegration. The force value was being recorded continuously.

The results of the *in vitro* strength tests were statistically analysed using Statistica 13.1 software (StatSoft). Descriptive statistics was applied in the analysis. The following values were determined: minimum and maximum values, the mean value and the standard deviation. The statistical significance adopted was p=0.05. The normal distribution of data for individual variables was evaluated (using the Kolmogorov–Smirnov test). Analysis of statistical significance of variables was performed using ANOVA followed by post hoc tests.

The second study method involved numerical modelling and strength analysis using FEM (finite element method).

The stress components were calculated in the models: normal and tangential stresses, and the main stresses were determined on their basis. Dental tissues and metal alloy are characterized by different tensile and compressive strengths. One of the criteria used to assess the effort of such materials in complex stress states is the modified von Mises criterion (mvM). It takes into account the quotient of compressive and tensile strength. In a simulation, the maps of the distribution of stress under the influence of occlusion forces were determined. The results of the equivalent stresses were presented as maps of these stresses distributions in the materials of the incisor models.

In the tests using FEM, the test material included maxillary incisors of identical shape together with periodontium, modelled on the basis of micro CT, which were virtually restored using individual posts of different length and marked with the same numbers as in the tests using the strength machine (Fig. 2).

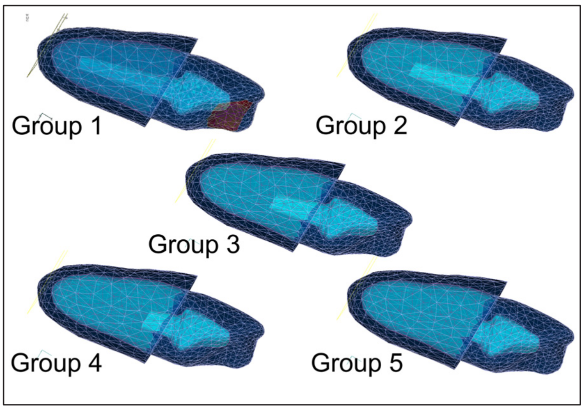


*Fig. 2. FEM test material.*

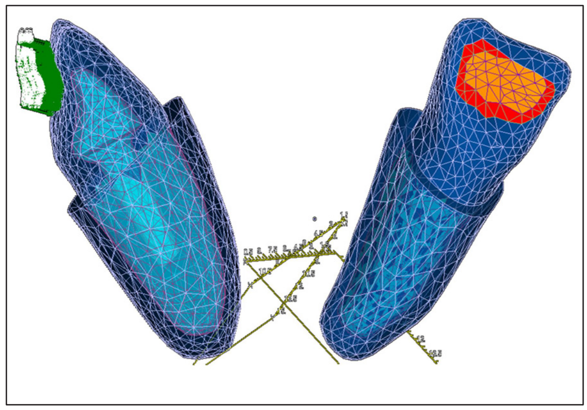

*Fig. 3. Boundary conditions for the modelled system.*

The procedure for creating virtual models was developed using software dedicated to spatial reconstructions, including: e-Film, Amira and involved:

– analysis of images - scans with automatic differentiation of structures according to the set gray scale thresholds in Hounsfield units based on the obtained histogram,
– generating curves limiting selected areas (enamel, dentine, pulp, periodontium) of the model structures in the scan planes with statistical development of these curves,
– three-dimensional reconstruction corresponding to anatomical structures,
– the discretization of solids - the result of dividing their volume into finite averaging elements (tetrahedral mesh).

The basis of the analysis was a transformed numerical model in which the discretized surface (nodes and mesh) was converted into the coordinates of the nodal points corresponding to the solid model.

The models were embedded in periodontium. The loads of 150 N were placed on the surface of the palate using vectors whose direction was determined on the basis of a biomechanical analysis and whose sense was toward the surface of the tooth (Fig. 3). The contact was created between all structures building the solid model.

The tissues material data and the construction material were entered in the FEM software (Table 1).[6,7]

All procedures performed in studies involving human participants were in accordance with the Declaration of Helsinki of 1964. The experiment was approved by the Jagiellonian University Bioethics Committee (No. 122.6120.165.2015, 26 June 2015).

Table 1. Material data of teeth tissues in models and construction material[6,7]

| Material | Young’s modulus, E, [MPa] | Poisson’s ratio, ν |
|---|---|---|
| Periodontium | 50 | 0.45 |
| Pulp | 2 – 0.0003 | 0.45 |
| Dentine | 18 300 | 0.31 |
| Enamel | 84 100 | 0.30 |
| Metal alloy | 218 000 | 0.33 |

T a b l e 2. Descriptive statistics for the results of *in vitro* strength tests

| Variable | Mean | Minimum | Maximum | SD |
|---|---|---|---|---|
| Group 1 | 4.92 | 4.41 | 5.61 | 0.34 |
| Group 2 | 4.62 | 3.19 | 5.71 | 0.79 |
| Group 3 | 4.01 | 2.09 | 5.50 | 1.07 |
| Group 4 | 2.16 | 1.09 | 3.69 | 0.87 |
| Group 5 | 1.17 | 0.41 | 2.79 | 0.72 |

## Results

The test results confirmed that the highest destructive force values were achieved for the restored teeth using the longest posts (group 1) and the second longest posts (group 2). The tests carried out using a strength machine for teeth with posts of different lengths did not produce unambiguous results on the optimization of the post length.

Table 2 shows descriptive statistics for the results of the *in vitro* strength tests. Analysis of variance (ANOVA) was followed by post hoc tests (Fisher's test and Bonferroni's test). No statistical significance was revealed between the analysed groups 1, 2 and 3 or between groups 4 and 5 (Fig. 4). The prepared teeth differed in terms of the length of the root part, the cross-sectional shape and diameter of the roots, their curvature, and the thickness of the root wall.

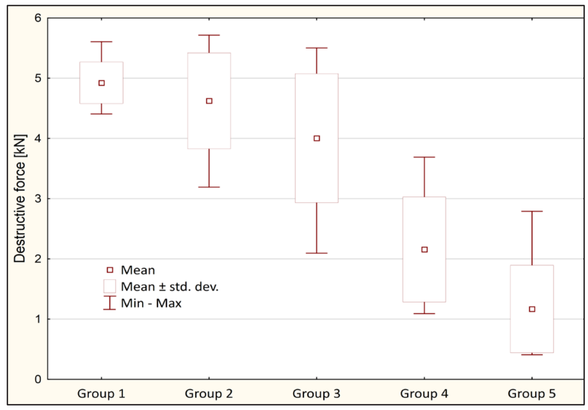


***Fig. 4. The destructive force in individual groups in in vitro strength tests.***

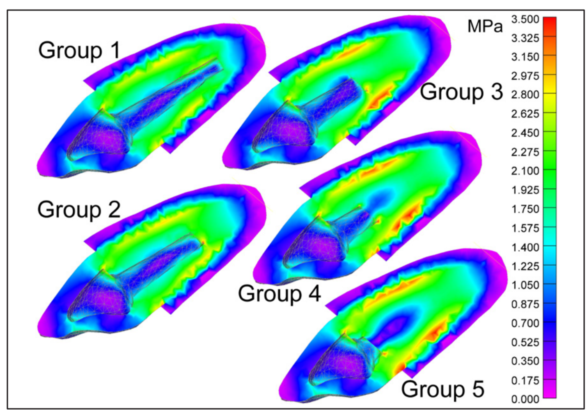


***Fig. 5. Maps of the equivalent von Mises stress distribution in the tooth structure, including the periodontium without the posts (the location of the posts has been marked).***

Figure 5 shows stress distribution maps for the teeth reinforced with posts of different length after finite element analysis. It was confirmed that the post-shaping of at least 2/3 of the root length leads to minor stress in the region of the tooth neck and an even distribution of stress along the entire surface of the prepared canal and ensures good post retention. The post whose length exceeds 2/3 of the length of the root leads to less stress within the tooth neck and, at the same time, to increased stress at the apex of the root (Fig. 6). Short posts cause much greater root stress than long posts. There is a particularly high concentration of stress in the coronal area of the root. This stress may lead to de-cementation of the post or a root fracture.

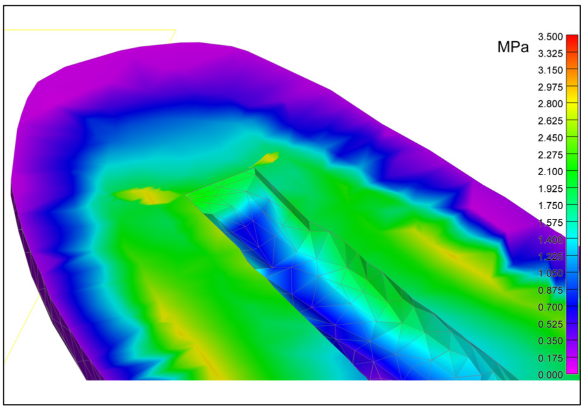


*Fig. 6. Maps of the equivalent von Mises stress distribution in the tooth structure including the periodontium without the posts in Group 1 – magnification of the root apex area (post location has been marked).*

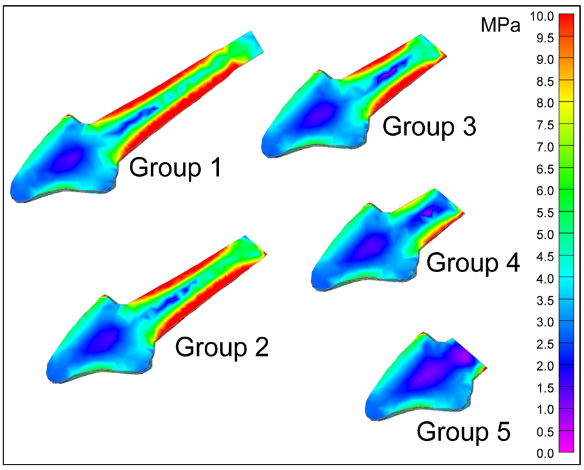


*Fig. 7. Maps of the equivalent von Mises stress distribution within the posts.*

Numerical simulations have shown that the higher the Young's modulus of the examined structure (post), the greater the stresses concentrated within it, and the smaller the stresses transferred to the tissues (Figs. 5, 7).

The length of the prepared root canal increases the area in which stress is distributed. A short post results in the concentration of equivalent stress in the coronal region, while a long one provides its even distribution on the entire area of the prepared canal.

As a result, the stress concentration zone is transferred within the root, far from the critical area of contact between dentine and the crown. As a consequence, the tooth is less susceptible to fractures and the prosthetic crown has better marginal integration.

## Discussion

*Tooth preparation for an individual post and core procedure*

In order to increase the area of bonding between the post and the tooth, as well as the restored structure of the crown abutment, it is recommended to leave the maximum amount of healthy tooth tissue. It has been proven that leaving a healthy dentine band, 2 mm high and 1 mm wide, on the entire perimeter of the tooth crown increases the strength of the tooth root thus reducing the risk of its fracture.

According to most reports, this kind of tooth preparation is more important than the type of post and the post material used. The higher the ring around the tooth, the greater the strength of the post and the hard tissues of the tooth.[8-10] According to *Pierrisnard* et al., the absence of the ring effect increases the stress near the tooth neck.[2] When preparing a tooth for a post and core procedure, it is also important to leave 3-5 mm of the tight layer of material filling the root canal to protect the tissues near the apex against infection and the impact of cement fixing the post.[11,12]

*The biomechanics of the tooth reconstructed using an individual post and core procedure*

The action of forces during the act of chewing causes the tooth reinforced with a root post to be subject to complex stresses. The vertical component of the force (along the long axis) places, above all, a compressive load on the tooth. This is why, in order to protect the tooth against cracking, the area of contact is increased – the prepared load-bearing area is flat and the post is fixed in the canal using cement. The horizontal component of the chewing force causes bending: it bends both the tooth and the post. The labial wall of the root stroma may break under it. Furthermore, the tooth is subjected to torsional loading by the chewing forces.

These forces generate stress in the teeth and surrounding tissues. The most important task of the post is to distribute stress in an even and safe way. The post must be sufficiently resistant to absorb stress without the risk of tissue fatigue. In their studies, *Okamoto* et al. and *Pegoretti* et al. showed that the application of posts made of rigid materials results in reduced stress, in particular near the tooth neck.[4,5]

*Adanir* et al. and *Mc Laren* et al. also indicated that the stress distribution in the root tissues around long posts is more balanced.[13,14] According to the studies by *Nissan* et al., stress within the dentine near the tip of a short post is three times greater.[15] If a short post is necessary due to atypical tooth anatomy, it should be fixed with resin-based cement, which will increase its retention. *Macedo* et al. considered the length of the post and the application of adequate cement as important factors to improve post retention.[16]

## Conclusions

In dentistry, modelling and numerical analyses are recommended. The finite element method (FEM) makes it possible to compare and optimise the length of posts used in the post and core procedure (the optimal length of the post's radicular part is approximately 2/3 of the root's length, group 2 in the present research).

The utilization of tooth roots in prosthetic restoration should be widespread due to the important functions performed by the periodontium. Periodontium absorbs the transfers caused by chewing forces and stress provides a compressive physiological stimulus to the alveolar process.

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