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**Retention force of overdenture retained with telescopic crowns: A
comparison of polyetheretherketone and zirconia ceramic crowns**

Ретенциона сила протезе ретиниране телескоп крунама: компарација
телескоп круна од полиетеркетона и цирконија керамике

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Retention force of overdenture retained with telescopic crowns: A comparison of polyetheretherketone and zirconia ceramic crowns

Ретенциона сила протезе ретиниране телескоп крунама: компарација телескоп круна од полиетеркетона и циркониа керамике

SUMMARY

Introduction/Objection Recently, new materials for double crowns have been introduced, such as zirconia and polyetheretherketone (PEEK). However, some characteristics of these materials are not investigated sufficiently such as retentive force and duration of “settling in phase”. During “settling in phase”, telescopic overdenture has not yet achieved its definitive retention force, and it can be harmful for periodontal tissue if the value is above optimal for long time.

Objective was to measure the *in-vitro* overall pull-off force of telescopic crowns where primary crowns were made from zirconia ceramics and a survey of the “settling in phase” duration.

Methods Forty zirconia primary telescopic crowns were produced on prepared canine teeth. Twenty secondary crowns were of PEEK and other 20 of zirconia with electroplated gold copings. The pull-off force measurements were conducted utilizing a dynamometer until a constant value was obtained.

Results The specimens of the PEEK group showed higher initial retentive force values. Settling in phase was finished between 800 and 900 cycles of separation for both groups. Comparing the value of pull-off force between individual different cycles, a statistically significant reduction was recorded up to the 800th cycle, while between the 800th and 900th cycle there was no difference.

Conclusions The settling in phase was finished between 800 and 900 cycles of separation in both groups. Final retentive force values for both tested telescopic groups were in the optimal range which is 5-9 N per one telescopic crown.

Keywords: telescopic crowns, PEEK, zirconia ceramics, retentive force, CAD-CAM

САЖЕТАК

Увод/Циљ Последњих година, нови материјали за двоструке круне су уведени у праксу, као што је циркониа и полиетеретеркетон (PEEK). Међутим, неке карактеристике ових материјала нису довољно испитане, као што је ретенциона сила и трајање „фаза уходавања“. “Фаза уходавања“ је иницијални период употребе телескоп протезе када финална ретенциона сила још увек није постигнута, и може имати штетни утицај на пародонтално ткиво ако су у том периоду силе превисоке и предуго трају.

Циљ је био да се измери *in-vitro* укупна сила раздвајања телескоп круна, где су примарне круне израђене од циркониа керамике и испитати трајање фазе уходавања.

Метод Четрдесет примарних телескоп круна од циркониа керамике су израђене на препарисаним очњацима. Двадесет секундарних круна је израђено од PEEK-а 20 круна за секундарне циркониа круне са галванизованим златом. За мерење силе раздвајања коришћен је динамометар, а мерење је вршено док није добијена константна вредност.

Резултати Узорци из PEEK групе показали су вишу иницијалну вредност ретенционе силе. Фаза уходавања је завршена између 800 и 900 циклуса раздвајања код обе групе. Када се упореде индивидуалне вредности силе раздвајања између различитих циклуса, статистички значајно смањење је забележено до 800-ог циклуса, док између 800 и 900 циклуса није било разлике.

Закључак Фаза уходавања је завршена између 800 и 900 циклуса раздвајања у обе групе. Финална ретенциона сила код обе тестиране групе показала је оптималне вредности које износе 5-9Н по телескоп круни.

Кључне речи: телескоп круне, PEEK, циркониа керамика, ретенциона сила, CAD-CAM.

INTRODUCTION

Although dental implants placement has become a standard procedure in prosthetic rehabilitation, there are still some situations where conventional overdentures retained with double crowns are the best solutions especially in elderly patients, having in mind some diseases such as osteoporosis, their economic situation and number and position of leftover teeth [1,2]. They are indicated in cases where there are few leftover teeth (2-4) with good biological value, preferably distributed on both sides of the dental arch [3]. Double crowns consist of two main parts: a primary or male part permanently fixed to an abutment tooth or

implant, and a congruent secondary or female part, rigidly connected to a removable partial denture. A cylindrical structure known as a telescopic crown, is often used for double crowns and is characterized by equivalent gingival and occlusal circumference, therefore no taper is employed [4]. Double crowns systems offer more advantages than other types of attachments such as cross-arch stabilization of the abutment teeth, axial loading of the teeth, good retention, longevity, and therefore are suitable for elderly people, giving them oral comfort and self-confidence [5,6]. Commonly, double crowns are made of metal alloys, precious and non-precious, making homogenous or heterogeneous friction pair. During decades of use, gold alloys have proved to be the best solution in terms of creating clinically acceptable values of retention force, longevity and biocompatibility [2,4]. However, despite these many advantages of double crowns they have been repressed from usage mainly due to high prices of gold alloy. Consequently, dental technicians have less experience in double crown production and avoid doing them.

Double crowns have been changes recently, in the material selection, manufacturing technique and design concepts, mainly in order to increase the level of precision through digitalization and consequently its' performance. Modern systems of double crowns are based on zirconia ceramics (ZrO_2) and polyetheretherketone (PEEK). Ceramic materials combined with electroplated gold provide numerous advantages such as small plaque susceptibility, absence of marginal gingiva discoloration and important esthetic qualities [7]. Another material utilizing CAD/CAM technique for manufacturing double crowns, PEEK provides many advantages. It is a cheaper material, compared to gold alloys, it is light weight and easy to work with compared to non-precious metal alloys, titanium and ceramics. Its insolubility distinguishes it as an excellent material for patients with allergies [8].

Precision made, telescopic crowns achieve reliable and long lasting retention, usually by friction of touching surfaces. However, during the telescopic retained overdenture initial period

of use the retentive force value is variable. The retentive force is highest immediately after the denture construction [3] and progressively decreases until the end of the “settling in phase”, i.e., until the retention force value becomes well established. Throughout the settling-in phase, wear of the material occurs, thus only after a certain period of wear, telescopic crowns achieve their final geometric form.

The aim of the study was to measure the in-vitro overall retention force of telescopic crowns where primary crowns were fabricated from zirconia ceramics with PEEK secondary crowns, and those where primary crown were fabricated from zirconia ceramics and gold electroplated secondary crowns made with zirconia ceramics. Also, the intention was to evaluate the number of cycles after which the retentive force becomes steady for all mentioned telescopic crowns under simulated clinical conditions. We hypothesized that different materials of secondary crowns have an impact on: (i) initial retentive force value and (ii) duration of initial retentive force value reduction.

MATERIAL AND METHODS

Specimen preparation

Maxillary canine typodont resin model (KaVo Dental GmbH, Germany) was prepared for conventional telescopic crowns. Height of the prepared canine was 5mm with 2mm occlusal reduction, with a 1mm thick 360° rounded shoulder margin. Afterwards, impressions of the resin model including the prepared tooth were obtained utilizing standard metal trays and additional silicone material (Zhermack, Italy). According to 40 silicone impressions, 40 master

casts were fabricated in dental stone type IV (Fuji Rock, GC, Leuven, Belgium) and were subsequently used for fabricating ZrO₂ primary crowns.

Primary and secondary crowns fabrication

All 40 primary crowns (40 master casts with prepared canine teeth) were fabricated from zirconia blocks (ZENOSTAR, 98mm, Ivoclar Wieland group, Liechtenstein). The stone models were scanned using an extraoral scanner (3 Shape D 800 scanner, 3Shape A/S, Copenhagen Denmark), designed (Dental System Premium 2014, 3Shape A/S, Copenhagen Denmark) and milled in a milling unit Wieland dental CNC (Ivoclar Wieland Group, Liechtenstein). The primary crowns were polished with a special bur kit for zirconia (sets 4430 and 4431, Komet, Germany) with water cooling using a hand piece [9].

The prepared primary crowns were afterwards divided into two groups, 20 primary crowns were randomly selected for PEEK secondary crowns (Fig. 1). The rest of the 20 crowns were left for ZrO₂ secondary crowns with electroplated gold copings (Fig. 2). The parameters used for PEEK secondary crowns were adjusted for breCam BioHPP blanks (Bredent, Senden, Germany, LOT: 394172); with proximal extension to enable precise separation of the crowns. Twenty PEEK secondary crowns were milled utilizing Wieland dental CNC (Ivoclar Wieland Group, Liechtenstein). The polishing procedures of the outer surfaces of peek secondary crowns were conducted under standardized condition, which implies silicone polishers (Ceragum Wheel, Bredent, Germany) and polishing brushes (Komet Dental, Germany) with polishing paste (Abraso-Starglanz asg, Bredent, Germany), inner surfaces were not polished due to recommendation of manufacturer [8].

Another 20 secondary crowns were fabricated combining electroplated gold copings and ZrO₂. The gold copings were produced in the electroforming machine (Gammat Optimo 2, Gramm Dental, Germany). The primary crowns were covered with thin layer of electroconductive lacquer (Conductive Silver Lacquer art No. 910.00.049) using a special brush. Special attention

was paid on a thin homogeneous layer. The sum of gold solution (Ecolyt SG 200), activator (Activator SG 200), and time required were automatically calculated by the system to create a 0.2 mm thin layer of gold. Afterwards, the copings were submersed in a 40% nitric acid solution for 15 minutes to remove metallic lacquer. On the master cast with primary and secondary telescopic crowns in place, another digital scan was performed and a tertiary structure was designed (Dental System Premium) and milled (Wieland dental CNC, Ivoclar Wieland group, Liechtenstein) from zirconia blocks (Zenostar, Ivoclar Wieland group, Liechtenstein). Afterwards the gold copings were introduced into the ZrO₂ secondary crowns and luted using Multilink Automix adhesive (Ivoclar Vivadent AG, Liechtenstein) according to the manufacturer's directions.

Pull-off force measurement

Measurements were performed on 40 sets of telescopic crowns. The study adopted the "pull off force" as a force needed for pulling off the secondary from the primary crown. The measurements were performed manually as complete separation of the telescopic crowns with artificial saliva substitute interposed (Biotene; GSK UK in physiological sodium chloride solution, ratio 1:2). The pull-off force measurements were conducted by a Bredent dynamometer (Friktionsmesgerat fmg 20; Bredent, Senden, Germany) [10]. This dynamometer measures forces ranging from 0-20 N. The existence of proximal extensions on the secondary telescope crowns was required for precise separation of the crowns. Measurements of the overall pull-off force were done in a couple of steps. First, the interiors of the primary crowns were filled with autopolymerizing acrylic resin, and using the movable arm of the surveyor the dynamometer pins were immersed into the acrylic (Fig. 3). Following the polymerization of the acrylic resin, adequate secondary crowns were seated over the primary crowns with finger pressure. The telescopic crown and pin assemblies were mounted onto the perforated plate of the dynamometer and fixed with an appropriate screw. The vertical post was then secured using

a proper screw. The described method was performed for each of the 40 telescopic crown specimen sets. In summary 40 specimens for each telescopic system were fabricated consisting of 20 for each material group combination.

Manual complete separation of the secondary crowns from the primary telescopic crowns in an axial direction was performed respectively at the baseline and presented the initial pull-off force. Readings of the pull-off force values were evaluated on the dynamometer scale. Insertion and separation of the telescopic crowns and adequate measurements were repeated until a constant value of the pull-off force was obtained. The final measurement refers to the pull-off force values that repeat in at least 10 consecutive readings, while the number of cycles until steady force value was achieved, represents the settling-in phase.

Statistical analyses

For statistical analysis, the values of pull-off force obtained after the first measurement (baseline) were used, as well as after each hundred measurements to the end of the settling in phase (the end of the test). Statistical analyses were performed using SPSS software v. 24.0 (SPSS Inc., Chicago, IL, USA). Descriptive data for all groups and variables were expressed as mean \pm standard deviation, median and interquartile range. Obtained data were tested for normal distribution by the Kolmogorov-Smirnov test. All our data was non-parametric. Quantitative non-parametric variables, between two groups, were compared by Mann-Whitney U-test. For the comparison within group (between different observed times), Friedman and Wilcoxon test was performed. Logistic regression model was used to determine predictors of

different groups: PEEK group and electroplated gold ZrO₂ group. All reported p values were two-sided; differences were considered significant when p value was <0,05.

RESULTS

The initial settling in phase was finished between 800 and 900 cycles of separation, due to the fact that the 900th cycles of separation was presented as the end of the test for both groups. On average, the initial settling in phase was finished after 892 cycles of separation in the PEEK group and 858 in the electroplated gold ZrO₂ group. The initial values showed the range of pull-off force – from 7.5 N to 10.2 N for the PEEK group and from 2.4 N to 10 N for the electroplated gold ZrO₂ group. The respective final pull-off forces were 4.1 N and 3.0 N. The descriptive statistics, such as mean with standard deviation (SD), median and interquartile range (IQR) together with the result from Mann –Whitney and Friedman Test are summarized in Table 1. By comparing the values of the pull-off forces between the groups analyzed, a statistically significant difference was found at all observed times, commencing from the baseline to the 900th separation cycle. The p-values in question are also shown in Table 1.

When comparing inside the groups, a statistically significant reduction in the pull-off force value was observed in both groups. By comparing the value of this parameter between individual different cycles, a statistically significant reduction was recorded up to the 800th cycle, while between the 800th and 900th cycle there was no difference (Table 2). The percentage change in the finish value (900th separation cycle) compared to the baseline (start) did not statistically significantly differ from the observed groups (Figure 4).

Multiple regression analysis was used for identification of parameters that may predict changes in the initial retention force of different telescopic crowns: PEEK group and electroplated gold ZrO₂ group. For assessment of univariate predictors, all values for pull-off force and the percentage change from baseline to finish values were analyzed. When the univariate predictors

were obtained, all values of pull of force during different cycles of separation were introduced in a multivariate model. In multivariate model none of these factors showed statistically significant differences between the observed telescopic crowns.

DISCUSSION

While evaluating the obtained results regarding the first hypothesis it could be said that both groups of investigated telescopic sets had achieved sufficient retention forces. The PEEK telescopic crown group in our study showed higher initial retentive force values (mean value 9,3) compared to the ZrO₂ crowns (median value 7,0). Also, PEEK group showed a larger range of retention force before the end of the settling-in phase and slightly longer duration of settling-in phase compared to the ZrO₂ group. The possible explanation may be that known recommendation not to polish inner surfaces of PEEK crowns contributes to an initial high abrasiveness and consequently robust initial retentive force values. In addition to that, PEEK as a flexible material undergoes the process of better adaptation to the primary coping [9,10,11]. The results concerning the second hypothesis showed that final pull-off forces were 4.1 N and 3.0 N, respectively for each group. Phenomenon that occurs during the settling-in phase represents plastic deformation of materials with an increase of actual contact surface area resulting in tension reduction between surfaces [3, 11]. The existing tension will decrease as long as the limits of elasticity are exceeded anywhere in the contact area, whereas elasticity is specific for any given material. The results corresponds to the statement that the retention mechanism of electroformed secondary crowns is based on adhesion, not on the wedge effect [5].

The retention of telescopic crowns in which the secondary parts are electroplated is based on the combination of capillary gap and saliva [13]. Capillary gap occurs as a result of gold ion deposits on a thin layer of silver lacquer which is applied during the fabrication of the coping.

Furthermore, by implementing the artificial saliva, design of the tooth preparation and chamfer design and dimensions may have an impact on adhesion between the smooth surfaces of telescopic crowns, as well as having a hydraulic effect, thus increasing the initial retentive force [10]. Also, as stated by Weigl et al. (2000) double crown assemblies with electroformed secondary crowns have more stable retention forces than double-crown assemblies with cast secondary crowns [14].

The main limitation of this study is that the dynamometer pin was positioned manually, and that some errors may occur when reading the measured values. However, to avoid significant errors, the dynamometer pin was positioned using the surveyor arm thus providing the vertical direction for the separation /insertion process. Under „in vivo“ conditions the insertion path of denture in most cases is slightly different from the path used during the measurements. Also, the lubricant was interposed during the “pull-off force” measurement, although the presence of artificial saliva is a controversial subject concerning the validity of the results ranging from those that indicate the presence of saliva substitute does not alter the withdrawal force in individual withdrawal force tests to those that assert the absence of such intermediary leads to significant changes in frictional wear [15].

Double crowns have been exposed to numerous criticisms over decades of use. However, research has shown that properly planned and precisely manufactured overdenture retained with double crowns does not show a higher incidence of complications than other types of attachments. Ishida et al. investigated survival and complication probabilities of the prosthesis retained with clasps and double crowns. Decementation was the most frequent cause of failure in double crowns (which is neither expensive nor complicated to solve), but other complications such as fracture of crown restoration, fracture of tooth, caries and periodontal disease were more frequent in abutment teeth with clasps [16]. Similar conclusion was made by Hofmman et al who reported loss of cementation for double crowns and fractures of the

clasps [17]. Schwindling and associates concluded that the most frequent complications of double crown retained overdentures were: decementation of primary crowns, need for denture relining and fracture of the veneer of secondary crowns. All these complications are considered as minor and low cost, and overall survival rate was 90% after 7 years [18]. According to the most recent research, the cumulative survival rate of double crowns was higher in implants compared to tooth supported overdentures, but still above 80% in both teeth and implant supported overdentures over 10 years [19]. Based on these results, it can be said that the main drawbacks of the telescopic overdenture are in the complex design and production as well the price of gold alloys. For this reason, the idea of introduction of new materials for double crowns means a potential reduction of the production cost, but above all in digitalization, which reduces the errors caused by the human factor. For example, due to CAD-CAM fabricating, casting beads that are inevitable during conventional casting were avoided [20, 21]. In addition, recent study has shown that fully digital protocol for RPD production with clasps is possible, meaning digital impression, design with CAD software, fabrication with CAM machine and 3D printer and assembly with adhesive material [22]. That means it will be possible soon to produce telescopic overdenture with fully digital protocol as well.

Non-precious metal alloys are convenient because of the much lower price compared to gold alloys but also PEEK and ZrO₂. However, literature data and also experience in practice point out that these alloys often cannot reach sufficient retention force and therefore need additional retention elements which complicate more process of production. Also, because of the existence of carbides, oxide layer creation and high elasticity module, double crowns made of non-precious alloys are much more difficult to handle and process [23, 24, 25].

The optimal retention force value per one telescopic crown amounts to 5-9 N [3, 8, 23] which correlate to our results. The results from Stancic and Jelenkovic (2008) demonstrate that when a larger number of matrix-patrix components are present as in most cases there is an initial

force that is larger than optimal and settling-in phase will last longer, thus providing the possibility of potentially harmful damage to the periodontium over a longer interval [4]. Considering the retention force values, contrary to our results, initial retentive force in range 3,6 – 3,7 N or lesser values were reported by Özyemişçi-Cebeci, and Yavuzylmaz (2013) prior to applying different friction varnishes that improved retention to satisfied 4,6 and 6,0 N [12]. Güngör et al. (2004), similar to our results, reported that only until the initial 800 cyclic procedures were performed, decrease in retentive force could be found with no further changes afterwards [25]. Contrary to our findings, the results of Stock V. et al. (2016) showed a decrease of retention force in PEEK secondary crowns already during the first twenty cycles [8]. Bearing in mind the obtained results but also the difference in the crown production cost which is approximately 2: 1 in the favor of PEEK, authors give mild advantage to the electroplated gold ZrO₂. However, further prospective clinical studies are needed to determine which material is more durable and has better clinical characteristics after some period of use. Nowadays, more implant-supported overdentures are retained with double crowns [2, 26] with good survival rate, and researches about different computer-aided technologies for those double crowns should give precious information [19, 22].

CONCLUSION

The first hypothesis that different materials of secondary crown have an impact on initial retentive force value has been shown as correct. The specimens of the PEEK telescopic group showed higher initial retentive force values than electroplated gold ZrO₂ group. The settling in phase was finished between 800 and 900 cycles of separation in both groups, thus material

combination didn't have an impact on duration of initial retentive force reduction. Both tested telescopic groups showed retentive force values in the optimal range.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest.

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Table 1. Descriptive statistics values.

Number of test cycles $\bar{x} \pm SD$ (Med, IQR)	PEEK group	Electroplated Au- ZrO ₂ group	p-value ^a
baseline	9.3 ± 1.2 (9.7; 2.4)	7.0 ± 2.6 (7.3; 2.4)	P=0.001*
100	7.9 ± 1.6 (7.2; 3.0)	6.1 ± 2.1 (6.4; 1.4)	P=0.006*
200	7.1 ± 1.3 (6.4; 2.2)	5.5 ± 1.9 (5.8; 1.6)	P=0.017*
300	6.1 ± 0.8 (6.1; 1.8)	4.6 ± 1.5 (4.8; 1.0)	P=0.001*
400	5.4 ± 0.6 (5.38; 1.0)	4.2 ± 1.3 (4.4; 0.8)	P=0.000*
500	4.8 ± 0.6 (4.65; 0.8)	3.7 ± 1.2 (4.0; 0.6)	P=0.000*
600	4.5 ± 0.6 (4.4; 0.3)	3.5 ± 1.2 (3.6; 0.3)	P=0.000*
700	4.3 ± 0.4 (4.4; 0.8)	3.4 ± 1.1 (3.6; 0.8)	P=0.000*
800	4.2 ± 0.5 (4.3; 0.8)	3.1 ± 1.1 (3.2; 0.6)	P=0.000*
900	4.1 ± 0.5 (4.3; 0.8)	3.0 ± 0.9 (3.2; 0.6)	P=0.000*
p-value ^b	p=0.000*	P=0.000*	

*statistical significant; ^a Mann–Whitney U test ^b Friedman Test
All values for pull-off force are presented in Newton (N).

Table 2. Statistically significance of reduction of pull-off force over time in two groups.

Test cycles	PEEK group	Electroplated Au-ZrO ₂ group
baseline-100	p=0,000*	p=0,000*
100-200	p=0,000*	p=0,000*
200-300	p=0,000*	p=0,000*
300-400	p=0,000*	p=0,000*
400-500	p=0,000*	p=0,000*
500-600	p=0,000*	p=0,001*
600-700	p=0,004*	p=0,045*
700-800	p=0,002*	p=0,004*
800-900	p=0,157	p=0,063

*statistically significant; Wilcoxon test



Figure 1. PEEK secondary crown.



Figure 2. ZrO₂ secondary crown with electroplated gold coping.

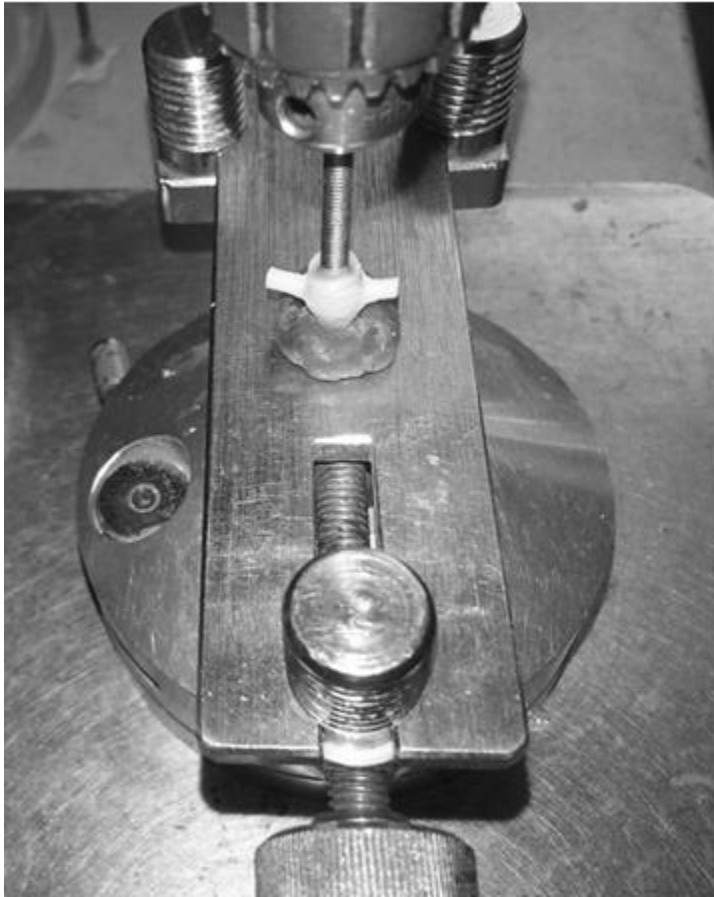


Figure 3. The dynamometer pin was immersed into the acrylic using the movable arm of the surveyor.

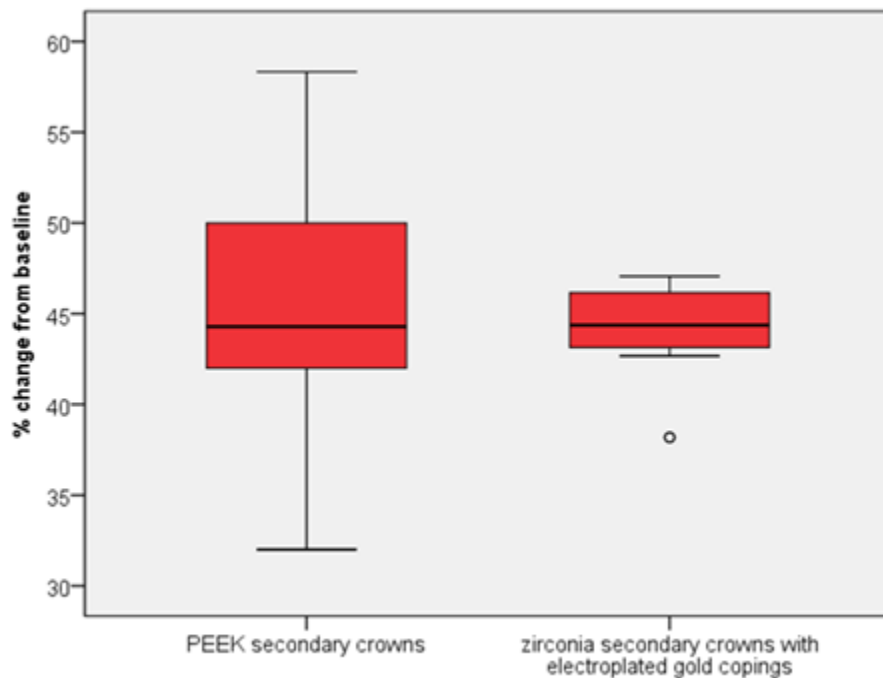


Figure 4. The percentage change from baseline to finish values.