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The fracture load and failure types of veneered anterior zirconia crowns: An analysis of normal and Weibull distribution of complete and censored data

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ABSTRACT

Objectives. The aim of this study was to compare the fracture load of veneered anterior zirconia crowns using normal and Weibull distribution of complete and censored data.

Methods. Standardized zirconia frameworks for maxillary canines were milled using a CAD/CAM system and randomly divided into 3 groups ($N = 90$, $n = 30$ per group). They were veneered with three veneering ceramics, namely GC Initial ZR, Vita VM9, IPS e.max Ceram using layering technique. The crowns were cemented with glass ionomer cement on metal abutments. The specimens were then loaded to fracture (1 mm/min) in a Universal Testing Machine. The data were analyzed using classical method (normal data distribution (μ, σ); Levene test and one-way ANOVA) and according to the Weibull statistics (s, m). In addition, fracture load results were analyzed depending on complete and censored failure types (only chipping vs. total fracture together with chipping).

Results. When computed with complete data, significantly higher mean fracture loads (N) were observed for GC Initial ZR ($\mu = 978$, $\sigma = 157$; $s = 1043$, $m = 7.2$) and VITA VM9 ($\mu = 1074$, $\sigma = 179$; $s = 1139$; $m = 7.8$) than that of IPS e.max Ceram ($\mu = 798$, $\sigma = 174$; $s = 859$, $m = 5.8$) ($p < 0.05$) by classical and Weibull statistics, respectively. When the data were censored for only total fracture, IPS e.max Ceram presented the lowest fracture load for chipping with both classical distribution ($\mu = 790$, $\sigma = 160$) and Weibull statistics ($s = 836$, $m = 6.5$). When total fracture with chipping (classical distribution) was considered as failure, IPS e.max Ceram did not show significant fracture load for total fracture ($\mu = 1054$, $\sigma = 110$) compared to other groups (GC Initial ZR: $\mu = 1039$, $\sigma = 152$, VITA VM9: $\mu = 1170$, $\sigma = 166$). According to Weibull distributed data, VITA VM9 showed significantly higher fracture load ($s = 1228$, $m = 9.4$) than those of other groups.

Significance. Both classical distribution and Weibull statistics for complete data yielded similar outcomes. Censored data analysis of all ceramic systems based on failure types is essential and brings additional information regarding the susceptibility to chipping or total fracture.

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1. Introduction

Zirconia reconstructions substitute the metal–ceramic fixed-dental prosthesis (FDP) due to their high biocompatibility [1] and comparable mechanical properties with metal–ceramics [2,3]. Several in vitro studies reported that zirconia seems to provide the desired long-term stability for clinical applications [4,5] and this was also confirmed in clinical studies [6–11]. Zirconia seldom fractures, due to its high flexural strength with 1000 MPa [10,12] that surpasses the flexural strength of the veneering ceramics (50–120 MPa) [13]. Confirming this information, chipping of the veneering ceramic is often reported in clinical studies [6–11]. The stability of the complete system consisting the zirconia framework and the veneering ceramic is of clinical importance that could be tested with the Voss test [14]. In this kind of test, the anatomy of the crowns is not excluded and therefore could better represent the clinical conditions compared to standard tests where geometrical specimens with standard dimensions are used. The restoration is cemented on the metal abutments, and force is applied to the crowns simulating the antagonist load. The Voss test was originally developed to test the fracture load of metal–ceramic FDPs [14] but it is also being applied for zirconia FDPs [4,5].

The obtained fracture load results could be statistically analyzed with different methods. The common approach using the classical method assumes normal distribution and uses analysis of variance (ANOVA) followed by a post hoc test. More recently, the Weibull statistic was also used for facture load analysis of FDPs [15]. The Weibull statistics in the dental materials research provides information on the reliability of zirconia [16]. The fracture load data of zirconia FDPs could also be censored considering the failure types (chipping vs. total fracture) [4]. Censoring could not be practiced in metal–ceramic FDPs since the alloys often do not fracture due to their ductility [17].

Therefore, the objective of this present study was to compare the fracture load results of veneered zirconia crowns and analyze the results with both classical method (assumption of normal distribution) and the Weibull statistics (complete vs. censored) considering chipping and total fracture. The primary hypothesis was to test whether the fracture load results (complete and censored data) analyzed with the classical method yields similar results compared to Weibull statistics. The secondary hypothesis was to test whether the censoring of data with respect to failure types (chipping and total fracture) under classical distribution and Weibull statistics give similar information in term of significant differences between fracture load results of all-ceramic systems.

2. Materials and methods

2.1. *Specimen preparation*

Standardized zirconia frameworks were prepared using a metal abutment analog in the shape of an anatomically prepared maxillary canine with a chamfer preparation of 1 mm. They were cast from a CoCr alloy (Wironium plus, Bego, Bremen, Germany) and scanned (3Shape D 250, Wieland Dental, Pforzheim, Germany). An anatomically supported zirconia framework was constructed (ZENO TEC, Wieland Dental), milled (ZENO 4030 M1, Wieland Dental) in the white state (ZENO TEC Zr Bridge, Wieland Dental) and densely sintered according to the manufacturer's instructions (ZENO TEC Fire, Wieland Dental).

The zirconia frameworks were randomly divided into three groups ($N = 90$, $n = 30$ per group) and veneered with three layering ceramics: GC Initial ZR, Vita VM9 and IPS e.max Ceram (Table 1). The firing schedule took place in one ceramic oven (D4, Dekema, Freilassing, Germany) strictly following the instructions of each ceramic manufacturer (Table 2). After liner application, veneering ceramic for dentin was applied using a silicone key to achieve a standardized shape and size of the veneers. A second dentin firing was performed after adding a new layer of ceramic to compensate for the shrinkage due to sintering process. Prior to the second firing, the slurry was condensed into the mold with a vibrator for 2 s at 50 Hz (Elektro Vibrator Porex, Renfert, Hilzingen, Germany). After the final firing, the veneering ceramic was glazed and the restoration was finished.

The crowns were cemented with glass ionomer cement (KetacCem, 3M ESPE, Seefeld, Germany) on their corresponding metal abutments. During cementation, they were secured with finger pressure for 2 min. After 10 min, the specimens were subjected to loading.

2.2. *Fracture load measurement*

The cemented specimens were loaded in the Universal Testing Machine (Zwick/Roell Z010, Zwick, Ulm, Germany). The load was induced with a flat loading cell on the palatinal surface of the incisal edge at an angle of 45° to the long axis of the tooth at a crosshead speed of 1 mm/min [14]. In order to avoid force peaks, a piece of a 0.5 mm tin foil (Dentaurum, Ispringen, Germany) was placed between the incisal edge and the loading jig. The measurement was stopped as soon as the maximum fracture load decreased by 10%.

The failure types after fracture tests were classified as follows: (a) chipping of the veneering ceramic or (b) total fracture of zirconia framework together with veneering ceramic (Fig. 1). Failure types were observed under the optical microscope (M3M, Wild, Heerbrugg, Switzerland) at 25× magnification by two operators.

2.3. *Statistical analysis*

The analysis was performed in MINITAB Version 14 (MINITAB, State College, PA, USA). Results of the statistical analysis with *p*-values smaller than 5% were considered to be statistically significant.

The Anderson–Darling test for normality and the adjusted Anderson–Darling goodness-of-fit estimates based on the Normal and Weibull distributions were computed for complete and censored data to determine the better fit.