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Influence of Cervical Finish Line Type on the Marginal Adaptation of Zirconia Ceramic Crowns

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Clinical Relevance

Cervical finish line type has an influence on the marginal adaptation of Y-TZP restorations. Both shoulder and mini-chamfer exhibited the least marginal opening values for zirconia crowns and can be recommended for clinical applications.

SUMMARY

The current study evaluated the effect of different cervical finish line designs on the marginal adaptation of a zirconia ceramic. Four different marginal finish lines (c: chamfer, mc: mini-chamfer, fe: feather-edge and s: rounded shoulder) were prepared on phantom incisors. Die models for each preparation group (N=28, n=7 per finish line design group) were made of epoxy resin. Y-TZP (ICE Zirkon) frameworks were manufactured by a copy-milling system (Zirconzahn) using prefabricated blanks and tried on the master models for initial adaptation of the framework; they were then sintered, followed by veneering (Zirconzahn). The finished crowns were cemented with a polycarboxylate cement (Poly F) under 300 g load and ultrasonically cleaned. The specimens were sliced and the marginal gap was measured, considering absolute marginal opening (AMO) and marginal opening (MO) for each coping under a stereomicroscope with image processing software (Lucia). The measurements were statistically analyzed using the Kruskal Wallis, Mann Whitney and Wilcoxon Signed Ranks tests at a significance level of α=0.01. Means of AMO measurement (µm) for the feather-edge finish line (87 ± 10) was significantly lower than that of the chamfer (144 ± 14), shoulder (114 ± 16) and mini-chamfer finish line types (114 ± 11) (p<0.01). Means of MO measurements was the lowest for feather-edge finish line (68 ± 9) (p<0.01) and then, in ascending order, shoulder (95 ± 9), mini-chamfer (97 ± 12) and chamfer (128 ± 10). The cervical finish line type

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had an influence on the marginal adaptation of the tested zirconia ceramic. Although the feather-edge finish line resulted in lower AMO and MO values, with its proven mechanical disadvantage, it cannot be recommended in clinical applications of zirconia crowns. This type of finish line has acted solely as a control group to test the null hypothesis in the current study. For better marginal adaptation, both shoulder and mini-chamfer finish line types could be suggested for zirconia crowns.

INTRODUCTION

Achieving close marginal adaptation is crucial for the long-term clinical success of single- or multiple-unit fixed-partial-dentures (FPD) and for the prognosis of the restored tooth. Luting agent solubility may, in time, result in gap formation between the tooth and the restorative material, leading to microleakage, plaque accumulation, caries and subsequent failure of the restoration. While a clinically acceptable range of marginal discrepancies is advised to be less than 120 µm,[1] in CAD/CAM or copy-milling systems, the marginal opening has been reported to range between 60 µm and 300 µm.[2-3]

Several *in vitro* studies demonstrated that the marginal adaptation of metal-ceramic FPDs is influenced by the type of cervical finish line, shrinkage after firing procedures of the veneering ceramic,[4-5] differences in thermal expansion coefficients of the framework and veneering ceramic and, most importantly, the amount of circumferential ceramic thickness of the substructure.[6] However, the results on the effect of finish line design on the marginal discrepancies are controversial in the dental literature.[4-5,7] Some studies performed on metal-ceramic restorations revealed that the finish line design had no influence on marginal adaptation,[5,7] while others reported that the shoulder type of preparation had less marginal distortion than the chamfer type after repeated ceramic firings.[4,7-8]

Yttrium tetragonal zirconia polycrystal (Y-TZP) (hereon: zirconia) frameworks can be fabricated mainly with the help of CAD/CAM or copy-milling techniques by means of grinding a zirconia block. These blocks can be milled either in the green, pre-sintered or completely sintered stage.[9-10] Frameworks made from green and pre-sintered zirconia are milled in an enlarged form to compensate for the shrinkage that occurs during sintering, which usually is equivalent to 20%-25% for partially sintered frameworks.[10] Completely sintered Y-TZP blocks are prepared by presintering at temperatures below 1500°C, then processed by the hot isostatically-pressed (HIP) technique at temperatures between 1400°C and 1500°C under high pressure in an inert gas atmosphere. This leads to a very high density in excess of 99% of the theoretical density.[11] The blocks can then be machined using a specially designed milling system. The milling of pre-sintered zirconia blocks is faster and causes less mechanical damage to the material compared to milling of fully sintered blocks.[12] The milled frameworks are then veneered with feldspar or glass-ceramics appropriate for zirconia use. However, the mechanical properties of zirconia ceramic are affected during the veneering stage that is performed at relatively higher temperatures.[13] The framework is subjected to distortion and shrinkage during the sintering and veneering stages. This may consequently have a negative effect on marginal adaptation.[13] When the coping margin begins to deform under the stress of contracting porcelain, the shrinkage stress has been shown to spread further around the circumference of the margin.[14] Because the porcelain shrinks towards its greatest mass, consequently, the fit of the coping changes due to non-uniform distortion during the porcelain firing and asymmetric form of the coping margin.[14] It can be anticipated that thin margins due to finish lines could suffer more from shrinkage and thereby result in inferior marginal adaptation.[15] The null hypothesis tested was that the decreased thickness of finish line would result in inferior marginal adaptation.

In a recent clinical study on zirconia FPDs, the overall survival rate was found to be 73.9% with marginal integrity problems, resulting in secondary caries (21.7%) and ceramic debonding (15.2%) being major causes of failure.[16] Unfortunately, in that study, the type of cervical finish lines were not reported. The amount of tooth structure removed during tooth preparation varies according to the finish line design, and sometimes the finish line cannot be changed due to the previous preparation history of the abutment teeth. Therefore, the aim of the current study was to evaluate the effect of cervical finish line design on marginal adaptation of veneered zirconia crowns.

METHODS AND MATERIALS

Specimen Preparation

Phantom teeth of maxillary right central incisors (N=28) (Frasaco, Frasaco GmbH, Tettnang, Germany) were stabilized at their apex and embedded in autopolymerizing polymethylmethacrylate (Palapress, Vario, Heraeus Kulzer, Wehrheim, Germany) with their long axes oriented perpendicular to the surface of the block up to 1 mm below their cemento-enamel junction. The teeth were prepared with four different cervical finish line designs; namely, circumferential rounded shoulder (s) (1.2 mm), chamfer (c) (1.2 mm), mini-chamfer (mc) (0.9 mm) and feather-edge (fe), following axio-gingival radii (Figure 1a). The preparations were made by the same investigator, using a new diamond bur each time (Brasseler, Savannah, GA, USA) in a high-speed handpiece under water cooling.

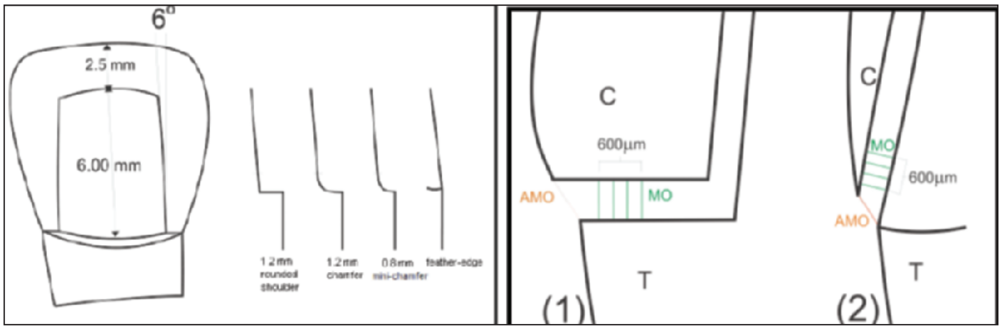

Figure 1. *Figure 1a) Preparation design of phantom teeth, cervical finish line forms and depths. Figure 1b) Schematic view of Absolute Marginal Opening (AMO) (1) and Marginal Opening (MO) (2) measurements with 200 µm intervals.*

A parallelometer (NEY surveyor, Dentsply, Ceramco, NJ, USA) and a digital slide gauge (Mitutoyo Corp, Tano-cho, Japan) were used in order to ensure standardized tooth preparations with an approximately 2.5 mm incisal reduction and convergence angle of 6°. The impressions were made with a polyvinylsiloxane impression material (Affinis, Coltène Whaledent, Hauptsitz, Switzerland), and die models for each preparation group were made of epoxy resin (EP85-215, Eager Plastics, Chicago, IL, USA). A total of 28 zirconia frameworks (n=7 zirconia copings/finish line design) were manufactured by a copy-milling system (Zirconzahn, Bruneck, Italy) using prefabricated blanks of zirconia ceramic (ICE Zirkon, Zirconzahn).

All specimens were fabricated by one experienced dental technician and tried on the master models for initial adaptation of the framework. Since zirconia framework shrinkage occurs even after the veneering process, which affects the marginal adaptation, zirconia specimens in this study were sintered followed by veneering and glazing (Zirconzahn Veneering Ceramic, Zirconzahn) in order to simulate a finished crown as in the clinical situation. Each finished crown was tried on its corresponding die and minor adjustments were made when necessary. Then, the crowns were cemented with a polycarboxylate cement (Poly F, Dentsply, York, PA, USA) under 300 g load for 10 minutes.

Measurement of Marginal Adaptation

Each specimen was sectioned perpendicular to its longitudinal axis using a diamond disk (Isomet, Buehler Ltd, Lake Bluff, IL, USA) under a stream of water to produce slices (thickness: 1 mm). Four beams were obtained per specimen. The outer mesial and distal residual parts were removed. Then, each surface was ground with 600-grit silicon carbide paper under running water prior to the measurement procedure.

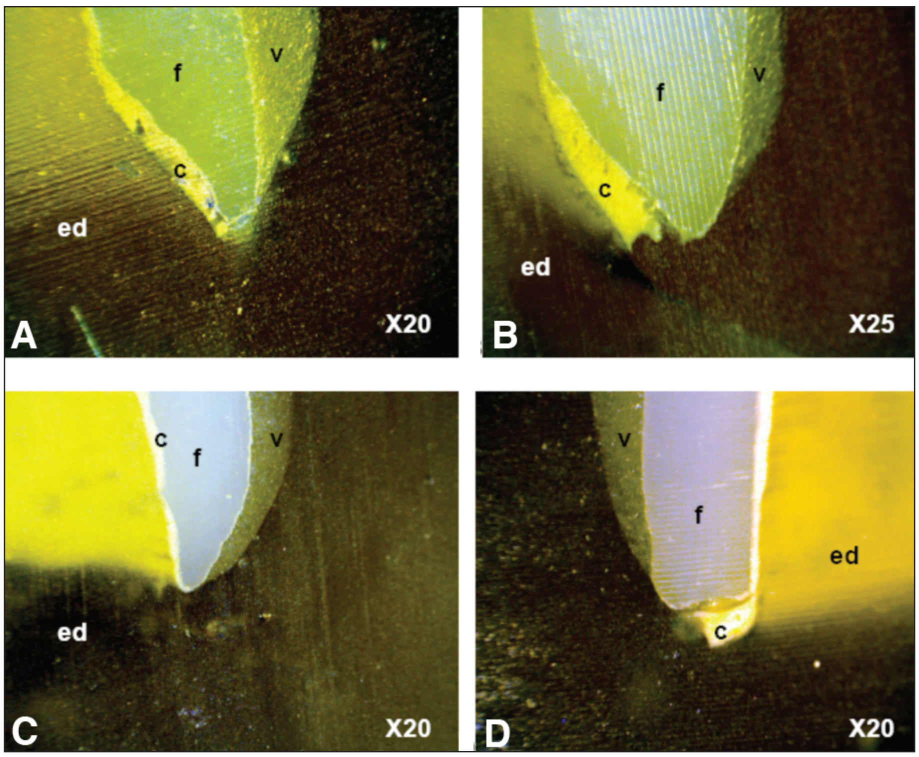

Figure 2. *Representative buccal cross-sections of die/crown assemblies. (A: Mini-chamfer, B: Chamfer, C: Feather-edge, D: Rounded shoulder; c: Cement, ed: Epoxy die, f: Zirconia framework, v: Veneering ceramic).*

The marginal adaptation was evaluated by considering two parameters: 1) absolute marginal opening (AMO), referring to the gap from the most external point at the crown margin to the most external point at the preparation margin and 2) marginal opening (MO), defining the distance from the external crown margin to the opposite preparation line or surface at the point in shortest perpendicular distance (Figure 1b). Measurements were made under a stereomicroscope with image processing software (Lucia, Nikon Corporation, Tokyo, Japan) (at original magnification 250x).

One calibrated examiner made and recorded all of the measurements. Four MO (approximately with 200 µm intervals) and one AMO measurement were made from each marginal aspect (buccal and lingual aspects), leading to a total of 64 MO and 16 AMO measurements from each specimen. The marginal fit of a crown was defined as mean values of (mean ± standard deviation in µm) MO and AMO measurements/crown separately (Figures 2a-d).

Statistical Analysis

The obtained data from the cross sections and total measurements of the die/crown assembly were statistically analyzed (SPSS 15.0 for Windows, Chicago, IL, USA) by the Kruskal Wallis, Mann-Whitney and Wilcoxon Signed Ranks tests at 0.05 and 0.01 significance levels.

RESULTS

The mean AMO measurement (µm) for the feather-edge type of cervical finish line (87 ± 10) was significantly lower than that of the chamfer (144 ± 14), shoulder (114 ± 16) and mini-chamfer (114 ± 11) finish line types ($p<0.01$) (Kruskal Wallis and Mann-Whitney tests). The Chamfer finish line showed significantly higher AMO values than those of the other groups. Differences between the mini-chamfer and shoulder-type of finish lines were not significant ($p>0.01$). The results of the AMO measurements for all types of finish line designs between the buccal and lingual aspects revealed no statistically significant differences ($p>0.01$) (Wilcoxon Signed Ranks Test) (Figure 3).

Mean values of MO measurements for the feather-edge type of finish line (68 ± 9) were significantly lower than those of the chamfer (128 ± 10), shoulder (95 ± 9) and mini-chamfer (97 ± 12) finish line types ($p<0.01$), with chamfer having significantly higher MO values. The differences between the mini-chamfer and shoulder were not statistically significant ($p>0.01$) (Figure 3).

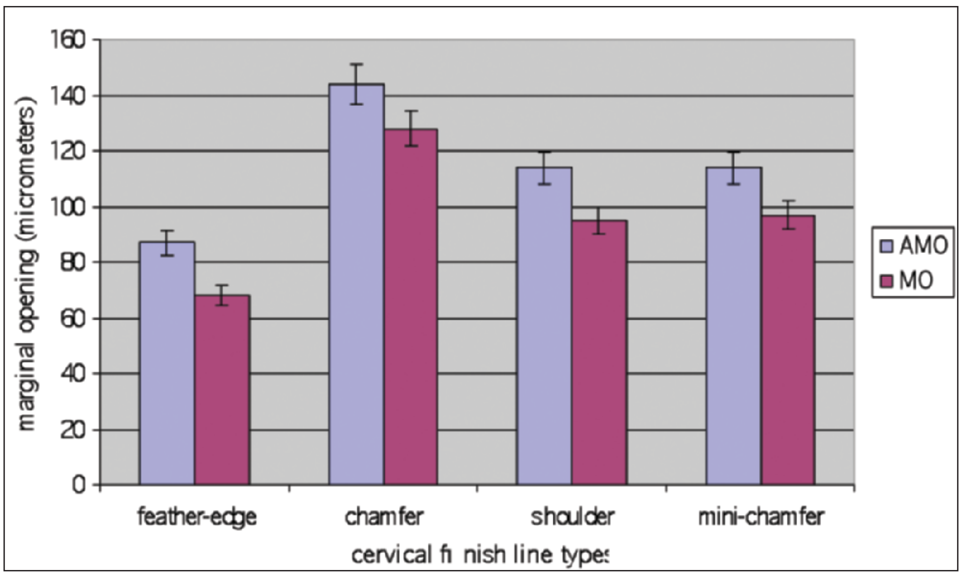

Figure 3. *Absolute marginal (AMO) and marginal openings (MO) (µm) for four cervical finish line types.*

Based on the results, the power of the study was determined in that it indicated the necessity of five specimens to obtain a power of 80% and seven specimens being needed for a power of 97% in detecting differences between the group mean values at a *p*-value of 0.05. Therefore, seven specimens assigned per group was sufficient to reject or accept the null hypothesis.

DISCUSSION

In the current *in vitro* study, the marginal integrity of veneered zirconia crowns with four different finish lines, namely, chamfer, rounded shoulder, mini-chamfer and feather-edge, were evaluated using optical image processing software. It was reported in a previous study that both scanning electron microscope (SEM) imaging and light microscopy measurement techniques can be used to measure marginal discrepancies, since there was no significant difference between the accuracy of the two techniques.[17] In the current study, light microscopy imaging software was preferred, due to the automatic detailed measurement, with the software providing means, standard deviations and minimum-maximum values at a time that would result in more standardized processing than SEM imaging measurements based on visual determination of the measurement areas.

In previous studies, the number of measurement points per crown used has varied considerably. Groten and others[18] suggested a measurement of ideally 50 points, or at least 20 to 25 measurements per crown. In earlier studies, the reliability of the marginal opening measurements were either validated by the larger sample sizes ranging from 5-10 specimens[1,18-19] or an increased number of measurements from different points. In the current study, seven specimens for each finish line type yielded up to 64 MO and 16 AMO measurement points. Both the specimen size and number of measurements fell within these recommended ranges. The power analysis results also confirmed the validity of the sample size and measurements.

AMO has been used as a generic term in most studies where the fit of the crown was assessed. However, since AMO might vary significantly, depending on the over-extension or under-extension of the crowns,[17] the locations of the marginal measurement may vary among studies. It is usually due to the fact that the margins of the crown and die may seem to be sharp clinically, but appear rounded when microscopically viewed. This makes it difficult to select a point where the marginal opening is to be measured.[20] Therefore, in the current study, not only AMO but also MO was measured in order to obtain mean values along the whole cervical finish line.

The results of the measurements revealed that the feather-edge type of finish line design exhibited the least marginal discrepancy (AMO and MO). This was attributed to the fact that the more the restoration margin ends with an acute angle, the shorter the distance between the restoration margin and the tooth, as had been described previously by Schillinburg, with the following formula:

$$d = D \sin m$$

(d: marginal opening; D: the distance by which a crown fails to seat and m: the acute angle of the margin).[21] Although the feather-edge type of finish line exhibited the least AMO and MO values, it is not highly recommended for clinical practice, since it triggers a wedging effect at the margins and may provide additional marginal bulk.[22] Although the practical feather-edge type of finish line cannot be recommended, especially for all-ceramic constructions, it was interesting to note that ceramic thickness at the margins did not affect the results. Therefore, the hypothesis was rejected. Given the fact that the marginal discrepancy in the chamfer finish line design was shown to be lower,[17,23] the results of the current study were not in accordance with this suggestion. On the other hand, the results of this study were concurrent with an earlier study in which heavy chamfer finish line exhibited more marginal opening than rounded shoulder on In-Ceram Alumina crowns.[23] Although a 90° shoulder with a rounded axiogingival line angle design is recommended for the preparation of all-ceramic and metal-ceramic crowns, rather than a chamfer preparation,[19] the rheological properties of zirconia framework material differ from these materials in many aspects, such as creep behavior.[24] This might be the cause of the poor-fitting crowns with chamfer finish line design in the current study. Furthermore, it was stated that the shoulder type of preparation is more resistant to distortion.[20]

In a previous study, it has been shown that there were no significant differences between shoulder and chamfer preparation designs in In-Ceram crowns.[25] However, a recent study recommended the use of shoulder finish line for all-ceramic crowns.[26] In the current study, mini-chamfer finish line also showed similar values to that of the shoulder finish line, and the differences among the overall means according to finish line type revealed that the difference between the mini-chamfer and shoulder was not significant. In principle, due to maintenance of the biological integrity at the cemento-enamel junction and the necessity of room for the core and veneering ceramic,[27] shoulder finish line and mini-chamfer could be preferable in conjunction with the ceramic system tested.

An earlier study tested the marginal adaptation of IPSEmpress 2 (Ivoclar Vivadent, Schaan, Liechtenstein) maxillary incisor crowns and found the mean marginal opening to be 62 µm.[26] However, another study on the marginal gap measurement of In-Ceram crowns revealed that the mean marginal openings were between 120 µm and 160 µm.[19] Tinschert and others reported that the mean marginal discrepancies ranged from 61 µm to 74 µm for the zirconia ceramic FPD frameworks fabricated with the Precident DCS system (DCS, Allschwil, Switzerland).[28] The marginal fit values of experimental all-ceramic FPDs ranged between 89 µm and 130 µm in an *in vivo* study.[29] On the other hand, the findings of an *in vitro* study revealed mean marginal gap values of Empress 2 FPDs between 58 µm and 68 µm.[30] An explanation for these differences in the literature regarding marginal gaps in all-ceramic crowns might be attributed to many parameters, such as measurement methodology, measuring instruments used, the differences in material properties, sample size and the number of measurements per specimen. Nevertheless, all these range of reported results are in accordance with the results obtained in the current study.

The rationale for choosing the cross-section method in the current study was that the measurements could be obtained not only from one point, but along the whole finish line, starting from the axial wall to the outermost extension point, as well as providing measurements after cementation. When the cross-section method is used, the reference measurement points in different studies may demonstrate different cement thicknesses, since a uniform cementation space between the intaglio surface of the crown and the die may not be provided. Moreover, cementation procedures may affect the marginal fit, because of the differences in viscosity of the luting agents and seating forces.[31] Therefore, in the current study, a polycarboxylate cement was chosen, due to its good visibility in measurements as opposed to the resin cements, and cementation was performed in a controlled manner under constant load in order to minimize these effects. However, although pre-cementation marginal opening measurements were not made in the current study, an increase in marginal opening width after cementation must also be considered, because of the minimal grain size of the dental cement when other faults do not occur.[30] Although detailed cross-sections were obtained, also allowing for internal fit measurements of the crowns, it was not assessed in the current study, since the aim was to offer an appropriate finish line design against debate on the marginal fit of the zirconia crowns.[13]

It was reported that there were no significant differences between the shoulder and chamfer preparation types[27] and among the mesial, distal, buccal and lingual aspects in a study conducted on Cerec3 crowns. In that study, each crown margin was evaluated in 360°, and another study revealed non-significant differences in marginal fit between metal-ceramic and all-ceramic crowns, where the margins were evaluated in 360°.[32] The differences between the buccal and lingual marginal opening measurements were also not significant in the current study, where most of the measured crown margins were overextended, most probably due to the milling process related with the Zirconzahn system. Thus, final manual trimming of the crown margins should be controlled under a light microscope to ensure that the excess material that remains after the milling process is completely removed from the preparation finish line.

The adaptation of zirconia ceramic restorations may be affected by the preparation design, milling process, size of milling burs and material conditions during the milling procedure. It has been previously shown that green and pre-sintered four-unit zirconia ceramic FPD frameworks of straight design exhibited better marginal adaptation compared to curved design.[13] These results were attributed largely to the distortion of the framework due to shrinkage of the ceramics during the final sintering stage. However, in that study, the marginal discrepancies of the four-unit FPD frameworks had been measured with no veneering ceramic. There is a lack of information on the effect of the application of veneering ceramic on the marginal adaptation on single and multiple unit zirconia FPDs. In the current study, although only zirconia crowns were evaluated, all the crowns were veneered with veneering ceramic in order to simulate the clinical situation and thereby obtain more clinically relevant results. On the other hand, the clinical relevancy of marginal opening value and caries incidence are one of the difficult issues to investigate clinically. Since oral hygiene strategies and the habits of patients vary between individuals, the consequences of big marginal gaps may not necessarily be correlated with caries incidence. This has been long known from amalgam restorations.[33] Similarly, since there is no clinical evidence to support the concept that marginal gaps lead to secondary caries and chippings at the margins with zirconia FDPs, future clinical studies with such restorative materials should accompany marginal and internal fit findings. Currently, only one clinical study[16] reported a high incidence of caries around the margins of zirconia FDPs. The validity of marginal openings may still carry some clinical importance, where oral hygiene is less than ideal. Therefore, extrapolation of the findings of the current study to the clinical situation remains to be further investigated.

CONCLUSIONS

From the current study, the following conclusions can be derived:

1. Shoulder and mini-chamfer finish lines showed comparable AMO and MO values and therefore both can be recommended in the clinical application of zirconia crowns.
2. The chamfer type of finish line resulted in the highest AMO and MO values.
3. From a technical standpoint, although the feather-edge finish line resulted in lower AMO and MO values, it cannot be recommended in the clinical application of zirconia FPDs. This group was involved only to test the null hypothesis.

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