Hypobaric Conditions and Retention of Dental Crowns Luted with Manually or Automixed Dental Cements

Andrej M. Kielbassa; Johannes A. G. Müller

BACKGROUND: There is only scant information on the influence of the hypobaric environment on luting agents and their efficacy on dental crown cementation. The objective of this study was to provide data on the retentive characters of two cements commonly used on implant abutment surfaces both under normal and under hypobaric conditions.

METHODS: There were 56 implant abutments supplied with CAD/CAM milled zirconia oxide crowns. 1) A zinc phosphate cement (ZP), and 2) a resin-modified glass ionomer cement (RMGI), each mixed either A) manually or B) by means of automix capsules, were used for cementation. The cemented crowns of the 4×2 subgroups were either kept on the ground or were transported in an aircraft at altitudes up to 13,730 m (45,045.9 ft; $N = 28$ each), thus being subjected to the pressure changes (80×) every aircrew member or frequent flyer is exposed to. All cemented crowns were stored in climatized boxes during the experimental phase.

RESULTS: Hand-mixing of ZP resulted in a significant reduction of mean (± SD) retention forces (581.6 ± 204.5 N) when compared to the control group on the ground (828.4 ± 147.9 N). Automixed ZP (931.9 ± 134.4 N in flight; 996.0 ± 107.4 N on the ground) and RMGI subgroups (ranging from 581.0 N ± 114.3 N to 662.4 N ± 92.5 N) were not affected by hypobaric conditions.

DISCUSSION: When treating patients frequently exposed to hypobaric environments, automixing of ZP would seem favorable, while manual mixing should be avoided. RMGI is considered suitable and is not influenced by hand-mixing or barometric pressure changes.

KEYWORDS: aviation dentistry, barotrauma, CAD/CAM, crown retention, dental cement, dental implant, hypobaric conditions, zirconia oxide crown.

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Modern passenger aircraft are capable of high altitude operations flying up to 55,000 ft (16,764 m) with their built-in pressurized cabins, which is considered one important improvement in modern aviation. Internal cabin pressure can be adjusted before each takeoff, thus maintaining the ambient pressure to a maximum altitude of 8000 to 10,000 ft (2438.4 to 3048 m) by means of cooled and humidified air bled off from the turbine engine (and regulated by outflow valves), and providing comfortable and necessary compartment conditions for passengers and crew, both to stay conscious and to conduct a safe flight.[19] Therefore, with commercial flights, aircraft personnel and passengers are exposed to only minor (but long-lasting) pressure alterations during flight, while military and aerobatic pilots are subjected to strong acceleration forces and rapid pressure changes.[14]

It is well-known that a hypobaric environment can cause severe dental problems for leisure as well as military and airline aviators, flight attendants, and frequent travelers;[11] moreover, astronauts, helicopter pilots, parachuters, and even mountaineers[5,8,30] have been described to suffer from barometrically induced damage, potentially occurring at both high and low pressures, known as 'head and face barotrauma.'[14] The latter includes barotrauma-related headache, external otitic barotrauma, barotitis media, barosinusitis, and barodontalgia

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(defined as dental pain evoked by a barometric pressure change);[29] it is well accepted that these adverse effects of flight altitude are all based on Boyle's Law. Dental barotrauma itself can manifest as microleakage and decreased retention of dental rebuildings, faulty dental restorations, and loosening or dislodgement of restorations and crowns.[7,15] Indeed, some reports have been published about restoration and/or tooth fractures on acute exposure to alterations of environmental pressure, and this obviously applies to both hypobaric in-flight[9,26,30] and hyperbaric diving conditions.[7]

Irrespective of a few papers reporting on fractures of sound and intact teeth at high altitude[9] or under laboratory decompression,[4] respectively, most cases of dental barotrauma described in the available literature revealed significant contributing factors after further in-depth analyses. In particular, this refers to excessive occlusal forces caused by clenching and grinding parafunctions commonly observed with (military) aircrews.[13,26,30] Additionally, there seems a broad consensus that dental barotrauma usually reflects a sudden flare-up of already prevailing subclinical dental disease due to barometric pressure changes.[5,29] This includes grossly restored teeth, leaking (amalgam) restorations of inferior quality, and (un)restored teeth with and without (secondary) caries.[4]

Taking into account the findings given above, several recommendations regarding oral rehabilitation as an integral part of aviation medicine have been published over the years; these fortunately have shifted from a primarily rigorous and exodontic treatment regimen to a more preventive concept (including early diagnosis), and have emphasized the strong need of enhanced retention of fixed prosthodontic devices.[3,14] However, when it comes to dental pain and tooth loss, personal performance of aircrew members may be hampered due to dietary deficiencies and, thus, dental rehabilitation by means of implants is considered to be an important issue in aviation dentistry.[28] Consequently, well osseointegrated implants as a timely and integral part of modern treatment concepts enable enhanced retention of crown and bridgework. As a matter of fact, however, contemporary recommendations and guidelines regarding aviation have scarcely covered implant-related aspects, and their respective impact does not focus on timely restoration techniques.

When it comes to the cementation of crowns with flight attendants, the available literature repeatedly refers to composite resins as materials of choice.[3,28] This has been deduced in particular from a few laboratory studies using epoxy models[23] or natural teeth,[16,17] but it has to be emphasized that all these experiments have been exclusively performed under simulated hyperbaric conditions of up to 304 kPa (which is equivalent to diving at 30 m/98.4 ft depth). By contrast, although the use of dental implant-supported restorations has increased tremendously over the last decades, no information on the retention of single cement-retained crowns on implant abutments is accessible with reference to the effect of aviation at hypobaric pressures; an altitude of 12,204 m (40,000 ft) above mean sea level results in a significant barometric decrease (from the standard pressure of 101.3 kPa to 18.8 kPa), and this might affect the mechanical strength of the luting agent, the resistance to functional forces, and the retention of implant-supported crowns.

Consequently, the present in vitro study aimed to demonstrate the retention of CAD/CAM manufactured zirconia oxide crowns on prefabricated implant abutments (luted with two commonly used cements) after submitting the cemented crowns to an in-flight environment, thus employing hypobaric conditions. The cements used to mount the crowns to the uniform titanium abutments were, on the one hand, a conventional zinc phosphate cement (representing the most traditional dental luting agent serving as a standard), while, on the other side, a modern resin-modified glass ionomer cement was used; both materials have recently been considered suitable for implant-supported crown cementation.[1,20,24] The cements were mixed either manually or by means of automix capsules. The null hypothesis (H_0) was that 1) there would be no difference in retention between the manual and the automix methods, and that 2) high altitude flying with its hypobaric environment would not affect the implant-based crown retention of either the manually or the automix cements; these hypotheses were tested against their alternatives of a difference (H_A).

METHODS

The National Library of Medicine (including PubMed/Medline) was searched to retrieve reliable pull-off forces for the cements used in this study. Based on that outcome a calculation for the number of cases needed (G*Power Statistic Software Version 3.1; Heinrich-Heine-Universität, Düsseldorf, Germany) revealed a case estimation of $N = 7$ for each subgroup and a total amount of specimens of $N = 56$. Due to the standardized and exclusively laboratory set-up using implant abutments, no approval of an institutional review board was necessary.

Materials

Fifty-six titanium abutments (S/RI 4.1 SUB-TEC PLUS WI; BEGO Implant Systems, Bremen, Germany) with a length of 5.5 mm, a diameter of 4.1 mm, and a taper of 4° were randomly divided into four groups (with $N = 14$ each). Each abutment was sandblasted circularly with aluminum oxide abrasive (Abrasive-blasting corundum, 110 μm; Orbis Dental, Münster, Germany) from a 15-mm distance for 10 s, along with a pressure of 2.5 bar, cleaned with steam as well as with 99% isopropyl alcohol (isopropanol 99.9%; Höfer Chemie, Sulzbach, Germany), and dried afterwards (**Fig. 1**). At first, one of the abutments was mounted on an implant analog (30 Ncm), which was embedded in a plaster model. The access to the screw was plugged with a cotton pellet and light-curing composite resin (G-aenial Flo; GC Europe, Leuven, Belgium). After sprinkling with Optispray (Cerec Optispray; Sirona Dental Systems, Bensheim, Germany) for 5 s, an optical scan followed by means of an imaging system (Sirona InLab inEos ×5, version 4.2.5.82936; Sirona Dental Systems).

A radial design was chosen when drafting the zirconia framework to obtain retention. Preliminary tests (unpublished)

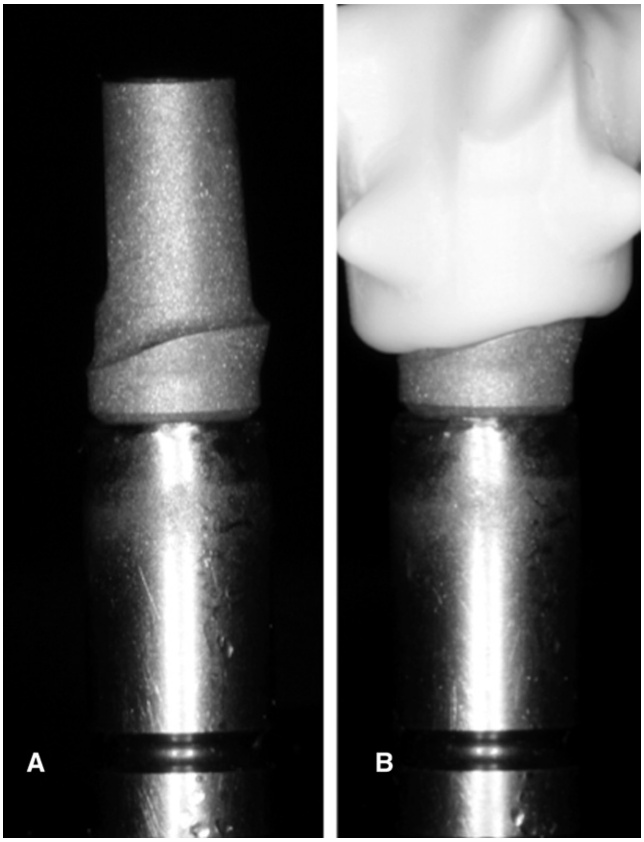

Fig. 1. A) Representative sample of the implant abutment used in the current study. B) CAD/CAM-processed zirconia coping revealing adequate passive fit.

showed that loops milled into the zirconia material have a tendency to fracture during pull-off testing. Subsequently, 56 zirconia copings were milled with a CAD/CAM wet milling machine (Sirona Cerec MC XL; Sirona Dental Systems), using 56 single ceramic blocks (Sirona inCoris Ceramics for inLab, super speed authorized, ZI F2 mono L; Sirona Dental Systems). The spacer was set to 80 μm, thus interpolating previous results investigating the internal gap width and retentive force of zirconia copings.[27] The copings desiccated for at least 24 h before the frames were speed sintered at 1541°C (Sirona inFire HTC speed sintering oven; Sirona Dental Systems) for 1 h and 45 min. Hereby, the oversized and smoothly milled frame of the charge used in the present study shrank linearly during the sintering process for some 20% to reach its designed dimensions and stability (Felber R, Sirona Dental Systems. Personal communication, 2017).

The sintered zirconia copings were checked for fitting accuracy using a silicon disclosing material (GC Fit Checker Advanced Blue; GC Europe), and the marginal area between abutment and coping was controlled using a binocular loupe (3.5× magnification). Neither the surface of the abutment nor the inner surface of the zirconia coping was worked on; the copings had to fit without additional adjustment (Fig. 1). Hence, inappropriate copings were excluded from the study (and were replaced by new ones).

Subsequently, the abutments were screwed on labor analogs (BEGO Implant Systems; torque: 30 Ncm) and embedded into cold auto-polymerizing acrylic resin (megaCRYL N; Megadental, Büdingen, Germany) lapped by a hollow lock screw using a perpendicular set-up. The zirconia copings were embedded vertically into a steel screw nut with the same resin (megaCRYL N) using the identical setup.

Procedure

The four groups were treated identically. At room temperature (23°C) the zinc phosphate cement (Harvard Cement; Harvard Dental International, Berlin, Germany) was mixed either manually or with automix capsules according to the manufacturer's instructions and was applied into the zirconia copings. The manually mixed cement was applied using a spatula ($N = 2 \times 14$), while with the automixed version the corresponding applicator ($N = 2 \times 14$) was used. The resin-modified glass ionomer cement (GC Fuji CEM 2; GC Europe) was mixed manually, and application into the copings followed by means of a spatula ($N = 2 \times 14$); for the automix cementation ($N = 2 \times 14$), the respective mixing tips of the automix cartridge were used. The copings were cemented on the abutments by means of an automatically compacting pressure of 50 N (Zwick Roell Z010, 10kn Proline MPMS S0206; Zwick, Ulm, Germany), with the force adjusted to be held for 5 min. Excess cement was removed after primary setting with a foam pellet and all cemented crowns were stored in a self-constructed, reproducible storage device (ensuring 95% humidity) for at least 3 d. Finally, the four groups were randomly divided, thus resulting in a total of eight groups (with $N = 7$ specimens each and with four flying and four ground control groups). A flow chart presenting the experimental set-up is given in **Fig. 2**.

The 56 test carriers were stored identically in two climatized boxes equipped with a thermostat (Digital Thermometer and Hygrometer; Trixie, Tarp, Germany) coupled with a heating element and a hygrometer with an attached vaporizer to ensure a constant temperature of 37°C and a humidity of 95%, respectively. Therefore, the upper side was made of a waterproof latex membrane, being sensitive to pressure (DermaDam medium; Ultradent, Cologne, Germany). To ensure portability, one box was linked to a 12-V car battery while the other one was stored on the ground.

To perform this study according to actual practice, a real aircraft (Cessna Citation Jet CJ 2+; Textron, Wichita, KS) was used (instead of a depressurized simulation chamber). Each carrier, including the abutment and the zirconia coping, was tested just once to avoid any inexactness or bias.

The portable box was stored in the pressurized baggage compartment of the jet for each flight. In total, 80 takeoffs and landings were done to altitudes between 37,000 and 45,000 ft (11,277.6 to 13,716 m), with a total flight time of 141 h. The pressure maintained in the compartment was adjusted to 10,000 ft (3048 m). The initial climb rate ranged from 2500 up to 3800 ft/min (762 to 1158.2 m/min).

After 6 wk, pull-off tests were performed with all 56 carriers. The specimens were mounted to a universal testing machine (Zwick Roell Z010, 10kn Proline MPMS S0206; Zwick) and the

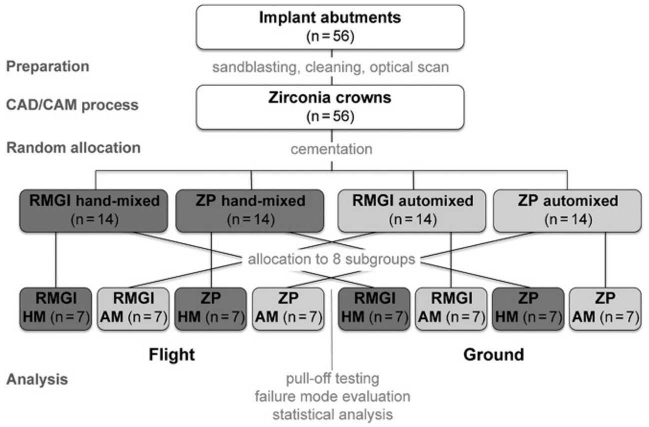

Fig. 2. Experimental set-up. A total of 56 zirconia crowns cemented with either resin-modified glass ionomer (RMGI) or zinc phosphate (ZP) on implant abutments were randomly allocated to eight subgroups (HM = hand-mixed; AM = automixed). Pull-off testing followed after exposing half of the specimens to hypobaric in-flight conditions.

copings were detached from the abutments with a speed of 2 mm/min. Uniaxial mounting to ensure that the applied forces operated in the direction of the path of insertion was secured to avoid any form of shearing stress, and tensile forces (F-max in Newtons) were captured by means of a dedicated built-in software (TestExpert II, version 3.61, reference xte000.zp2; Zwick) of the universal testing machine. None of the copings fractured during pull-off testing. After detachment, failure modes were evaluated as adhesive (debonding at the abutment/cement or the cement/coping interface) or cohesive (mixed failures, with bonded residuals on the abutment or on the coping surfaces).

Statistical Analysis

The Kolmogorov-Smirnov test was used to check for normal distribution of the evaluated tensile force values. Since differences between the method of mixing and the difference between the flight and ground group should be investigated, a two-sided Analysis of Variance (ANOVA) was performed, followed by Tukey's post hoc analysis ($\alpha = 0.05$). The significance level was adjusted according to Bonferroni. All statistical analyses were carried out using dedicated software (Statistical Package for the Social Sciences, v24.0.0.0; IBM, Armonk, NY).

RESULTS

The Kolmogorov-Smirnov test offered a normal distribution in each tested group ($P > 0.200$). Failure modes observed with the present experiments were classified as adhesive, with only few residual traces on some rare abutments' surfaces. The outcome of the present study is presented in **Fig. 3**, including minimum and maximum forces in Newtons needed to dislodge the copings.

The resin-modified glass ionomer cement generally showed the lowest retention forces, irrespective of ground or flight conditions, and this was not affected by the mixing methods. With this material, the mean (± SD) retentive forces ranged from 581.0 N (± 114.3 N) to 662.4 N (± 92.5 N) in the various subgroups.

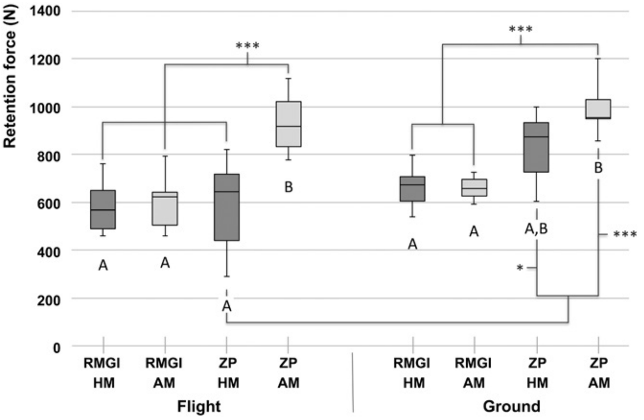

Fig. 3. Box-and-whisker plot (100%) presenting the outcome (retention forces) of the various subgroups. Resin-modified glass ionomer (RMGI) and zinc phosphate (ZP) subgroups (HM = hand-mixed; AM = automixed) specified with identical characters (A/B) indicate no significant difference. Significance levels are given by asterisks (* $P < 0.05$; *** $P < 0.001$).

The automixed zinc phosphate cement groups provided the highest retention values of all tested groups, both on the ground (996.0 ± 107.4 N) and in the flight group (931.9 ± 134.4 N). This was followed by the manually mixed zinc phosphate cement groups; here, the ground subgroup revealed a reduction (828.4 ± 147.9 N) of retentiveness, and this dropped to 581.6 N (± 204.5 N) after exposure to hypobaric conditions in the flight group.

Analysis of variance indicated significant effects regarding hypobaric flight conditions and mixing methods, and the respective details are summarized in **Table I**. Respecting only the outcome of the two-sided ANOVA, it can be stated, that, regarding the mixing method, there was a significant difference ($P < 0.001$) between all groups on the ground and those in flight. Disregarding the mixing method and comparing just flight and ground conditions, significant differences could be found ($P < 0.038$).

Pairwise comparisons (Tukey's post hoc test) offered no statistical differences between the resin-modified glass ionomer cement subgroups, either with regard to the mixing methods, or regarding flight ($P = 0.931$) or ground groups ($P = 0.981$). With the zinc phosphate cement groups, no differences could be detected with the automix version when comparing ground and flight groups ($P = 0.981$). However, significant differences were observed with the manually mixed zinc phosphate cement when comparing for flight and ground ($P = 0.015$). In addition, the manually mixed zinc phosphate cement showed significant differences regarding loss of retention between the automix groups ($P < 0.001$) after flying.

DISCUSSION

Although the first dental issues during flight were described some 80 yr ago,[2,26] dentistry in aviation has been astonishingly rarely discussed in the available literature.[14,29] Moreover, recent publications have noted that dental aspects of aviation have been much neglected both in dental education and

Table I. Analysis of Variance Table Summarizing the Effects of Hypobaric Conditions and Cement Mixing Methods.

SOURCE	SUM OF SQUARES TYPE I	DF	MEAN SQUARE	*F*	*P*
Model	31,081,629.4*	5	6,216,325.9	365.4	<0.0001
Ground/Flight	29,996,952.6	2	14,998,476.3	881.6	<0.0001
Mixing Method	1,084,676.8	3	361,558.9	21.3	<0.0001
Error	867,703.6	51	17,013.8		
Total	31,949,333.0	56			

* $R^2 = 0.973$ (corrected $R^2 = 0.970$).

research,[5,14] and have emphasized a growing importance of dental flight disorders, not justifying any further ignorance of the latter.[19] The latest report of the International Civil Aviation Organization (ICAO) documented some 3.7 billion passengers (with a continuously rising tendency and, correspondingly, with increasing aircrew numbers) in 2016.[12] With these numbers in mind, a steadily growing number of dental flight complications would seem conceivable, both with military flyers and with passengers and crews of commercial airliners;[11,30] however, actual occurrences of barotrauma have been rarely documented in the recent literature, if compared to reported incidences from the first half of the 20th century, and this obviously is due to continuously enhanced dental techniques, generally increased oral care awareness and improved oral health,[15,19] and should be owing to modern partially pressurized aircraft (representing less of a dental hazard if compared to former times).[7,29] No doubt some cases of barotrauma might remain unknown, either due to the patient's or caregiver's neglect.

With the use of both the uniform implant abutments and the identically processed CAD/CAM copings, a maximum standardization with reproducible precision could be achieved in the current investigation. It is known that low abutment heights and, in particular, high taper degrees of abutments do coincide with decreased retentiveness.[1,25] Therefore, together with the sandblasted and unvarying surface, height (5.5 mm) and convergence angle of the used abutments (4°) guaranteed maximum and uniform frictional retention of the zirconia crowns in a clinically relevant and near-to-reality set-up, thus allowing for evaluating mainly the effects of flying at high altitude on the various cements. Previous studies under hyperbaric conditions used manually prepared extracted teeth[15–17] (with unknown and presumptively varying preparation dimensions) or crown dies made of epoxy resins[23] (which is considered to be of decreased clinical significance). Hence, a considerable degree of variation regarding the preparation geometries must be assumed with the former investigations,[10] and this should have contributed to a momentous spreading of the respective outcomes.

A marginal gap of 80 μm was adjusted with the CAD/CAM software for the present set-up;[27] this was considered clinically relevant, both with regard to retentiveness of the used cements and to accuracy of fit, and with reference to clinical acceptance of the gap width.[21]

To allow reaching the final strength of the cementing materials, complete setting was guaranteed for at least 72 h before the first takeoff. All in all, our experimental setup concurred with the majority of the literature and with regard to internal validity, controlled for possibly influencing factors, thus revealing a low variability.[10] However, it should be emphasized that other parameters such as artificial ageing, water storage, or temperature cycling were not evaluated,[10] nor was any form of masticatory stress or grinding simulation performed.[13]

There is no doubt that manual mixing of dental cements is a widely spread technique when it comes to the cementation of fixed prosthodontics. However, hand-mixed luting agents reveal a greater number of larger diameter bubbles of trapped air when compared with capsulated cements;[22] the resulting porosities may effectuate higher water solubility and microleakage, contribute to reduced strength, and will greatly affect the longevity and success of a restoration.[18] It is to be emphasized that these aspects obviously have contributed to the (nonsignificant) decrease of the adhesive force with the manually mixed zinc phosphate cement in the (ground) control group (Fig. 3).

In the present study, the highest retention could be observed with the (automixed) zinc phosphate cement subgroups, and this was in accordance with previous studies using a comparable design.[1,20] However, all subgroups employed with the current set-up revealed a reduced mean retention after exposure to real hypobaric pressure changes (80 flights), and this was particularly pronounced with the zinc phosphate cement. It is a well-known fact that air density and atmospheric pressure decrease with increasing height, and this implies that standard pressure at mean sea level will be reduced by a factor of five with the flight altitudes used in the current set-up. The manually mixed zinc phosphate cement showed a significantly decreased adhesion and a wider spread of retention when compared to the automixed cement after exposure to hypobaric pressure cycling; nonetheless, mean retention values were still high and it may be speculated whether these adhesion values would have dropped to a more severe extent in the case of increased flight numbers. Notwithstanding, the current outcome corroborated previous results, revealing a significant decrease of retention with zinc phosphate-cemented crowns after cyclic hyperbaric pressurization.[15,17] Moreover, progressive disintegration and microleakage of zinc phosphate cement have been documented after exposure to marked variations in environmental pressure.[16,17]

The most probable reason for this effect should be microporosities incorporated accidentally during the manual manipulation of the cement. Alterations of the ambient pressure during and after flight will result in a continuously repeated dilatation and contraction of these voids and microtubules, thus weakening the cement structure, leading to disruption and microleakage,[15] and, finally, resulting in loss of retention and complete dislodgement of crowns.[11] Consequently, accidental air entrainment should affect all malleable dental materials (as used for direct and/or indirect dental restorations such as inlays and crowns). Indeed, similar observations have been reported even with fiber posts luted adhesively with composite resins[6] and after cementation of orthodontic bands using a traditional glass ionomer.[8] Thus, mechanical failure of luting cements after depressurization at high altitude obviously constitutes a further serious case of barotrauma.

In contrast, the resin-modified glass ionomer cement revealed a generally lower capability of adhesion during pull-off testing when compared to the hand-mixed zinc phosphate groups; however, the observed difference was not statistically significant. Moreover, with regard to both mixing method and depressurization, this type of cement provided more constant retention forces (Fig. 3). This again is corresponding to a previous investigation reporting that the retentive strength of orthodontic bands cemented with resin-modified glass ionomer cement was not significantly affected by pressure cycling.[8] Resin-modified glass ionomers are highly viscous and can be characterized by a high tensile strength, a low elastic modulus, and a high plastic deformation.[8,18] This could explain the current outcome and would support this cement's suitability for luting zirconia ceramic restorations over implant abutments.[24] Moreover, resin-modified glass ionomers revealed comparably low pore volumes after setting (along with a homogeneous cement layer).[18] This material's feature would mean a decreased susceptibility to barotrauma.

Interestingly, the samples of all subgroups revealed bond failures occurring at the abutment/cement interface, with only smallish remnants of cement retained on the surfaces of a few abutments. The cements almost exclusively stuck to the intaglio surface of the copings, which would suggest a missing adherence to the inert titanium abutment surfaces, even though the latter had been modified by air-borne particle abrasion. Instead of any adhesive bonding to the abutments, it seems obvious that retention was achieved by micromechanical interlocking only, thus explaining the predominantly adhesive failure modes observed with the present experiments.

All in all, the null hypothesis of the present in vitro study (assuming that there would be no difference between a manually and an automixed zinc phosphate cement or a resin-modified glass ionomer cement when linking a CAD/CAM milled zirconia oxide crown to a prefabricated implant abutment) was partially rejected. With the exception of the manually mixed zinc phosphate cement, however, no other group revealed significant differences regarding retention forces after repeated depressurization. With regard to the current outcome, it should be noted that absolute values between different studies are hardly comparable; moreover, pull-off testing of crowns is supposed to represent a clinically relevant evaluation method, even if conclusive evidence of whether the pull-off test (representing a crown dislodgment via the abutment's long axis) corresponds to an indisputable and clear clinical correlate has not been documented up to now.[10]

Without exception, contemporary recommendations for dentists treating aircrews and frequent flyers[3,5,28] are based on studies not referring to implant-supported CAD/CAM technology and its corresponding material-related aspects. With the present investigation actually using in-flight conditions (not relying on pressurized chambers to simulate the influence of flying), a significant effect of a hypobaric aircraft environment could be demonstrated for the first time. Due to the fact that there is an enormous amount of different luting agents, various ceramics, and alloys for linking crowns to varying types of abutments, the present study adds some minor but valuable appraisal on the effect of aviation dentistry to the retention of (nonretrievable) crowns attached to implant abutments. It would seem conceivable that the current outcome is well transferable to crown and bridge work fixed to natural teeth. However, further studies to provide evidence-based knowledge for treating aircrew members and frequent flyers are clearly warranted.

Within the limitations of the current in vitro study, the following conclusions can be drawn:

- Hand-mixing of zinc phosphate cement leads to a negatively affected retention of implant-supported zirconia oxide crowns. Even if this effect was not significant in the present study, its respective long-term influence on retention cannot be ruled out, and dentists should dispense with manual mixing procedures when using this material.
- Depressurized environments as occurring in modern aircraft are barotraumatic conditions negatively influencing the retention of CAD/CAM fabricated zirconia oxide crowns on implant abutments when using manually mixed zinc phosphate cement for definite mounting.
- Automixed zinc phosphate cement is not considered untrustworthy for hypobaric conditions and would seem favorable over resin-modified glass ionomer cement when striving for high retention forces of fixed prosthodontics.
- Taking into account the confirming external validation from previous studies,[8,18,24] dentists might consider using resin-modified glass ionomer cements when cementing crowns and fixed partial dentures for patients likely to be exposed to pressure cycling. This material class provides lower retention forces for implant-retained zirconia oxide crowns but does not seem vulnerable to manual mixing or hypobaric conditions.

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