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ORIGINAL ARTICLE

Clinical performance of screw-retained and cemented implant-supported zirconia single crowns: 36-month results

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Abstract
Objectives The objective of this clinical study was to evaluate the clinical performance of implant-supported zirconia crowns with a sintered veneering cap. Furthermore, the influence of the type of retention (screw-retained vs cemented single crowns) was analysed.
Materials and methods Fifty-eight patients were accommodated with 114 implants, inserted in the molar and premolar regions. Zirconia-based crowns with a sintered veneering cap were either screw-retained (n = 53) or cemented (n = 61) on the implant. Recalls were performed every 6 months. The state of soft tissue was documented by the modified plaque and gingiva index (mPI) and sulcus bleeding index (mSBI). The restorations were evaluated for technical failures like veneering porcelain fractures, surface qualities and marginal fitting.
Results Neither implant loss nor crown fractures occurred. After a mean clinical service time of 36.9 months, fractures of the veneering porcelain were registered in 1.8 % of the cases. The Kaplan-Meier survival probability regarding eventless restorations was 98.2 %. Chipping of the veneering porcelain was registered in two cemented crowns without statistical influence of the type of retention. The indices showed healthy soft periimplant tissues in both groups.
Conclusions Implant-supported zirconia crowns with a sintered veneering cap demonstrated good clinical performance. The type of retention had no influence on technical complications.

Keywords Implat · Implant-supported crown · Screw retention · Cementation · Single crown

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Introduction

Prosthetic restorations made of all-ceramic materials have proved suitability in the aesthetic zone due to their high aesthetics and outstanding biocompatible parameters [1–7]. Nevertheless, clinically based evidence is a key factor in distinguishing survival and longevity of one material versus those of another.

Dental ceramic materials have been developed to match with the demands of different indications like aesthetics, biocompatibility, wear resistance, low thermal conductivity and colour stability. Ceramic restorations are frequently placed in contemporary practice [8].

With the introduction of the high-strength ceramic zirconia, even the treatment of posterior teeth with all-ceramic restorations and the application of ceramic abutments for implant restorations became possible [9–11]. In addition to its high strength, zirconia exhibits lower plaque accumulation and bacterial adhesion compared to other ceramic materials used in the oral cavity [12]. Zirconia is processed by milling either presintered or fully sintered blanks with the aid of computer-aided design/computer-aided manufacturing (CAD/CAM) systems in order to achieve industrial quality standards [13]. Studies of layered zirconia have reported that chipping of the veneering porcelain is the major clinical problem [14–20] and influenced by several factors [21–27]. One technical solution might be the digital veneering of zirconia-based copings

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described several years ago, showing promising mechanical strength [24, 25].

Although implant-supported zirconia-based restorations exhibit high clinical survival rates [17], resembling the ones of tooth-borne reconstructions [28], the rate of chipping is higher than for tooth-supported restorations [16, 29, 30] due to missing periodontal receptors on implant-supported restorations [31, 32].

Implant restorations can either be screw-retained on the implant or cemented on standard or customized abutments. Both options have shown similar outcomes in clinical studies [28]. While cemented restorations exhibit more serious biological complications (periimplant inflammation), as a consequence of possible remaining excess cement [33–35], screw-retained reconstructions are retrievable but show more technical problems [28, 36–38].

The aim of the current study was to investigate the clinical survival rate of zirconia implant-supported all-ceramic single crowns with a sintered veneering cap with two different types of retention. The null hypothesis was that the used zirconia crowns show no adequate stability regarding chipping. The working hypotheses of this study were that the ziconia implant-supported crowns with sintered veneering caps show comparable survival rates to outcomes in the literature. The effect of retention was compared between both cemented and screw-retained restauration in a prospective study design.

Material and methods

Fifty-eight patients were included in this randomized prospective study between March 2008 and November 2013 from two dental offices in Munich. Inclusion criteria were in need of at least one implant-supported single crown, adult (≥18 years), good oral hygiene (API < 10 %, SBI < 10 %), non-smokers or moderate smokers (less than five cigarettes per day), no TMD problems according to the RDC criteria [39, 40], and no contraindications for surgery. After gathering detailed preimplant medical history (general as well as specific) from all patients, individual surgical implant planning was made based upon a panoramic radiograph and dental model analysis following a standardized protocol.

All clinical investigations have been conducted according to the principles expressed in the Declaration of Helsinki. Registration of the study was performed after conduction of the study as a result of changes in ethics policies. The study was approved by the institutional ethics committee of Munich University (no. 434/14). Patient gave their written consent.

Surgical and restorative treatment

A crestal incision was made, followed by the preparation of a mucoperiosteal flap to expose the alveolar bone. In cases of reduced vertical bone height in the maxilla, augmentation in the sense of a sinus lift augmentation surgery was performed before inserting the implants (Camlog Promote/Promote Plus; Conelog, Wimsheim, Germany) at a maximum torque of 50 N cm, using a drilling template (according to the insertion protocol). Additionally, simultaneous bone augmetation procedure with autologous bone, bovine bone graft substitute and resorbable collagen membrane (BioOss & BioGide, Geistlich Pharma, Wolhusen, Switzerland) was performed in cases where vestibular augmentation was needed. In all cases, a closed healing was performed by saliva-proof (resorbable/non-resorbable) sutures. For postoperative control, a panoramic X-ray was taken and patients were supplied with ibuprofen 800 in addition to the preoperative antibiotic and anti-inflammatory single-shot treatment (clindamycin, cortison). The surgical part was completed by the re-entry and insertion of the healing abutment 4 months after implant placement. Two weeks after re-entry, impressions were taken to transfer the implant position by the open tray technique by using polyether material (Impregum, 3M ESPE, Landsberg, Germany).

Dental laboratory

After producing the master casts and mounting them in a semi-adjustable (SAM PX 2, SAM, Gauting, Germany) articulator, the titanium abutments were selected by the technician depending on the implant axis and level of soft tissue. The models were treated to create an emergence profile [41–43]. If needed, the titanium abutment was customized by grinding, before the coping was fabricated in wax. Particular attention was paid to the minimum thickness of 0.5 mm. The wax pattern of the coping was scanned (D 700, 3shape, Copenhagen, Denmark) and then milled out of a presintered zirconia block (IPS e.max ZirCAD, Ivoclar Vivadent, Ellwagen, Germany) by a CAD/CAM system (Corona, Starnberg, Germany) and sintered to full density (Denta-Star S1 plus, Thermostar, Aachen, Germany) to obtain the zirconia coping of the crown.

The veneering was fabricated from lithium disilicate according to the CAD-on technique described earlier [44]. However, deviant from the traditional protocol, the veneering caps were fabricated in pressing technique instead of CAD/CAM fabrication. Therefore, a wax pattern of the veneering cap was produced and invested (IPS PrimaVEST Press, Ivoclar Vivadent) according to the manufacturer's instructions. After burning out the wax and heating up the muffle, the veneer cap was pressed by using a special lithium disilicate glass ceramic (IPS e.max Press, Ivoclar Vivadent). The two components (CAD/CAM framework and overpressed veneering cap) were sintered together in a conventional ceramic furnace (Austromat, Dekema, Freilassing, Germany) at a

temperature of 780 °C by the means of a low-fusing ceramic material (Hotbond Fusio Sytem, DCM, Rostock, Germany). In order to create a suitable surface quality, several glaze firings were performed after necessary adjustments were made by using diamond grinding tools (Table 1).

In cases of screw retention, the ceramic crown was bonded on the titanium abutment by using a resin-based luting material (Multilink Implant, Ivoclar Vivadent).

If a customized zirconia abutment was required for aesthetic reasons, also a wax pattern was fabricated; this wax pattern was scanned (LAVA TM ScanST2, 3M ESPE, Landsberg, Germany) and milled by a CAD/CAM system (Corona, Starnberg, Germany) from presintered zirconia (LAVA, 3M ESPE) and sintered in the furnace of the system (LAVA-Therm, 3M ESPE). The sintered zirconia abutment was bonded to the titanium base by a dual-curing composite resin (Multilink Implant). After the custom zirconia abutment was finished, the allceramic superstructure was produced in the same way as described above.

Prosthetic procedure

Prosthetic restorations were either screwed-in or cemented implant single crown based on a computer-generated randomized list. Fifty-three crowns were screw-retained (Figs. 1 and 2), whereby the access was sealed with Ketac Fil and flowable composite. The other 61 crowns were fixed on the abutment by using a resin-modified glass ionomer cement (Fuji Plus, GC, Alsip, IL (USA)/Ketac Cem, 3M ESPE, Landsberg, Germany). A postoperative radiograph was performed additionally to clinical observation for possibly remaining excess cement. The insertion of the implant crowns was carried out by the following proven prosthetic occlusion concept. Static, dynamic and approximal contacts were checked and removed if necessary. The objective was to avoid dynamic contacts on molars and to achieve less static occlusion contact on implant-supported crowns than on natural teeth, checked by the 8-μm-thick Shimstock foil (Bausch, Köln, Germany). Less static occlusion contacts of implant-supported crowns were achieved when the Shimstock foil was hold tight only at the adjacent teeth in maximum intercuspation. The occlusion was adjusted so that each tooth presented at least one stable occlusal contact in maximum intercuspation. Contacts in lateral excursions on the restorations were eliminated. If occlusal adjustments were necessary after cementation, diamond burs with 30–40 μm grain size were used (contra-angle handpiece; 100,000 rpm; water cooling 50 ml/min). Finally, the occlusal surface was polished again with ceramic polishing instruments in three steps (Zirconium Polishers fine and extra fine, Oridima, Ortenburg, Germany).

Table 1 Furnace program for sintering

Drying			20:00
Closing			03:00
Preheating	380 °C		02:00
Temperature 1	780 °C	35 °C/min	01:00
Temperature 2	500 °C	45 °C/min	00:30
Temperature 3	... °C	...°C/min	–
VAC	780 °C	100 %	–

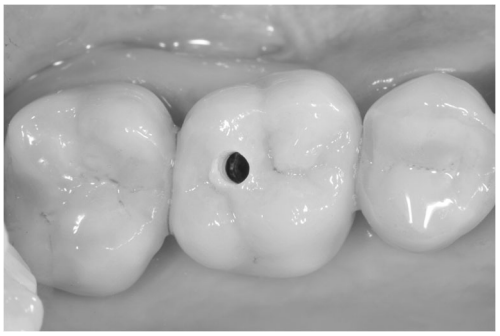

Fig. 1 Occlusal view on a screw-retained crown at the time of delivery

Recall

One week after insertion of the crown, the occlusion was checked again. At the next follow-up appointment after 6 weeks, crowns and periimplant tissues were inspected again and patients were reinstructed concerning adequate oral hygiene. Depending on necessity, professional tooth cleaning was performed two up to four times a year in addition to the 6-month recall monitoring. Contact wear was checked based on the Shimstock protocol as described above. Occlusal adjustments were protocolled by photographs in which each modification was indicated by one calibrated dentist.

Statistics

The monitoring and documentation of the results was performed by one calibrated dentist who was neither involved

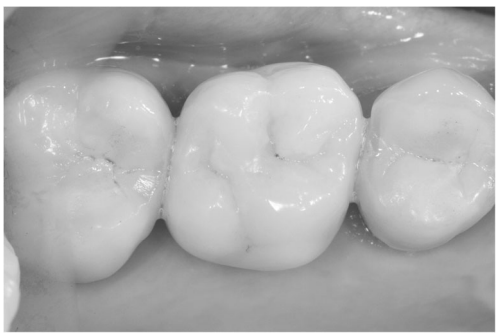

Fig. 2 Occlusal view on a screw-retained crown at the 6-month recall

in placing the implants nor in delivering the crowns. The following parameters were gathered: the modified plaque and gingiva index (mPI) by Silness and Löe and modified sulcus bleeding index (mSBI) described by Muehlemann. The modified Silness and Löe plaque and gingiva index is defined by a score from 0 (=no plaque and no inflammation), 1 (=mild inflammation and a film of plaque adhering to the free gingival margin which cannot be seen with the naked eye but only by using probe), 2 (=moderate inflammation with moderate glazing, redness, bleeding on probing and moderate accumulation of deposits within the gingival pocket and on the gingival margin, which can be seen with the naked eye) to 3 (=abundance of soft matter within the gingival pocket and/or on the tooth and gingival margin; severe inflammation with redness, hypertrophy and tendency to spontaneous bleeding). The modified Mühlemann sulcus bleeding index is scored from 0 (=no bleeding), 1 (=a single discreet bleeding point), 2 (=several isolated bleeding points or a single line of blood appears), 3 (=the interdental triangle fills with blood shortly after probing) to 4 (=profuse bleeding occurs after probing). The restorations were evaluated for technical failures like chipping behaviour, surface qualities and marginal fitting, as well as the interface quality of coping and sintered veneering and contact wear according to the modified US Public Health Service (USPHS) criteria rating system. Results of this rating system were evaluated by using the Mann-Whitney *U* test. Descriptive statistics for quantitative variables are given as the mean ± standard deviation. The data were analysed with the "Statistical Package for the Social Sciences" software (IBM SPSS Statistics for Windows, Version 22.0; IBM Corp., Armonk, NY, USA). Association of possible predictor variables with the dependent variable chipping was determined by using the Kaplan-Meier estimator and univariate log-rank test. The Kaplan-Meier method was used to plot survival curves for chipping as a putative binary prognostic factor. Differences were considered to be statistically significant for a two-sided p value of less than 0.05.

Results

Patients

A total of 58 patients were successfully treated in this study and were prospectively evaluated based on the study protocol. Over the observational time period, eight patients were excluded as dropouts because they did not agree to participate in the follow-up intervals in five cases, two patients moved, and one patient did not want to have his follow-up data collected. There were 36 women and 22 men included in this study. Of the 114 implant-supported zirconia-based crowns veneered with a high-strength ceramic by sintering, 53 crowns were inserted in a screw-retained manner, and 61 crowns were fixed on the abutment by using a resin-modified glass ionomer cement. The distribution of crowns applied is shown in Table 2.

The mean observation period for the restaurations of all patients included was 36.9 months (Fig. 3).

Prosthetic restoration

The cumulative incidence of veneering fractures was 1.8 % (Figs. 3 and 4), resulting in a 98.2 % overall success rate. After 3 years of follow-up, no chipping was detected in any group. Chipping occurred on two cemented crowns (3.3 %) after a mean time of 48 ± 5.7 months, whereas no chipping was found on screw-retained ones. Comparing both groups, no significant difference was detected between cemented and screw-retained implant crowns by using the univariate log-rank test ($p = 0.518$, Fig. 3).

The mean plaque index in all groups was 0.5 ± 0.6. In patients with cemented crowns, the mean plaque index was 0.6 ± 0.1 compared with 0.4 ± 0.1 in patients with screw-retained fixated crowns. There was no significant difference between both groups ($p = 0.08$). The mean gingival index was 0.4 ± 0.5. Patients with cemented crowns showed a mean gingiva index of 0.4 ± 0.1, whereas patients with screw-retained crowns had a mean value of 0.3 ± 0.1. Between both groups, no difference was detected ($p = 0.41$). The mean bleeding index was 0.6 ± 0.6 in all patients, for patients with cemented crowns with an index of 0.7 ± 0.1 compared with 0.5 ± 0.1 in screw-retained crowns. There was no difference between both groups ($p = 0.66$). Patients were restored with crowns at different gingival levels depending on the aesthetic and functional results. In cemented crowns, 15 were localized at the gingival level (isogingival), 3 above (supragingival), and 43 were applied under the level of gingiva (subgingival). There was no association with the gingiva, bleeding or plaque index in any group. Custom abutments were used for 27 crowns, while standard abutments were used in 34 cases. Again, there was no association between the type of abutment applied or chipping ($p = 0.196$). There was no influence on the plaque index ($p = 0.254$), gingival index ($p = 0.377$), nor the bleeding index ($p = 0.102$) of the soft tissue around the crowns. In comparison, crowns with screw retention, 7 were located at the gingival level (isogingival), 6 above (supragingival), and 40 were applied under the level of gingiva (subgingival). In these cases, no association detected with the gingival, bleeding or plaque index was found.

Table 2 Number of implant teeth restorations depending on the position of the applied crown

Tooth position [upper jaw]	17	16	15	14	24	25	26	27
Number of restaurations	3	5	4	6	2	5	3	3
Tooth position [lower jaw]	37	36	35	34	44	45	46	47
Number of restaurations	4	10	3	0	2	1	9	1

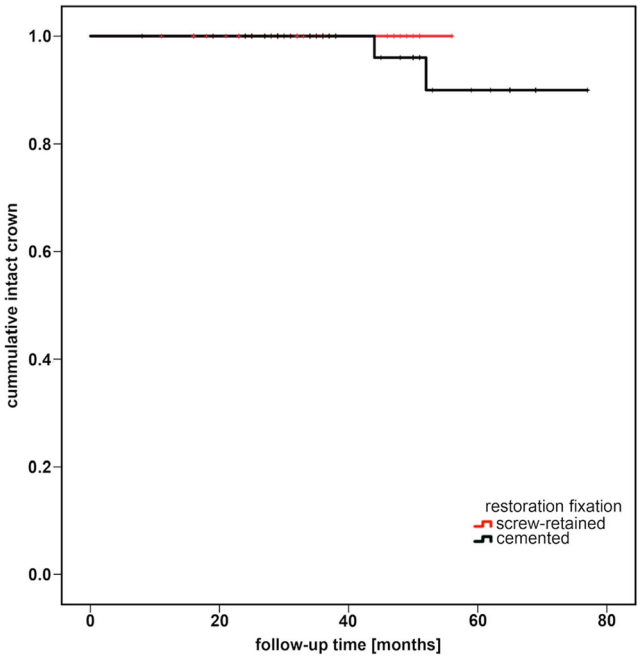

Fig. 3 Kaplan-Meier graph showing all events for screw-retained and cemented crowns in relation to the time of occurrence. Between both groups, no significant difference was noted evaluated by the log-rank test ($p = 0.518$)

The detailed clinical inspection revealed an apparently proper condition of the crown surfaces in general (beside the two chipping cases mentioned above). There were no irregularities or marginal gaps detectable on dental probe over time. On a range from alpha, bravo, charlie, to delta, 112 crowns could be classified to alpha and two crowns were bravo (modified USPHS criteria). Between both groups, no significant differences were detected.

Furthermore, it was investigated whether the all-ceramic superstuctures or antagonistic dentition showed any contact wear. The cemented restorations did show visible contact wear in 1.8 % of cases, whereas contact wear was found on screw-retained implant crowns in 4.6 % of cases without exhibiting statistical differences ($p = 0.480$).

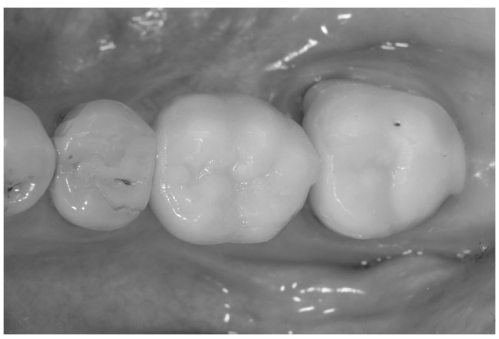

Fig. 4 Occlusal view on veneering porcelain fractures of a cemented crown (first molar); the tooth-supported crown on the second molar also exhibits a fracture of the veneering structure

Cemented restorations caused contact wear on the antagonistic teeth more frequently than screw-retained crowns (16.5 vs 10.7 %). Comparing these results by using the Mann-Whitney *U* test did not reveal any significant difference ($p = 0.318$). These traces of contact wear were found in patients who showed crossbite or extreme deep bite situations as well at those lacking a clear canine guidance.

Discussion

Regarding the survival rates of zirconia implant-supported crowns with a sintered veneering cap, the first working hypothesis of this study has to be rejected. The current study shows that zirconia-based crown copings being veneered with a high-strength ceramic cap show better performance with respect to their chipping behaviour and demonstrate potential significant lower risk of ceramic fractures compared with the literature. Based on the finding of this study, the null hypothesis could be rejected. Chipping of veneering ceramics has been reported in various clinical studies [14, 15, 45–48]. In a systematic review of the survival and complication rates of implant-supported single crowns, Jung et al. reported 4.5 % chipping after 5 years [17].

In a retrospective study, Schwarz et al. revealed an incidence of chipping in implant-supported all-ceramic single crowns of 24.5 % after an observation period up to 5.8 years [18].

A prospective clinical study, performed by Glauser et al., registered no chipping of implant-supported restorations after a median service time of 49.2 months, taking into account that the majority of the treatments were performed in anterior regions [49]. The results of the present study are similar, as chipping occurred after 48 ± 5.7 months.

In a systematic review, Sailer et al. detected that fractures of the veneering porcelain occurred more frequently on tooth-supported zirconia single crowns than on metal-ceramic single crowns ($p < 0.001$) after 5 years. They recommended that zirconia-based single crowns should not be considered a primary option due to their high incidence of technical problems [50].

According to the systematic review, conducted by Sailer et al. in 2007, all-ceramic crowns on natural teeth showed survival rates after 5 years comparable to those seen in metal-ceramic crowns when used in anterior regions. Lower survival rates of 90.4 and 84.4 % were found in glass-infiltrated alumina crowns and glass-ceramic crowns when used in the treatment of premolars and molars [51].

In vitro studies have demonstrated that CAD/CAM-produced veneerings were significantly less sensitive to ageing than hand-layered veneerings and show significantly lower initial load-bearing capacities (mean 1165.86 vs 395.45 N). During chewing simulation, 87.5 % of the crowns in the hand-layered group failed, whereas no crown in the CAD/CAM group failed [25]. The CAD/CAM production of veneers for

restorations with zirconia framework is a promising way to reduce failures originating from material fatigue [24, 44].

In vitro studies showed as well that zirconia-based crown copings being veneered with a high-strength ceramic cap have a better performance in terms of fracture load and demonstrate potential significant lower risk of chipping [44].

The second working hypotheses concerning the difference between cemented and screw-retained implant crowns can be accepted. In the present clinical study, chipping of parts of the veneering ceramic was registered on two cement-retained single crowns in the first molar of the lower jaw. According to Kaplan-Meier, there was no significant difference detectable in the chipping rate between cemented and screw-retained implant crowns ($p = 0.518$). Anyway, screw-retained implant crowns are more favoured by the clinician, due to their reduced risk of biological complications as a consequence of remaining excess cement. In the present study, we found no significant difference between both groups, either screw-retained or cemented. Based on these findings, both methods showed comparable results which offers the clinician both possibilities of retention without any disadvantage regarding the outcome in terms of plaque, bleeding or gingival indexes. In addition, the antagonistic teeth exhibited all-ceramic crowns in the first case and composite fillings in the second case.

With regard to the contact wear behaviour of the antagonistic teeth (14.1 %), no tendency is preferable. Abrasion occurred in natural teeth, as well as in teeth that had been provided with composite fillings, also in ceramic crowns or bridges and restorations made of gold and acrylic resin dentures. Further specific investigations are needed to answer the question if high-strength ceramic reconstructions as described above might even be too strong.

Most studies evaluating chipping after restorations with ceramics are limited by the fact that the patients are surveyed in a retrospective manner. Only large, controlled, prospectively designed studies can resolve clinical questions completely. Although the present study was performed in a prospective manner, there are also some limitations associated with the patients' selection over a long time period as well as with the limited number of patients, which still requires for more studies or participation of multiple centres. In addition, the cause of chipping cannot be deduced from the current study. The present results are promising, but still, more data is needed concerning hygiene, stability and patients' satisfaction.

Conclusions

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

Within the limited mean observation time of 36.9 months, implant-supported zirconia-based crown copings being veneered with a high-strength ceramic by sintering, both cement-retained and screw-retained, demonstrated a satisfying success rate under clinical conditions for premolar and molar regions. In regards of technical and biological outcomes, screw-retained single crowns showed comparable clinical performance to cemented single crowns.

Compliance with ethical standards

Conflict of interest Author FC and TM state that no conflict of interest exists.

The author CC lectures for Camlog and Ivoclar for an adequate honorarium.

The author PR lectures for Camlog and Ivoclar for an adequate honorarium.

The author JH lectures for Camlog and Ivoclar for an adequate honorarium.

The author FB lectures for Camlog and Ivoclar for an adequate honorarium and conducts third-party research for both companies.

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Ethical approval All procedures performed in studies involved were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the ethical review board of the Munich University (no. 434 14).

Informed consent Informed consent was obtained from all individual participants included in the study.

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