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Title picture hint: From case report of Noushin Vahdat-Pajouh and Edgar Schäfer, here figure 7: Radiographic follow-up of tooth 34 after 4 months, p. 60–66

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Monolithic zirconia: a source of temporomandibular disorders in the future?

Background

Proven porcelain fused to metal restorations are increasingly being superceded by milled zirconia ones. Initially, in the 1960s the porcelain fused to metal crowns were quite resistant to abrasion which led to the "softer" opposing tooth showing significant signs of wear. Figure 1 shows such a case. The upper arch was restored with a fixed horseshoe shaped, porcelain fused to metal construction which occluded against a mixture of natural teeth and precious metal crowns. Over the subsequent years the patient had abraded his mandibular anterior teeth down to the level of the marginal gingivae. Latterly, the veneering porcelains have become "softer" so that such clinical cases are less often seen nowadays.

Occlusal surfaces milled from zirconia are considered to be very wear resistant [8, 11, 12]. This raises the issue of what are the consequences of such wear resistant materials on the cranio-mandibular system? Do they damage the temporomandibular joint (TMJ)? Do they trigger parafunctional habits? Do they result in wear of the occluding dentition? Presently, there is insufficient evidenced based research to answer these questions adequately, there being only a few in-vitro and in-vivo studies [4, 6, 7]. In-vitro studies have

Figure 1 Lower jaw teeth with attrition down to the level of the marginal gingiva; antagonist: metal ceramic reconstruction

Figure 2 Monolithic zirconia restoration; crown 36 and 37 were occusally distal adjusted. Staining and gloss were removed. The surface was not polished after adjustment.

Figure 3 Antagonists to the fixed partial denture shown in Fig. 2; tooth 26 was occusally adjusted. The adjusted surface is very rough and unpolished.

Translation: Graham Wroe
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(Fig. 4a/4b: P. Proff)

Figure 4a Example of a dental arch of elder patient with attrition of enamel and dentine

Figure 4b Teeth with attrition: no cusps are seen anymore.

(Fig. 1–3 and 5: M. Behr)

Figure 5 Tooth 46 is one of the first monolithic crowns. The other teeth had on the occlusal surface enamel or resin composite.

shown that highly polished zirconia surfaces will not "wear out" tooth enamel or other silicate based ceramics [8, 10]. However, this does not apply to rough, unpolished zirconia. This is often discovered, for example, after making occlusal grinding adjustments. Figures 2 and 3 show an example. Both the opposing teeth (Fig. 3) and the restoration (Fig. 2) have become severely abraded through use. All the outer surfaces were insufficiently polished after making grinding adjustments. The area of contact on the occluding tooth is badly worn down. In-vitro and as the first in-vivo studies demonstrate [3, 8, 11]: non or poorly polished zirconia surfaces can cause considerable abrasive damage to the opposing dentition. So, one of the basic tenets is that occlusal surfaces fabricated from zirconia must be highly polished.

Taking these factors into consideration the following question remains. What happens in the masticatory system to the position of the occlusal plane, when over the years natural wear results in one part of the dentition but not another? (Fig. 4a, Fig. 4b) In the 1950s Begg [1, 2] and Pedersen [9] studied the dentitions of Australian aborigines and eskimos and then compared them to people who had "western" lifestyles. The elderly from these indigenous groups had substantial wear of their teeth. The cusps and occlusal enamel were totally abraded and the remaining dentin surfaces had been ground flat in a circular manner. However, they had no gaps in their dental arches with periodontally closed, small papillary spaces and edge to edge bite relationships. Evidently, the masticatory system was able to adapt to a lifetime of hard tooth substance loss by compensation of the jaw bones and periodontium, the TMJs and also the muscles of mastication to prevent any occlusal dysfunction. In other words: The masticatory system is set up to cope with lifelong tooth wearing phenomena and to compensate for hard tooth substance loss. Of the components of this system, the bones, periodontium, muscles and associated fascia are all flexible elements, whereas once the permanent dentition is established this represents an inflexible non-adaptive component.

Against this background we must ask ourselves: How does the masticatory system respond over years/decades when occlusal surfaces are restored with abrasion resistant materials in the neighborhood of less wear resistant hard tooth substance or dental restoratives such as composite resins or silicates. Figure 5 shows a possible situation. Molar tooth 46 has been restored with a zirconia crown. The adjacent teeth have "softer" occlusal surfaces comprising composite fillings, enamel or dentin exposed surfaces. It must be anticipated that the occlusal level will bend or tilt depending on the position of the less malleable components. Overall, the interaction of the various factors such as stress, Angles classification, cranial morphology and the direction of muscle forces can over the years cause a temporomandibular dysfunction; or else the masticatory system is adaptible enough to accommodate the morphological dynamics and can correspondingly compensate for the resistant occlusal surfaces. The masticatory adaptations become even more difficult when implants are restored using milled zirconium dioxide crowns. Here the tactile feedback of the chewing forces cannot be compared to that of the periodontium.

Also implants are unable to "cushion" against occlusal loads or easily divert the direction of a force as is possible within a healthy periodontium.

There is no evidence for the frequently expressed view that a "hard" occlusal surface causes damage to the TMJ. A physiologically working TMJ functions with chewing forces in such a way that the articular surfaces can move freely without being loaded. Torque built up in the musculature around the condyles is such that the chewing forces are not transmitted directly into the articular fossae [5]. A bone thickness analysis of the skull demonstrates that the thickest part is anteriorly towards the articular eminence. Directly towards the brain the bone above the articular fossa is very thin. Nature would have formed our skulls otherwise, if when chewing our condyles were moving towards the cranium with any substantial forces. A TMJ having to function under high loads on its articular surfaces also couldn't perform the quick precise movements required for speaking or singing. Therefore the physiological functioning of the TMJ is more akin to a needle bearing rather than say to a roller bearing. If load triggering does not play a major role, then occlusal surface hardness is irrelevant. Indigenous populations also demonstrate the obvious compensation of the masticatory system due to the differences between the initially hard enamel and the subsequent exposure of softer dentin.

Statement

During occlusal reconstruction, it should be taken into account that every dentition will be subject to considerable abrasion throughout its lifespan. Therefore, when planning occlusal rehabilitations it is advisable to use materials whose wear characteristics are similar to those that were previously used in the oral cavity. It is currently difficult to estimate how the masticatory system will tolerate occlusal surfaces of vastly different abrasive resistances which lead to tipping and changes in the position of the bite plane. It follows that temporomandibular/masticatory dysfunction cannot then be excluded.

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Glide path and root canal preparation in reciprocating motion: root canal treatment of a mandibular premolar with complex root canal morphology using R-Pilot and Reciproc Blue

Introduction:
The mechanical preparation of a root canal system is indispensable for a successful endodontic treatment outcome. Teeth with complex root canal morphologies, in particular, represent a special challenge; the practitioner should possess thorough knowledge of root canal morphology, as well as, be able to employ suitable endodontic instruments. The development of new nickel titanium alloys, through modifications made to their material properties, now permits the production of endodontic instruments which can meet even the highest requirements for root canal preparation. In this manner, the incidence of preparation errors and instrument fractures can be considerably decreased.

Materials and Methods:
A female patient with acute dental pain, originating from tooth 34, presented herself to the Department of Periodontology and Conservative Dentistry, a part of the University Clinic Münster. Following a detailed examination, root canal treatment on the tooth was performed. In this case report, R-Pilot and Reciproc Blue instruments (both VDW, Munich, Germany) were employed to treat a first mandibular premolar with a Vertucci type III canal configuration.

Results:
In the present case, in spite of complex root canal morphology, a sufficient and satisfactory root canal treatment outcome was achieved. This was realized through the use of R-Pilot files to establish an initial glide path and the subsequent use of Reciproc Blue files for further canal preparation.

Conclusion:
Knowledge of possible root canal system configurations and identification of such cases in daily clinical practice is a prerequisite for successful root canal therapy. Furthermore, a case-specific selection of endodontic instruments should be performed in order to prevent preparation errors and instrument fractures. It is also important to point out that a preceding glide path preparation helps to facilitate an easier and safer canal preparation and should therefore be considered as obligatory.

Keywords: Blue-Wire; glide path; M-Wire; Reciproc-Blue; R-Pilot

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Introduction

The ultimate goal of root canal therapy is the long-term preservation of the tooth; this is achieved by removing the irreversibly damaged pulp tissue as well as the preparation, disinfection, and subsequent three-dimensional obturation of the root canal system. An essential step in performing root canal therapy represents the mechanical preparation of the root canal system. In order to provide sufficient space for chemical disinfection, the original root canal course should be maintained by means of even and circumferential removal of root canal wall dentin. Also, the shape of the prepared root canals should ease the three-dimensional obturation [21]. Although there exist numerous root canal preparation techniques, which all have the scope of ensuring optimal root canal shaping, preparation errors remain a frequent problem in daily practice. For the preparation of more curved root canals, the selection of suitable instruments plays a critical role.

Enormous progress has been made in the field of rotary (or mechanical) root canal preparation since the development of nickel-titanium (NiTi) alloy in the 1960s and its introduction in endodontics [8]. Despite the fact that conventional NiTi instruments have significantly increased flexibility in comparison to conventional stainless steel instruments [28], instrument fractures and preparation defects, such as ledge formation or canal perforation, continue to be a problem in clinical practice, especially when preparing curved root canals [19]. For this reason, various patented thermomechanical processing methods have been developed for the purpose of optimizing the mechanical properties of NiTi root canal instruments. Modifications made to the NiTi alloy have aimed to further improve the flexibility of the NiTi instruments and to reduce their risk of fracture, without adversely affecting their cutting efficiency [32]. Therefore, a number of modified NiTi alloys such as M-Wire, CM-Wire, Gold- and Blue-Wire or MaxWire have been developed, each of which displays different material properties [32].

Besides the effort made to facilitate root canal preparation through the optimization of endodontic instruments, there exist additional measures related to the exposure and instrumentation of root canals, which could minimize preparation errors and contribute to the avoidance of iatrogenic damage to the root canal system. One such measure is represented by the need to perform preflaring before initial root canal instrumentation; dentin overhangs, which hinder the straight-line insertion of the endodontic instruments into the root canal, must be removed before actual canal preparation.

Another important aspect worth consideration, in order to avoid preparation errors, is the preparation of a glide path from the canal entrance to the physiological terminus [30]. This is especially recommended when narrow and/or strongly curved canals are present, and mostly before the use of mechanically operated preparation instruments. In this respect, stainless steel manual instruments as well as mechanically operated NiTi instruments could be employed. Stainless steel hand instruments (so-called pilot instruments) allow tactile control, may be pre-curved, have a low fracture risk, and permit inferences to be made about existing canal curvatures. The creation of a glide path with mechanical glide path instruments is described as being time-saving and safe [15]. According to some studies, mechanical glide path preparation is better able to preserve the original canal course in comparison to manual stainless steel instruments [1]. Moreover, subsequent debridement of the root canal in the periapical tissue after mechanical glide path preparation should be performed in order to reduce the risk of postoperative discomfort [16, 22]. The created path during glide path preparation allows for improved centering of succeeding instruments, thus reducing unwanted preparation errors such as root canal displacement, ledge formation and instrument fracture [17].

In this case report, a mandibular premolar with Type III (1–2–1) root canal configuration according to Vertucci (Fig. 1) was prepared with R-Pilot and Reciproc Blue files (both VDW, Munich, Germany).

Reciprocating motion

Ongoing metallurgical development of conventional NiTi alloys has enabled the introduction of reciprocating root canal instruments. To date, there are numerous reciprocating endodontic instruments available on the market; these include Reciproc, Reciproc Blue, R-Pilot (all VDW, Munich, Germany), WaveOne, Wave One Gold, WaveOne Gold Glider (all Dentsply Maillefer, Ballaigues, Switzerland), R6 ReziFlow (Komet Dental, Lemgo, Germany) and Sendoline (Sendoline, Täby, Sweden).

The reciprocating movement pattern is based on the manual balanced-force technique; preparation of the root canal occurs with small 1/4 rotations clockwise or counterclockwise. This concept in the sequence of motion has been transferred to mechanical NiTi instruments, but with modifications. In contrast to the balanced-force technique, tooth substance (dentin) removal by means of the working movement occurs in a counterclockwise direction. As part of the reciprocal movement pattern, the instrument is first rotated in the cutting direction (counterclockwise). Subsequently, a reverse movement in the opposite direction (clockwise) takes place, therefore allowing the instrument to be disengaged from dentin. In this manner, jamming of the instrument in the canal is prevented. The movement in the cutting direction is greater than in the return movement, thus fostering a progressive advancement of the instrument in an apical direction with each movement cycle. Counterclockwise rotation of the reciprocating instrument is greater (150°) than clockwise rotation (30°), thus allowing a complete turn (360°) to occur after about three to four reciprocating movements [12]. Moreover, the cutting angles of the instruments are predetermined so that they cannot exceed their elastic limits. This allows a considerable reduction in the risk of torsional fracture. Also, noteworthy is that it is necessary to use a special motor with a corresponding program of reciprocating movement in order to carry out the pro-

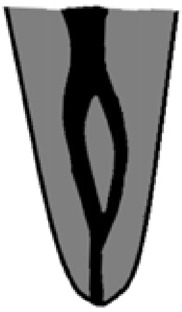

Figure 1 Schematic drawing of the Vertucci Class III root canal configuration (1–2–1)

Figure 2 Above Reciproc Blue, below R-Pilot instruments

cedure in accordance to the manufacturer's recommendations. This applies to the use of the R-Pilot file as well.

Glide path – R-Pilot instruments

The R-Pilot instrument (VDW) is a machine-driven file which prepares a glide path in the root canal system prior to preparation of the canal in reciprocating mode (Fig. 2). Before its use, it is recommended that a manual glide path up to ISO size 08 is created. The R-Pilot instrument has a non-cutting tip with a diameter of 12.5/100 mm, a taper of 4 %, a S-shaped cross-section, and is composed of a modified NiTi alloy named M-Wire. In the production of M-Wire NiTi alloy, 55.8 % nickel and 44.2 % titanium is used [32]. The patented thermomechanical machining process results in a superior alloy, which is more flexible and more resistant to fatigue-induced fractures than conventional NiTi alloy [18, 5]. These properties are attributed to the altered phase composition of the material when compared to conventional NiTi.

Reciproc Blue instruments

The Reciproc Blue instruments are the result of continued development of Reciproc instruments (Fig. 2). Like their predecessor, they constitute a single-file system. The Reciproc Blue files are available in sizes 25/.08, 40/.06, 50/.05, have a regressive taper, a S-shaped cross section with 2 cutting edges, and a non-cutting instrument tip. Only in their metallurgical properties alone do the Reciproc Blue instruments differ from the other Reciproc instruments. Whereas Reciproc is made from M-Wire, Reciproc Blue is made from Blue-Wire. This material is a modified NiTi alloy produced by a special heat treatment, which ensues after the instruments have first been ground according to the proven method. This heating process alters the phase composition of the alloy [32]. Interestingly, owing to the heating, an accompanying color change of the instrument also takes place. It is speculated that heating results in oxide layer formation on the instrument surface, thus endowing it with a blue color. To date, however, there are no studies which have investigated the precise metallurgical phase composition of Blue-Wire. It is assumed that the martensite fraction in the alloy is higher than that in M-wire alloy; this may explain why Blue-Wire heat-treated instruments show significantly higher flexibility and increased resistance to cyclic bending fatigue [7]. Instruments made of this material can be easily pre-curved and display a memory-effect, meaning that they have the ability to return to their initial shape. These properties should therefore warrant an accurately shaped preparation of complex channel configurations.

Case representation

Anamnesis and diagnosis

Due to acute pain originating from tooth 34, a 56-year-old female patient presented herself to the Polyclinic for Periodontics and Conservative Dentistry, part of the University Hospital of Münster. Apart from medicated hypothyroidism and long-term tobacco consumption, the general medical history showed no abnormalities.

Clinical and radiological examination (Fig. 3) revealed a profound carious lesion distally on tooth 34; percussion was negative and pulp vitality was significantly delayed. A mental nerve block was performed using Septanest anesthetic with epinephrine 1: 200,000 (Septodont, Niederkassel, Germany). The pulp tissue was exposed during excavation of the carious dentin, thus producing profuse, uncontrolled bleeding. Subsequently, complete excavation was performed and a pre-endodontic construction was made. In order to provide pain relief, Ledermix (Riemser, Greifswald, Germany) was applied on the crown pulp and the cavity was first temporarily closed with Ketac Fil Plus (3M Germany, Seefeld, Germany).

Trepanation, access cavity, canal exposure

Afterwards, the patient was referred to the Department of Endodontics, a part of the Polyclinic for Periodontology and Conservative Dentistry. A periapical radiograph using the paralleling technique was made prior to further treatment (Fig. 4). The root canal configuration was identified as being type III (1–2–1) according to Vertucci (Fig. 1). A mental nerve block anesthesia was administered at the beginning of treatment using Septanest with epinephrine 1:200,000 (Septodont). After that, a rubber dam was applied in order to ensure compliance with aseptic work-

Figure 3 Preoperative panoramic radiograph. Tooth 34 shows an extensive carious lesion distally.

Figure 4 The radiograph of tooth 34 suggests a Vertucci typ III canal configuration

ing conditions throughout the duration of therapy. Trepanation of the tooth was performed and a dental microscope was utilized during the whole course of treatment. With the purpose of creating straight-line access for the instrumentation of the canals, the coronal portion of the canal was extended up to the point of canal branching using the Endo-Explorer Set (Komet Dental, Lemgo, Germany; Fig. 5). This allowed for the selective removal of dentin overhangs. The root canals could be localized in the mesio-distal position and were instrumented using C-pilot hand files (VDW) of ISO sizes 08 and 10. Using pre-curved instruments, patency could be achieved via the mesial canal. The distal canal ended 3 mm short of the apex; this was interpreted as indicating the confluence of this canal at an obtuse angle into the mesial canal, and was therefore verified by introducing instruments into both canals. Using an apex locator, a working length of 23 mm was established for the mesial canal. Meanwhile, the distal canal opened into the mesial canal at 20 mm.

Chemomechanical debridement

After determining the working length, the R-Pilot instrument (12.5/.04) was used to mechanically prepare the glide path. The Reciproc Blue instrument (size R25) was used subsequently to prepare the canals. During the procedure, each canal was rinsed with 5 ml NaOCl (2.5 %) and the instrument was moved slowly towards and away from the apex using very slight pressure. The amplitude of the up and down movements was not more than 3 mm. After 3 picks, the file was removed from the canal and cleaned in Clean-Stan. Each time, the root canals were also rinsed. Between preparation steps, a C-Pilot file of ISO size 10 was used for recapitulate the canals and to check for apical continuity. This measure was taken to prevent apical blockage. Upon completion of the preparation, the working lengths were rechecked by means of an apex locator. Then, the canals were rinsed with 10 ml each of citric acid (17 %) as well as 10 ml NaOCl (2.5 %). Ultrasonic irrigation of sodium hypochlorite was performed in each canal based on the EDDY approach (VDW) for 3 x 20 seconds each. In order to achieve this, a polyamide tip driven by an Airscaler at a high frequency of up to 6,000 Hz was employed. The created oscillations trigger cavitation and swirl the rinsing fluids, thereby achieving a significantly improved cleaning performance [25]. To end with, each root canal was rinsed with 5 ml chlorhexidine (2 %) and dried with paper tips.

Guttapercha (R25 Reciproc Blue pens) were adapted to the preparation system so that a noticeable „tug-back“ was present. Due to reproducible readings with the apex locator, a master point radiograph was omitted. The thermoplastic obturation was then made using the continuous wave technique by means of the Beefill 2in1 device (VDW). An epoxy resin sealer (2Seal, VDW) was used. At first, the distal canal was filled. The fit of the mesial masterpoint was rechecked in order to obturate the mesial canal. This was done in order to ensure that no bubbles could form in the area of the confluent canals.

The Guttapercha was separated at the branching point of the two canals. Then, the coronal third of the root canal was conditioned with dentin adhesion promoter (Optibond FL, Kerr Dental, Rastatt, Germany) and filled with SDR (Dentsply DeTrey, Constance, Germany) up to the level of the cementoenamel junction. The covering filling was made using Estelite Sigma Quick (Tokuyama Dental Germany, Altenberge, Germany). Finally, a radiograph was taken to control the root filling (Fig. 6). The film showed an adequate root canal filling, which appeared homogeneous and edge-tight.

Follow-up Control

After 4 months, the patient presented herself once again for the radiographic control of tooth 34. The patient reported no symptoms on tooth 34. The tooth also remained free of any symptoms upon performing ongoing routine check-ups. The absence of apical periodontitis and the continuity of the periodontal ligament is suggestive of successful root canal treatment (Fig. 7).

Discussion

Root canal treatment of teeth with a Vertucci Class III configuration presents a major challenge. For long-term therapeutic success, it is first and foremost

Figure 5 Endo-Explorer set

critical to recognize that an anatomical variation is present, which occurs in only 4 % of the cases for first mandibular premolars [27]. It also implies that the dentist should be acquainted with the possible variations of root canal morphology. In this manner, deviations from the standard morphology could be detected quicker and more reliably. Furthermore, from a clinical point of view, it is necessary to use an optical magnifying aid in every case. The use of a dental microscope permits detailed exploration of root canal morphology and enhances the viewing conditions needed for correct access cavity preparation. A prerequisite for the instrumentation of root canals is the creation of straight-line access by removal of dentin overhangs, as overhangs could obstruct the view of other possible canal entrances. Moreover, the mandatory diagnostic radiograph, preferably from 2 projection angles, should serve to provide important preoperative hints with respect to root canal morphology. To exemplify this, when analyzing a radiograph, the abrupt disappearance of a large-lumen root canal in the upper or middle third of the root is indicative of a canal bifurcation (Fig. 4).

In this case report, due to the existence of irreversible pulpitis and no signs of apical periodontitis on tooth 34, a one-step root canal treatment was selected. The goal of the applied rinsing protocol was to remove pulp tissue rests and organic components from the smear layer through the use of NaOCl (2.5 %). Additionally, irrigation with citric acid (17 %) was performed in order to remove inorganic components from the smear layer. When used in alternation, these two root canal solutions provide clean root canal walls and open dentinal tubules [29]. The final chlorhexidine (2 %) rinse was used to expand the spectrum against particularly problematic germs found in root canals; its usage is, however, controversially debated. From a purely microbiological perspective, a final rinse with chlorhexidine is not considered necessary when performing vital pulpectomy. Nevertheless, since a final rinse with chlorhexidine ensures significantly better wetting of the epoxy resin-based sealer onto the root canal wall following smear layer removal, final irrigation with chlorhexidine was not omitted in the present case [6].

The mechanical glide path preparation with the R-Pilot instrument, followed by the subsequent preparation of the root canals with the Reciproc Blue instrument, achieved a satisfactory treatment result. After the root canal filling was completed, the tooth was temporarily treated with a dentin-adhesive composite filling. In the long-term, a ceramic crown restoration is planned for the tooth. Thus, the remaining tooth hard substance can be conserved and stabilized when having to cope with a daily chewing load.

The case-related selection of suitable root canal instruments represents an essential and relevant step in root canal therapy; this is discussed below. Pertaining to this case, the specific root canal morphology as well as the findings in recent literature were taken into consideration.

Both types of utilized instruments worked using reciprocating motion. Studies show that the reciprocating movement pattern hinders instrument jamming in the root canal, therefore increasing the fracture resistance of NiTi instruments [11]. Furthermore, reciprocating instruments have been reported to have longer lifetimes in comparison to fully rotating instruments [26]. However, whether or not the reciprocating motion leads to increased debris extrusion compared to the fully rotary motion remains controversial; this seems to be dependent on study design among other factors [3, 13].

Since the introduction of Reciproc Blue instruments, several studies have examined if there are differences between them and previous generation Reciproc instuments. When compared to Reciproc M-Wire-NiTi instruments, it has been shown that Reciproc Blue instruments have significantly increased flexibility and resistance to cyclic fatigue owing to their modified alloy composition, [7, 23]. More recent studies have compared how highly curved root canals were shaped by Reciproc Blue and WaveOne Gold, the latter being another reciprocating Gold-Wire-NiTi instrument. For the preparation of root canals with 25°–35° curvatures, neither Reciproc Blue nor WaveOne Gold produced a more correct preparation form than their predecessors made of M-Wire-NiTi (Reciproc and WaveOne) [4]. Topçuoğlu et al. showed that Reciproc Blue was more resistant to cyclic fatigue when compared to WaveOne Gold in canals with root canal curvatures of 60°. On the other hand, for root canals with curvatures of 45°, no significant differences between the two instruments were observed [24]. Based on the results from these two studies [4, 24], it can be inferred that Reciproc Blue instruments may offer advantages, especially, when preparing highly curved canals.

Although root canal preparation with Reciproc and Reciproc Blue instruments does not usually require previous glide path preparation according to the manufacturer, recent studies suggest that glide path preparation has certain benefits. One study observed that the presence of a glide path resulted in less pronounced apical foramen transportation during processing with Reciproc files [2]. Moreover, preparation-related debris extrusion into the periapical tissue was reduced by prior glide path preparation in curved root canals [22]. According to Pasqualini et al. glide path preparation with rotary NiTi files resulted in less pronounced postoperative complaints compared to manual glide path preparation

Preliminary evidence also suggests that the preparation of a glide path prior to the use of Reciproc Blue instruments improves subsequent root canal preparation in highly curved canals [10]. Owing to glide path preparation, Reciproc Blue instruments are better able to remain properly centered during canal preparation, thus allowing them to follow the original canal course more accurately. The transportation of the apical foramen, the so-called canal displacement, could therefore be largely avoided.

In this case, the R-Pilot instrument was chosen for glide path preparation. According to studies, it has a higher resistance to cyclic fatigue in comparison to other mechanical glide path instruments, such as One G (Micro Mega, Besançon, France), ProGlider, WaveOne Gold Glider (both Dentsply Maillefer) and HyFlex EDM (Coltene, Altstätten, Switzerland) [31, 14].

A possible explanation for the beneficial properties of the R-Pilot instruments may lie in their S-shaped cross-section, which ensures a comparatively small core diameter. As a general rule of thumb, the smaller the cross-sectional diameter of an instrument, the greater its resistance to cyclic fatigue and the greater its flexibility [20]. In this way, R-Pilot instruments are considered safe from a clinical point of view; they possess high fracture resistance as well as facilitate the preparation of a glide path without canal displacements or preparation errors (great flexibility) in the presence of anatomically complex and strongly curved root canals. For the treatment of the case presented here, the R-Pilot and the Reciproc Blue instruments were selected. Certainly, the root canal treatment could have been possible with other instruments. Similar metallurgical and physical properties exist, for example, in the WaveOne Gold Glider (Dentsply Maillefer), which represents an alternative to the R-Pilot instrument. This machine-operated glide path instrument also works using reciprocating motion. It consists of Gold-Wire, which is another type of heat-treated NiTi alloy and has a progressive taper between 2 % and 6 % as well as a diameter of 15/100 mm at the instrument tip. The instrument's cross-section is in the form of a parallelogram. One study has shown that the R-Pilot instrument and the WaveOne Gold Glider are more resistant to cyclic fatigue when compared with various rotary glide path instruments [9]. In a direct comparison with one another, however, the two reciprocating glide path instruments showed no significant differences in the aforementioned study. Another alternative to the employed Reciproc Blue instrument is represented by the WaveOne Gold system (Dentsply Maillefer). These instruments are made of Gold-Wire, have the same cross-sectional shape as the WaveOne Gold Glider, and use reciprocating movement [4].

Figure 6 Radiographic control of tooth 34 after root canal obturation

Figure 7 Radiographic follow-up of tooth 34 after 4 months

(Fig. 1–7: N. Vahdat-Pajouh)

Conclusion

The decision-making process for choosing a suitable instrument and its associated working motion depends on a number of factors. A case's particularities are relevant in deciding whether or not a previous glide path preparation is required in order to simplify the preparation of the root canals. Since the principal goal in selecting the appropriate instrument is to provide safe canal preparation while also preserving the original canal shape, special attention should be given to glide path preparation. In summary, it can be generally stated that the use of the R-Pilot instrument is recommended in cases of severely narrowed canals or more complex root canal configurations, which could lead to difficult preparation of the root canals. Despite the benefits of its use, it should be clearly noted that abrupt root canal curvature (large angle of curvature with low radius of curvature) in the apical region is a contraindication for the use of the R-Pilot instrument. In such cases, preparation should be done with pre-curved hand instruments. This also applies to the use of Reciproc Blue instruments. In spite of the manufacturer's claim that glide path preparation is not required in the majority of cases when using Reciproc Blue instruments, the clinical benefits of a glide path preparation should still be carefully considered. One such example is the reduction of postoperative discomfort.

A careful selection of case-related preparation tools and techniques can markedly reduce the risk of preparation errors and instrument fractures in daily clinical practice.

Conflicts of interest:

The authors declare that there is no conflict of interest within the meaning of the guidelines of the International Committee of Medical Journal Editors.

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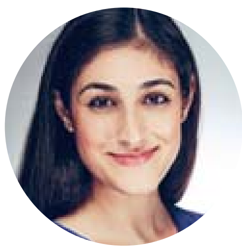

(Photo: privat)

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Reproducibility and reliability of intraoral spectrophotometers

Introduction:
In the 1990s computerized tooth colour measuring instruments were introduced on to the dental market that facilitated the practical recording of tooth shades in everyday practice. This experimental study evaluated two such devices; comparing the reproducibility, reliability and interreliability of the dental spectrophotometer QuattroShade (QS, Goldquadrat GmbH, Hannover, Germany) and the VITA Easyshade Advance 4.0 (VES, Vita Zahnfabrik, Bad Säckingen, Germany).

Material and Method:
Under simulated clinical conditions the tooth colours and L*a*b* data were measured for 2 extracted human teeth (tooth 12 and tooth 21) in three experimental phases. (I) 3 series of measurements were taken using both devices on both teeth. Initially, calibration took place after every measurement, then in the two following series at intervals after every five and ten measurements respectively (n = 250). (II) 51 recruits each made three measurements (n = 153) for tooth 21 using both devices. Equipment was calibrated before each new user. (III) tooth 21 was measured 153 times (n = 153) with calibration after every third reading. The statistical program SPSS (Inc., U.S.A for windows version 24.0) was used to analyse the data.

Results:
Significant differences (Wilcoxon-test, Friedman-test, $p \leq 0.05$) were found between the reproducibility measurements of each device. A comparison of measurements between the devices also showed differences. A correlation between frequent and longer calibration intervals was evident. Less deviation occurred with fewer calibrations (after every ten measurements) than with more frequent calibrations (after each measurement). The reproducibility of the L*a*b* values was higher using the VES when compared to the QS. Concerning reliability, slight differences in delta (Δ) E values were noted for both devices. The QS showed better values between multiple users than the VES. All deviations are not relevant for clinical purposes (ΔE = 0.8–2.2).

Conclusion:
This study has shown that both devices for tooth colour determination are suitable for daily practice. However, a visual check should still be made with a conventional colour scale.
Keywords: digital tooth colour determination; spectrophotometer; reproducibility; reliability

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Introduction

One of the goals of restorative dentistry is to provide the patient with an esthetic attractive smile [31]. This is challenging because the human eye can detect and discern the subtlest color variations between two adjacent teeth, e.g. two central incisors. Routine prosthetic procedures usually involve selecting the replacement teeth colors by means of a comparison to a standardized shade guide. The selected shade is then communicated to the dental laboratory. However, teeth are not uniform in color and the incisal, middle and cervical regions all reflect incident light differently [25]. Further, color perception varies between individuals and this hampers the correct shade choice when matching the shade guide to the intraoral situation. Thus, choosing an appropriate tooth shade for the patient is far from straightforward and depends on numerous exogenous and endogenous factors [4, 8, 13, 27, 42].

With the introduction in the 90s of tooth shade recording devices these problems were first addressed. Tooth shade could be exactly determined using a meter that detected the color which was then referenced on a color chart in order to record it. But, there remains much skepticism concerning the reliabilty and accuracy of such color measuring devices such as spectrophotometers, colorimeters and digital cameras [2]. In this study both devices presented and evaluated belong within the classification of spectrophotometers.

The VITA Easyshade Advance 4.0 (Vita Zahnfabrik, Bad Säckingen, Germany)(VES) is a portable system used intraorally to determine the shade of individual teeth. The original model was introduced and has been available on the dental market since 2004 [14]. It comprises an electrical base unit upon which rests a detachable electronic unit which incorporates an integral handpiece with a measuring probe at its tip. This handpiece unit has a lamp, a Vacuum Fluorescent Display (VFD), a navigation key, a select key, and contains a Central Processing Unit (CPU). Data can be stored in the unit and later transmitted using Bluetooth to a personal computer. A detachable USB „dongle“ is provided for this purpose to be used with the VITA Assist software. The base has a detachable white balance calibration block to ensure consistency in shade determination. The device illuminates a sample using standardized light (illumination angle from 0° to 30° from a D65 light source (6500K)) over the entire measuring area and measures the light intensity remitted back from the sample using a viewing angle of 2°. Every specific reflected wavelength in the range 400–700 nm is recorded to measure the sample‘s brightness, chroma and hue from which the respective shade can be calculated. Taking readings for most teeth involves covering their middle and cervical thirds with the handpiece tip. When activated, light is scattered through the enamel and propelled towards the dentin where it is partially reflected back to the probe. This spectrophotometer model (VES) only measures reflected light and is optimized for dental materials having optical properties similar to a typical tooth; the most important of which being its translucency. Consequently, when a material sample is too thin (thickness < 0.7mm) or a tooth is very transparent the resulting readings are erroneous i.e. they are too low. The VES comes with a 20 Watt halogen bulb which has a resilient tungsten filament providing an average life of 100 hrs usage. The lamp‘s color temperature (3350 K) covers the entire visible light spectrum up to the infrared range and is ready to use after a 15 seconds warm up [24,33,43]. A newer model, the VITA Easyshade V came on the market in 2015.

The QuattroShade (Goldquadrat GmbH, Hannover, Germany) (QS) is a portable tooth colorimeter and has been available since 2015. Unlike the VITA Easyshade, it analyzes tooth color across the entire tooth surface. It has two light sources each utilizing a magnetic diaphragm which switch over from the digital camera mode to the spectrophotometer when the color measuring button is pressed. A specially coated diffraction grid divides the measuring light into the colors of the spectrum at 10nm intervals which are sent sequentially through the light guide to the measuring head. The light guide also splits the light so that monochromatic, polarized light is emitted at 45° angles from the measuring head thereby illuminating a test specimen from both sides. Light reflected back at a 0° angle is received by a monochromatic photosensor (Charge Coupled Device, CCD). This is especially setup for a 2x45°/0° measuring geometry and is optimized for light registration between 410–680nm wavelengths. Light captured by the CCD is then processed in 20 nm increments by a „Leutron Frame Grabber Card“ in conjunction with the QuattroShade software. This software compares color data by referencing factory scanned color rings. All common color scales are supported [10, 24, 44]. The measured area encompasses approximately 18 x 14 m, measured in 640 x 480 pixels. Besides the monochromatic CCD color measuring sensor the device also has a second polychromatic CCD sensor and an integrated autofocus lens. This enables sharp full color images of teeth to be displayed on the screen which is lit by a 12 volt, 100 watt halogen lamp contained within the unit.

Color system and ΔE-value

The most common color system referenced in dental studies is the CIE-L*a*b*/C*h* system. It is a standardized protocol which includes the essential color dimensions that the human eye requires in order to differentiate colors [3]. With this system, particularly when using electronic shade devices accurate tooth shades can be determined [24]. L* measures the brightness of an object, a* quantifies red/greenness, and b* similarly yellow/blueness. A graphic depiction of the L*a*b* system is shown in Figure 1: Every color is referenced in the three-dimensional color space by specifying its 3 independent coordinates, the L * a * b * values on their corresponding axes.

The assessment of the interplay between the parameters of brightness (L*), color intensity (C*) and hue (h*) has been found by clinicians to be less problematic as characteristics

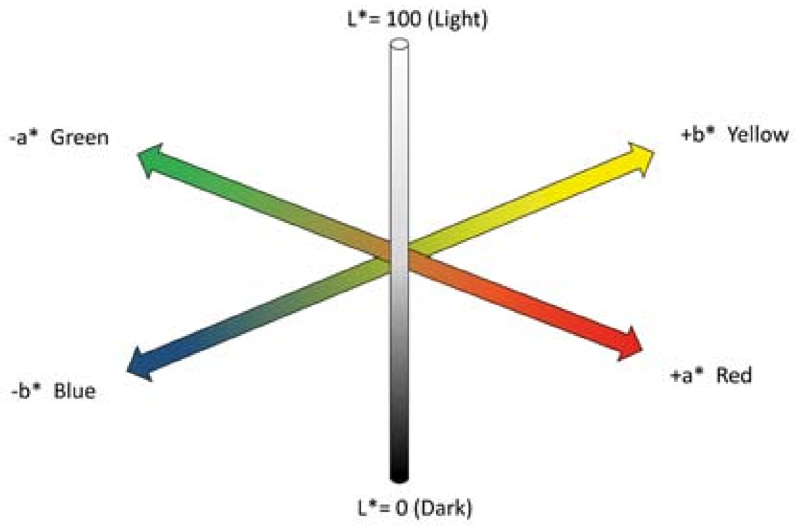


Figure 1 The L*a*b* system

when determining tooth shades. Therefore the a* and b* coordinates have been converted to color intensity (C*) and hue (h*) [3].

The definition of the perception of the difference between two colors is given by the ΔE value. Delta (Δ) stands for the difference, E being the abbreviation for sensation. ΔE thus reflects the difference between two colors as perceived by the human eye [1].

The calculation of the ΔE value takes place by using the coordinates in the L * a * b * color space [1]. It follows the Pythagorean calculation formula for the space diagonal:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

The calculated result from this formula shows that the ΔE value indicates the absolute „size" of the color distance between the reference color (e.g., the color on a color scale) and the test color (the natural tooth shade to be detected). But, which of the parameters (brightness L *, color intensity C *, color h *) that the deviation in ΔE can be attributed to cannot be inferred from its value.

The calculations of ΔE values for all occurring tooth shades show that brightness (L*) and color intensity (C*) together have about 25 times more influence than the hue (h*) with respect to the perception of the color difference. The reason for this is that there is only a small red-yellow distance between the shades of natural teeth, and consequently the hue plays only a minor role [1]. By comparison, human perception of the agreement or difference between tooth shades is largely based on the criterion of brightness (L*), which should therefore be given the strongest weighting. Errors in the hue or in the color intensity only affect the impression of a color match to a limited extent [3].

Paravina et al. [36] found that colors differing by $\Delta E < 1.5–2$ are so close to each other that the human eye finds it difficult to perceive any difference. Eleven years later, Paravina et al. [38] investigated ΔE values in the range 1.2 to 2.7. They reported that a $\Delta E = 1$ can be defined as the smallest color difference perceptible to the human eye when viewed under optimal conditions [3]. If the ΔE value is greater than 5 between a reference tooth and a test sample, then the human eye perceives the color difference to be disturbingly large [20]. King and deRjik [23] proposed the following classification for color differences:

ΔE ≙0–2: imperceptible
ΔE ≙2–3: barely perceptible
ΔE ≙3–8: to some extent perceptible
$\Delta E > 8$:very perceptible

Objective

The present study researched the reproducibility, reliability and interrater reliability of the dental spectrophotometers QuattroShade (QS) and Vita Easyshade Advance 4.0 (VES). The aim was to evaluate the quality of the color determinations of these two dental spectrophotometers. Specifically, the question was addressed as to what would be the differences in color measurements recorded, under standardized conditions, between measurement series repeated at different times, both on the same, or the alternative dental spectrophotometer. Also, the effects of different users as well as different calibration sequences were also considered in the study.

Hypothesis

In order to be able to quantitatively answer these questions the following null hypotheses were formulated:

Regardless of the number of users and/or the calibration sequence, each instrument produces consistent (reproducible) and reliable color measurement results from identical inputs.

The ΔE values of both devices show no significant difference ($p > 0.05$).

The L*a*b*/C*h* values from a triad of measurements with both instruments are not significantly different ($p > 0.05$).

Material and methods

For this in vitro study, two extracted human incisors (teeth 21 and 12) were stored in normalphysiologic salt solution. In order to eliminate error messages or false readings during color measurement, teeth were chosen that were free of any direct or indirect restorations. Both teeth were prepared by ultrasonic cleaning and polishing to remove any exogenous deposits. Their roots were shortened in order to adapt their clinical crowns to the gingival form of an upper jaw model (KaVo, EWL Basic model upper jaw/lower jaw V16). They were secured in this upper jaw model which was next mounted in the appropriate phantom head (KaVo, G50) and then attached to a suitable phantom unit. Both spectrophotometers could now be brought into position, as required in order to access this simulated oral environment, for the purpose of taking color readings. Next the operatory environment was set up to be a typical dental workspace. Even though both manufacturers claim that their devices work independently of ambient light and variable lighting conditions [10, 43] some degree of lighting consistency was preferred. The background lighting was from fluorescent tubes (400–500nm) and indirect daylight. To create as uniform as possible practice-like conditions, the dental unit operating light remained switched off during the taking of measurements. By these means the influence of extraneous light sources was minimized. To begin the study, the „actual" tooth shades of the extracted teeth were recorded by 10 dentists from the department. All of them were experienced with using the VITA 3D Master color scale and the shade readings were taken under optimal conditions (daylight at lunchtime, gray background). The authors of the study did not participate in this process.

The manufacturers' user manual recommendations for the operation of both devices were followed exactly.

To facilitate accurate and reproducible measurements, a thermoformed positioning guide was custom made for use with the Easyshade system [5, 15, 33]. This enabled the measuring probe of the VES to be identically repositioned on the teeth whilst taking color readings. A positioning guide was not required for the QS, but instead the tooth being measured was correctly centered and aligned using the device's screen.

An overview of all 3 experimental setups is shown on the flow chart in Figure 2.

In the first experimental setup (I) the reproducibility of measurements made with both the QS and VES and the effect of different calibration intervals were analyzed. A single user carried out the test measurements for both devices. Under clinically simulated conditions both teeth (teeth 21 and 12) were assessed consecutively using both devices. In the first phase the devices were calibrated after each reading (n = 250), in the second phase calibration was done after every 5 readings (n = 250), and in the third phase calibration was done after every 10 readings (n = 250). The investigatorfor the 3 phases was a 25 year old, female dental student in her 9th semester. She had no prior experience with tooth colorimeters, but she was given detailed instruction and training in the handling of both devices.

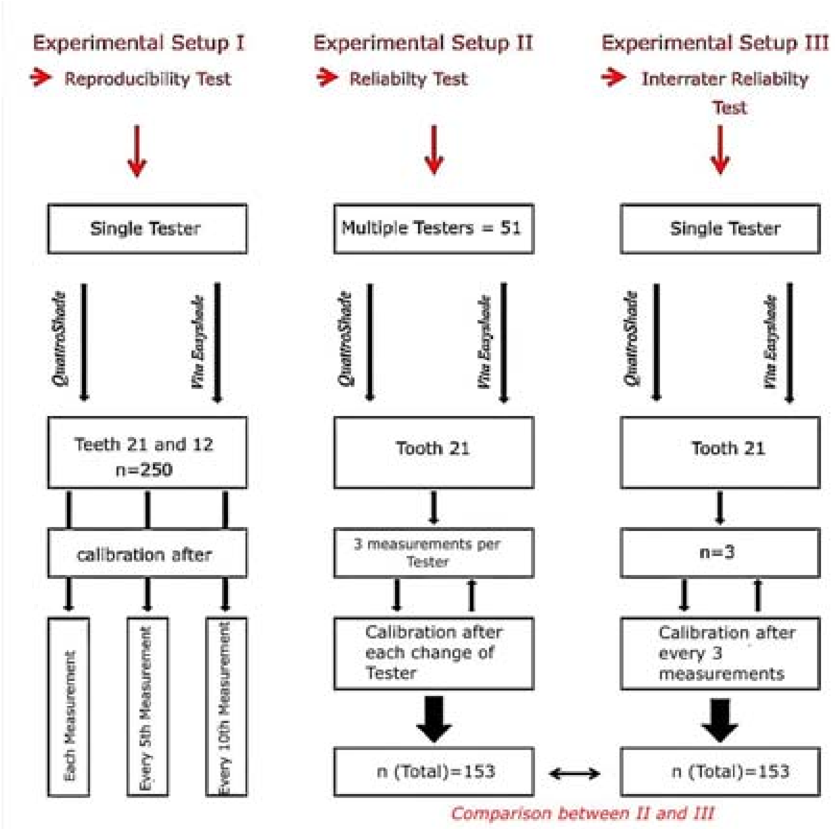


Figure 2 Overview of the three examinations

The second experimental setup (II) scientifically investigated the reliability of both devices. A total of 51 preclinical dental students, consecutively recorded three measurements each, with both devices on tooth 21 (n = 153). Calibrations immediately took place after every change of user. The tooth was stored before and between measurement series in physiologic salt solution, it was cleaned before every test series, fixed in the identical maxillary model (KaVo, EWL Basic model upper jaw/lower jaw V16) and installed in the phantom unit. By these means, the same standardized conditions as experimental setup I were reproduced. Every student received detailed instructions for handling both devices.

The recruitment of these preclinical students took place on the Phantom Course II, during their 5th semester at the University Hospital of Leipzig. Every student investigator also received a detailed curriculum about clinical tooth shade differentiation [35], covering both theoretical and practical aspects. However, they had had no practical, „hands on" familiarization with intraoral digital measuring.

To investigate the interrater reliability of both devices, a third setup (III) was arranged. In this final part of the series, a single user measured tooth 21 for a total of n = 153 times, calibrating after every 3rd reading. The results could then be directly compared with the results from setup II (51 subjects, calibration after every 3rd reading before the next user).

For a valid comparison of the data, in each case the total tooth color value was recorded for the analysis. For this, the VES has an operating mode „Basic color determination on the natural tooth". In rare cases, the VES emitted mixed shades (e.g., 1M2–2M2), and in these instances the first mentioned color was then included in the analysis. With respect to the QS, there is a menu function that enables it to calculate average tooth

	25th Percentile	Median	75th Percentile	Minimum	Maximum	Count
L (QS/VES) - calibration after every x1 measurement	77.1/82.6	78.4/83.0	79.2/83.6	73.7/81.8	79.8/92.6	250/250
L (QS/VES) - calibration after every x5 measurements	78.9/81.8	79.1/82.3	79.2/82.7	78.2/79.0	79.9/86.2	250/250
L (QS/VES) - calibration after every x10 measurements	76.4/81.3	76.8/81.8	77.2/82.2	75.2/78.4	78.1/84.4	250/250
a (QS/VES) - calibration after every x1 measurement	2.9/2.5	3.0/2.6	3.1/2.8	4.4/0.8	3.8/3.2	250/250
a (QS/VES) - calibration after every x5 measurements	3.2/2.3	3.4/2.4	3.5/2.6	18.8/1.9	3.9/3.0	250/250
a (QS/VES) - calibration after every x10 measurements	3.1/2.1	3.2/2.2	3.3/2.3	0.6/1.8	3.6/3.0	250/250
b (QS/VES) - calibration after every x1 measurement	18.5/27.1	18.7/27.6	18.8/28.1	18.0/17.8	28.8/29.0	250/250
b (QS/VES) - calibration after every x5 measurements	18.7/26.4	18.9/27.0	19.2/27.4	18.4/25.4	43.9/28.8	250/250
b (QS/VES) - calibration after every x10 measurements	20.6/25.7	21.1/26.2	21.5/26.6	19.1/24.7	24.6/28.4	250/250

Table 1 Reproducibility test data QS/VES. L*/a*/b*- values

color, from the 3 regional (cervical, middle and incisal) area specific values that it measures. However, for this study it was deemed more suitable, to select and use the QS's option „Determination of the total color" for the measurements. The tooth color values that were ascertained from both devices were then documented using the VITA 3D Master Color System. The data were further classified in preparation for the appropriate nonparametric statistical tests. All of the L*a*b*/C*h* values produced by the devices together with the average color were noted after each measurement. The calculated ΔL, Δa, Δb, ΔC, Δh and ΔE values were entered into an Excel spreadsheet and statistical analysis was undertaken using SPSS software (Statistical Program SPSS Inc., U.S.A for Windows Version 24.0). The median and quartiles for each series of measurements were calculated, followed by significance testing ($p < 0.05$), carried out with either the Wilcoxon or the Friedman test. The appropriate test was chosen according to the characteristics of the measurement series under consideration.

Results

There were statistically significant differences (Wilcoxon test; Friedman test, $p \leq 0.01$) between the measurements for reproducibility both within and between the devices, both by single and multiple users. Deviations within the L*a*b* measurement data were found to correlate with the calibration frequency. Scattering of the data occurred more often with frequent calibration (after each measurement) than with calibration after every 10th measurement (Table 1). The reproducibility of the L*a*b* values was higher for the VES as compared to the QS.

ΔE values for each individual device (Friedman test) as well as between the devices (Wilcoxon test), returned significant differences ($p < 0.05$). Figure 3 shows the deviations of all ΔE values for both devices, together with a comparison of the calibration values after every 1st, 5th and 10th measurements. For the QS, a noticeably high extreme value was detected during the calibration after every 5th measurement. The VES presented significantly higher median, upper, and lower percentile values (8.1–11.5) for each calibration sequence than the QS (2.14–2.67). All 3 categories did not differ significantly. Compared to the QS (0.1–0.6), there was a greater variation found in the values of the VES (1.2–1.4).

With regard to reliability, all values (L*, a*, b*, C*, h*) showed different results between the different users. However, for individual experimenters, the data of the L*a*b*/C* h* values were very consistent across each of their 3 measurements. This was applicable to both the QS and the VES, there being only a few outliers observed. Considered seperately, for the VES all the values (L*,a *, b*, C*, h*), and for the QS the a*, b* and h* values, no significant differences were found (Friedman test, $p > 0.01$). As an example, Figure 4 shows the boxplots of the L* values for both devices relating to the 1st, 2nd and 3rd measurements.

Discussion

The aim of this study was to analyze and compare the reproducibility, reliability and interrater reliability of the spectrophotometers QuattroShade (QS) and VITA Easyshade (VES). To accomplish this, three different experimental setups were used. In each case, the shade of two extracted human teeth was measured with both colorimeters. The frequency of calibration as well as the effect of different users as variables has been taken into account.

The first null hypothesis reads: Regardless of the number of users and/ or the calibration sequence, each instrument produces consistent (reproducible) and reliable color measurement results from identical inputs. The color measurements collected in the study showed statistically significant differences ($p < 0.05$) and therefore this hypothesis was rejected. As far as the two devices are concerned, the data points obtained using the VES demonstrated less statistical spread, and therefore, has a better reproducibilty than the QS.

Similarly, the second null hypothesis was rejected, because here, significant differences in ΔE values ($p<0.05$) were established. These deviations highlight an inherent inaccuracy in the functioning of these devices.

The third null hypothesis reads: The L*a*b*/C*h* values from a triad of measurements with both instruments are not significantly different ($p> 0.05$). All values (L *, a *, b *, C *, h *) showed varying results between the different users and therefore, the third null hypothesis was also rejected. However, considering the devices individually the null hypothesis is supported for the VES in all the values (L*, a*, b*, C*, h*) and as concerns the QS by the a*, b* and h* values ($p > 0.05$).

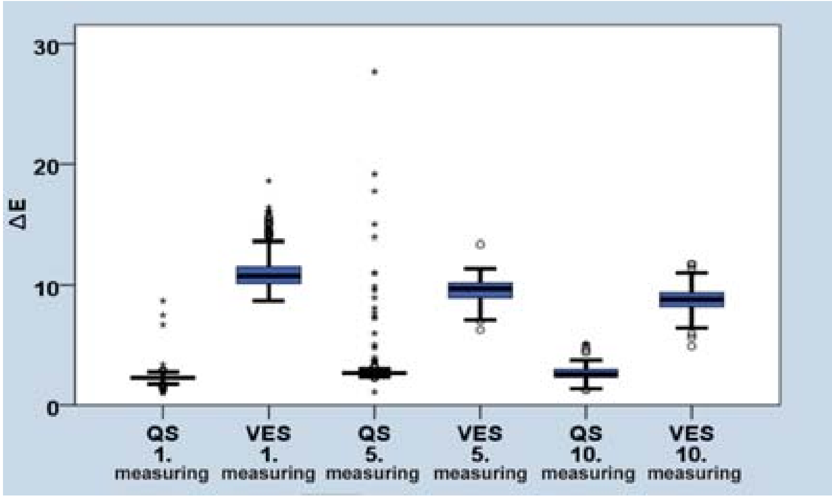
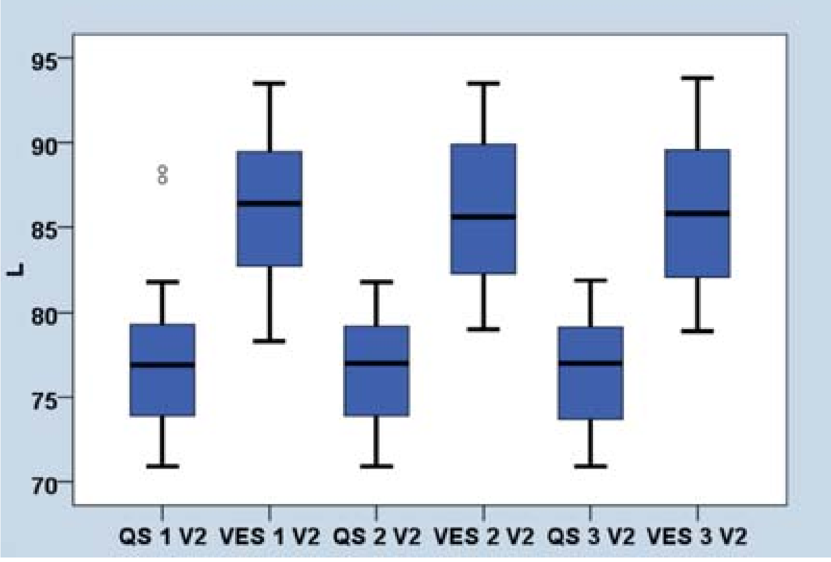


Figure 3 ΔE, tooth 12, calibration after 1, 5, 10 measurings, QS and VES

In comparison, both devices showed significant differences in color measurements, and this was independent of whether it was in operation with a single or multiple users. The VES showed a lower variability in the values for several of the parameters, and therefore, has better reproducibility than the QS. The best reproducibility was obtained, for both devices, when they were calibrated after every ten measurements, although the results from the differing calibration frequencies varied only very slightly. For this reason, calibration protocols did not play a significant role, as Olms et al. [33] have previously reported for the VES. Changing users on both devices demonstrated very good reliability results, but, the QS had a smaller data spread and thus gave a slightly superior performance than the VES.

The most important factor in dental spectrophotometry is to have a device that returns the most precise and error-free recording of tooth shades [6]. The VES 4.0 is considered to be the most frequently evaluated spectrophotometer, and has become the reference standard for digital tooth shade determination in clinical trials [32, 37, 45]. The 5th generation digital colorimeter, VES V, was introduced in 2015 [43], but was not yet available at the time that this study was begun. So far, there are no published studies about the VES V. Likewise, for the QS, there are as yet no published scientific studies regarding its reproducibility and reliability for shade determinations. Even a comparison between the two spectrophotometers, VES 4.0 and QS, is not available in the current literature. The present study was not performed in vivo, because of the difficulty in controlling for diverse factors, for example, the differences between tooth shades, surface morphologies, tooth convexities and degrees of opacity occurring in teeth. Furthermore, the high number of measurements (1056 per device), as well as wanting a controllable system for recording repeat measurements were more suitable for an in vitro study. Nevertheless, consideration was given to simulating a normal dental surgery environment for all the test procedures. It is recognized that the time consuming construction of a positioning guide, would not be a viable option under everyday clinical conditions, but was utilized in this study for the VES. Incorporating this guide provided audit quality, because the measuring head of the VES could be replaced in an identical position on the tooth being scrutinized. Previous studies by Olms et al. [33] and Leibrock et al. [30], have confirmed improved measurement reproducibility when a positioning guide was being utilized. Another study by Blum et al. [5] found that for pure color measurement (VITA 3 D-Master) a positioning guide does not significantly influence the color result. However, for making



(Fig. 1–4, Tab. 1: C. Olms)

Figure 4 Reliability, L-value, QS and VES, 1.–3. measuring

a comparison of the L* a* b* values a positioning guide is preferred. In use, the QS illuminated the entire surface of a tooth and therefore a positioning guide was unnecessary.

According to the manufacturer' instructions, a calibration of the VES should be carried out after switching on the device and also after changing the cross-infection protection sheath. In use, the measuring tip must lie flush against the tooth surface [43]. The QS must be calibrated after starting as well as after each color determination. It has on its screen an angle control for correct positioning on the tooth [10].

Most existing studies which used the VES [9, 14, 22, 26, 46] are lacking information regarding calibration frequencies. Only Olms et al. [33] reported different calibration sequences after 5 and 20 measurements using the the VES. With this in mind, the influence of the calibration sequence on the reproducibility of measurements was deemed important enough to be included as a factor investigated by this study.

The VES can be categorized as a spot meter because it uses only a small area of about 3 mm² from the entire tooth surface to evaluate tooth color. A published study [20] showed that data collected with a spot meter can be error prone due to irregularities of the tooth surface, an increased likelihood of tooth dehydration and errors when capturing images. However, other published studies [9, 12, 22], explicitly showed that spot meters are accurate and can be relied upon. QS partitions and identifies tooth color across the entire tooth surface („complete tooth measurement") and is able to create a topographic color map of the tooth. Furthermore, devices such as the QS are able to allocate average values from the three tooth areas (cervical, middle and incisal) by means of only one data capture. In other published studies concerning the reproducibility and reliability of spectrophotometers, the teeth were divided into their thirds during measurement taking [7, 18, 44]. But, since individual thirds have no influence on the results [44], such a dividing protocol was not considered in this present study. The QS is also capable of capturing the reflected spectrum from the entire tooth surface. The supporting software converts these spectral data into color information which can then be analyzed in the familiar L* a* b*/C* h* format [17]. Like the spot meters, the data from these complete tooth-measurment devices are also reliable and able to improve the final result [24, 39].

Baltzer and Kaufmann-Jinoian [1] found in their study that teeth with brightness levels 1 and 5 are extremely rare and about 50 % of all natural teeth present in the middle, with a brightness level 3. This study used predetermined teeth assessed with the VITA 3D Master Color Scale. With tooth 21 registering 2M3, and tooth 12 being 1M2, these test specimens corresponded to brightness levels of 1 and 2 respectively.

Both the VES and the QS presented different color distributions. Dozic et al. [9], measured five predefined teeth as templates using five different colorimeters, and obtained different color distributions between the devices. A possible explanation, is that these device specific hues and distributions, were caused by fluctuations in the individual colors of the teeth that were serving as templates. The various color calculation algorithms of the individual devices could also be responsible. The algorithms may define color boundary decisions differently and may also allocate differing weightings to the color parameters hue, brightness and saturation. Another possibility, is that an extracted tooth being assessed was of an unsuitable color. For example, if it was of such a color that fell midway between two of the templates defining the color space in the reference model, then an unambiguous assignment of its hue would be more difficult [44].

Although, the L*a* b* values are absolute and standardized, it is important to realize, that they are not interchangeable between two different measurement devices [19, 28, 29, 40]. This study's results also support this opinion. A possible reason for deviating results may be due to variability between the measuring devices being used. Already, Kim-Pusateri et al. [22] have reported deviations between colorimeters and devices from the same manufacturer. The VES showed better reproducibility in several parameters than the QS. Several publications [9, 26, 46] have confirmed excellent reproducibility of the VES. This study found that both devices showed their best reproducibility when calibrated after every 10 measurements. This contradicts the results of Olms et al. [33], whereby a lower standard deviation was found, with more rather than less frequent calibration. However, Olms et al. [33] confirmed that for the VES, the calibration protocol only plays a minor part, in affecting the color measurements.

The influence of different users on color measurements was also determined. Both devices were rated as very good but their reliability results differed. All values (L*, a*, b*, C*, h*) gave different results when measuring the same tooth. This was applicable when using one of the devices for repeated measurements, but also, when comparing measurements recorded from the alternate device. This is in agreement with the clinical observations of Kim-Pusateri et al. [22], who measured and compared the reliability of four different colorimeters, which included the VES. Nevertheless, the QS recorded a lower variance for the L*, a*, b*, C*, h* data, which is a result that is confirmed by the work of Schmitter et al. [41]. These authors also graded the reliability of the QS's precursor model, ShadePilot as „acceptable to excellent."

The ΔE value is often used to express the difference between two measured colors. The range of detectable ΔE values for an excellently trained eye starts at 0.4 [11] under laboratory conditions and extends to a mean of 3.7 [16]. Paravina et al. [38], however, found a ΔE range from 1.2 to 2.7 in their study. All of the ΔE values in this study varied between 0.1 and 2.2. Therefore, according to the research just mentioned above, this study's ΔE values would have been reported as barely perceptible and considered to be clinically irrelevant.

A fundamental point is that, an objective reference or control group, could have been used as the standard for the „true values" of the teeth that were being color measured. However, there was no distinction made in this study, as to whether the devices were correctly identifying the „true colors" of the teeth, and therefore no control group was used. The measured results only relate to the consistency of the color devices. A device that produces more reliable measurements is also likely to be more predictable than an inconsistent one. However, that is just an assumption and further clinical research is needed to support it and to explain the meaning of any differences.

This in vitro study did not adequately simulate a patient in a clinical situation, but the results suggest that both spectrophotometers provide very good to excellent results in both reproducibility and reliability. Nevertheless, the manufacturers have not yet succeeded in eliminating all imprecision from their devices. Therefore, a visual check of the color selection should always be done when operating either of the devices.

Conclusion

The present study evaluated the quality of color determination measured using the dental spectrophotometers VITA Easyshade and QuattroShade.

The results on reproducibility and reliability demonstrate, that both devices can be considered to be dependable and precise. However, significant differences in color measurement values were noted both internally and when comparing devices, irrespective of whether they were used by single or multiple users.

But, for use in a clinical setting these differences were not practically relevant. Therefore, these electronic devices can serve as a convenient alternative for taking dental shades. However, it is recommended that in clinical practice shade choices should be safeguarded by checking them against a standard shade guide.

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Conflict of interest:

The authors declare that there is no conflict of interest under the guidelines of the International Committee of Medical Journal Editors.

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(Photo: I. Riemer)

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Effectiveness of the "CIOTIPlus"-system on cleaning of approximal surfaces

Introduction:
An efficient removal of biofilm plays a major role in the prevention of caries as well as gingivitis and periodontitis. In this respect, besides the professional hygiene measures performed in the dental practice, an effective, self-responsible, home-based oral hygiene should also take place. A predilection site for caries and gingivitis is represented by the tooth surfaces below the proximal contact points, which can hardly be cleaned with toothbrushes alone. The aim of the present cross-over pilot study was to investigate whether two-times brushing in accordance with the CIOTIPlus-System (**C**hewing, **I**nside, **O**utside, **T**ongue and **I**nterdental area, Plus: second brushing) using different brushing regimens (time and type of interdental hygiene tools) has an effect on interdental cleaning (IDC).

Methods:
15 subjects (7 females, 8 males, mean age 50.1 ± 6.5 years) were included in this study with a split-mouth design. On five appointments, each of which was preceded by a 72-hour plaque accumulation phase, ten brushing regimens were evaluated on their ability to clean the approximal surfaces; these regimens employed the use of a standard manual toothbrush and interdental hygiene tools. Six brushing regimens using the sequence "brushing – IDC-brushing" (flossing vs. flossing + interdental brushing vs. interdental brushing vs. soft picks vs. interdental brushing from vestibular and oral with or without gel) and four brushing regimens using the sequence "IDC – brushing – brushing" (flossing vs. interdental brushing vs. flossing + interdental brushing vs. soft picks) were tested. The participants were instructed to brush their teeth according to the "CIOTIPlus"-System. The Quigley-Hein Index (QHI) and the modified Approximal Plaque Index (QH-API) were determined at three time points in order to assess plaque reduction: before brushing (t0), after the first brushing and IDC (t1) as well as after the second brushing (t2).

Results:
At t1, a significant reduction of the QHI and QH-API values was observed in all groups compared to t0. The highest reduction of the QH-API was observed in the group "brushing – interdental brushing from vestibular and oral – brushing" (BI2B) (ΔQH-API-t0-t1: 2.44 ± 0.45). At t2, the QHI and QH-API values were further significantly reduced in all groups. The greatest reduction of the QH-API was once again observed in the group BI2B (ΔQH-API-t0-t2: 3.16 ± 0.41). However, after the second brushing, the group differences were very small (except for BI2B).

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Conclusion:
Interdental brushing from vestibular and oral seems to be the most effective IDC regimen for reducing the approximal plaque values. Second brushing, as part of the "CIOTIPlus"-System, leads to a higher plaque reduction on smooth and approximal surfaces compared to the one-time brushing, no matter what kind of interdental hygiene tools/ brushing regimens are used. Therefore, any cleaning performance deficits associated with the use of different hygiene tools in the approximal surfaces could be compensated using this approach.

Keywords: CIOTIPlus-System; interdental cleaning; plaque reduction; second brushing

1. Introduction

Mechanical plaque control and the removal of biofilm play a major role in the prevention of caries, gingivitis and periodontitis [4]; they represent an essential prerequisite for the long-term preservation of dental and oral health, not to mention general health. Preponderantly, patients use manual toothbrushes for mechanical plaque control as part of their self-responsible, home-based oral hygiene [30]. Reliable cleaning of the tooth smooth surfaces can be achieved using both manual and electric toothbrushes, if they are used correctly [38]. The most frequently recommended brushing technique by dentists is the "Bass technique" or modifications thereof [40]. However, this technique is difficult to learn. Studies have shown that this technique is hardly implemented by patients. In an investigation performed by Ganss et al. (2009), none of the 103 adult subjects in the study applied the "Bass Technique". The patients predominantly used rotationally movements (73.8 %), performed horizontal scrubbing movements (8.7 %), or combined these two movements together (13.6 %) [9]. The "scrubbing technique" is the primary technique which is learned from a very early age because it follows the individual movement pattern and is therefore easy to perform [41]. As motor skills continue to evolve later in life, the "Fones Technique", with its rotational motion pattern, can be easily learned [14]. These two techniques are often combined with a brushing system, which comprises of the following brushing sequence: first the chewing, followed by the outside and then the inside surfaces (COI-System) [41]. Research in the field of behavioral science has revealed that the techniques and behaviors, which are acquired in childhood, are often carried into adult life [34]. As a consequence, health-related behavioral changes in adulthood are more difficult to attain [3]. This would explain why the primary recommended "Bass technique" by dentists is not implemented by patients. However, there are no published findings demonstrating the superiority of the "Bass Technique" over other techniques. Much more important than the technique seems to be the adherence to a brushing system [11, 25].

Neither a manual nor an electric toothbrush can clean all the tooth surfaces, as they cannot fully penetrate into interdental area; thus, they are ineffective for cleaning the interdental surfaces [32]. However, effective cleaning of the interdental surfaces is of particular importance in the context of gingivitis and caries prophylaxis, because the tooth surfaces below the proximal contacts present a predilection site for caries and gingivitis [26]. In the fifth German oral health study (DMSV) a correlation was found between younger seniors using interdental hygiene tools and lower DMF-T values [17]. Interdental hygiene tools such as floss and interdental brushes are recommended when toothbrushes alone cannot sufficiently remove the interdental biofilm [10, 29]. However, user acceptance of these aids is classified as being low [31]. Zimmer and Lieding (2014) conducted a survey on a representative sample of the German population and found that only 23.2 % of the total population used dental floss and 15.1 % interdental brushes at least several times a week [44]. Thus, the authors concluded that a maximum of 38.3 % from the total population used dental floss or interdental brushes at least several times a week to clean interdental areas [44]. The use of interdental brushes seems to be easier for patients and it has also been shown, that they are more effective than dental floss in terms of approximal cleaning [7, 32]. Although, from a scientific standpoint neither the effectiveness of dental floss nor that of interdental brushes has been sufficiently proven [23, 27]. Nonetheless, the use of interdental cleaning tools is expressly recommended once a day to remove food rests and existing microorganisms [29]. In literature, no recommendations or references regarding the precise time of interdental cleaning exist. Thus, it remains unclear whether the patient should perform interdental cleaning before or after smooth surface brushing, and if the sequence of this action is relevant for plaque removal.

In previous studies could be shown that a simple modification of one's home-based oral hygiene, in the form of second brushing in accordance with the "CIOTIPlus"-System, results in improved plaque removal, significantly reduced caries formation on root surfaces and crown margins in older people, as well as stabilized or improved periodontal conditions [12, 13]. Using this brushing system, the sequence of tooth cleaning is: first the chewing, followed by the inside, then the out-

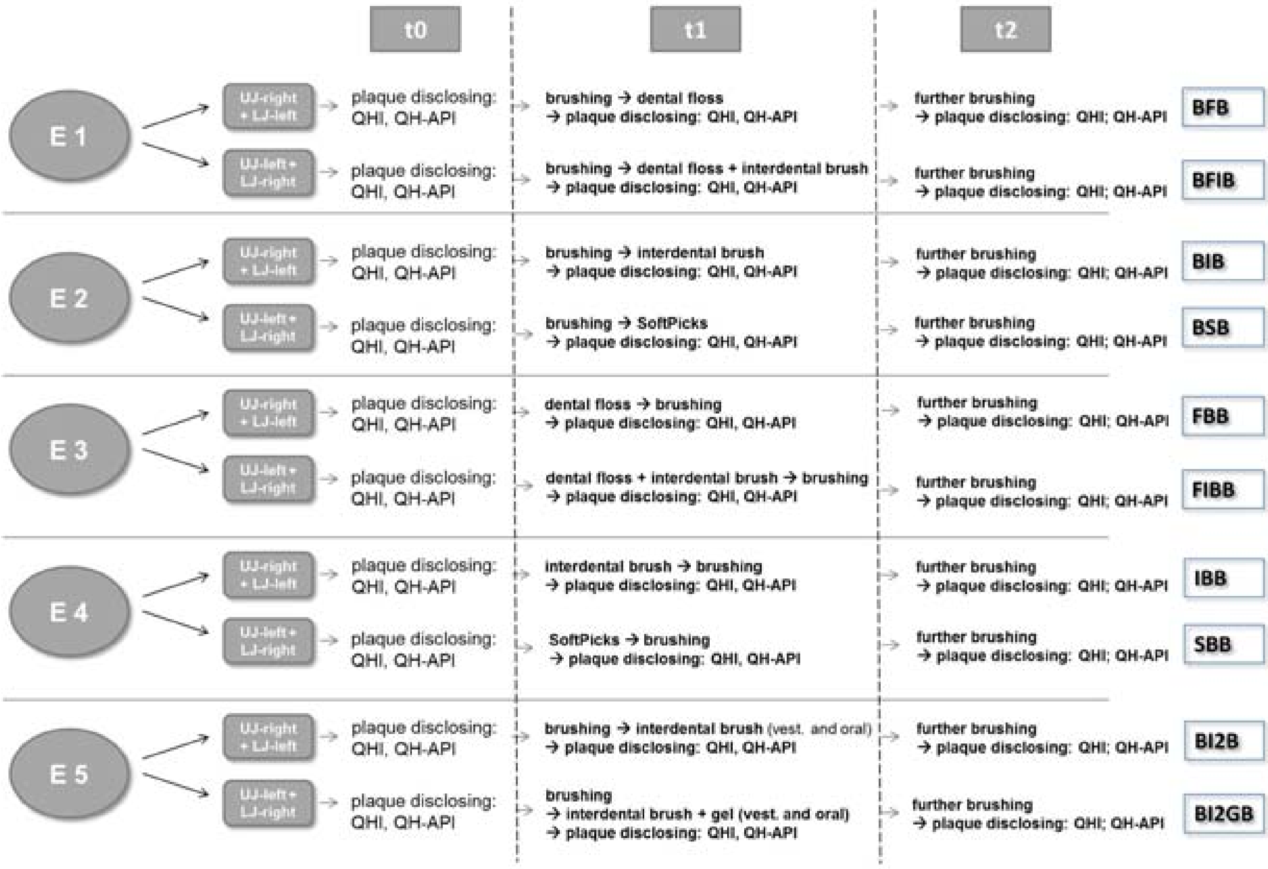


Figure 1 Clinical approach (E1–E5: Examination 1-5; UJ: Upper Jaw; LJ: Lower Jaw

side surfaces, after the tongue, and finally the approximal surfaces. Succeeding this first cleaning procedure, the patient brushes all of the tooth surfaces and the gums in a rotation motion with a same (pea-sized) amount of fluoride toothpaste again [12]. The purpose of the present cross-over pilot study was to investigate whether second brushing according to the "CIOTIPlus"-System, using different cleaning regimens (time point and type of interdental cleaning tools), has an effect on interdental cleaning.

2. Methods

2.1. Participants

The participants were randomly selected patients from the Department of Conservative Dentistry, Periodontology and Preventive Dentistry of the Hannover Medical School. Inclusion criteria for participation in the study was a remaining dentition of at least 20 teeth in the absence of any crown restorations, an age between 35–64 years, and a Periodontal Screening Index (PSI) < 2. Exclusion criteria included any physical disabilities that made adequate oral hygiene difficult, head/neck radiotherapy in the past, heavy smoking (> 10 cigarettes per day), and drug intake that could result in false clinical values (e.g. anticoagulants). Project participation was voluntary and could be revoked at any time without the need to give reasons. The project received a positive vote from the ethics committee of the Hannover Medical School (Vote No.: 1054–2011).

2.2. Study design and collected parameters

All examinations were performed by a practitioner with the support of an assistant. As part of the initial examination (E0), an anamnesis, a detailed oral examination and an evaluation of the PSI values was conducted on each participant. The dental plaque was visualized with the aid of a plaque disclosing solution (Mira-2-Ton, Hager & Werken, D-Duisburg) and a magnifying loupe (2.5-fold, Orascoptic Lupensysteme, Sigma Dental, D-Handewitt). In order to quantify the amount of plaque, the modified Quigley-Hein Plaque Index (QHI) according to Turesky [35] and the modified plaque index for assessing the extent of plaque in approximal areas based on the Quigley-Hein Plaque Index (=modified QH-API) [13] were used. The "CIOTIPlus"-System of tooth cleaning was explained, demonstrated and practiced. The system entailed first brushing the **c**hewing surfaces of teeth, followed by the **i**nside and then the **o**utside surfaces followed by the brushing of the **t**ongue for at least two minutes and lastly **i**nterdental cleaning (CIOTI). Afterwards, the already cleaned tooth surfaces including the gums were brushed systematically (CIO-System) with the same (pea-sized) amount of fluoride toothpaste in rotational movements for at least one minute (= Plus). Moreover, in preparation for the upcoming appointments, the sizes of the interdental brushes were individually selected for each participant, so as to correspond to the dimensions of his/her interdental spaces (IAP-probe, Curaden Germany, D-Stutensee). In order to create uniform starting conditions, all of the participants received a professional tooth cleaning afterwards.

Five follow-up examinations (EU1-E5) ensued, each of which was preceded by a 72-hour plaque accumulation phase (no home-based oral hygiene and no use of oral hygiene products or dental care products such as menthol-containing candies or chewing gum). After the examination, an associated "washout phase" for at least 2 days was followed, during which the participants performed home-based oral hygiene with their usual oral hygiene tools. After this phase, the next 72-hour plaque accumulation phase began.

At each examination, the dental plaque was first visualized like in E0 and the modified QHI and the modified QH-API [13] were recorded (t0). For each participant, the entire dentition was not assessed as a whole. Instead, the upper right jaw and lower left jaw were combined together and evaluated separately from the upper left jaw and the lower right jaw in a split-mouth design.

Subsequently, the participants were instructed to brush their teeth systematically for at least 2 minutes; this always involved brushing the tooth smooth surfaces in the sequence chewing, inside and outside surfaces, followed by the brushing of the tongue (CIOT system) with a standard manual toothbrush (1–2–3 Classic Care/OralB, Procter & Gamble, Sulzbacher am Taunus) and toothpaste with medium abrasiveness (Elmex Sensitive Professional Repair and Prevent, CP GABA, D-Hamburg). The cleaning of the interdental surfaces varied in terms of the type of cleaning tool employed and time point of application, so that a total of 10 different cleaning regimens resulted (see Fig. 1): six of the regimens employed the sequence "brushing – interdental cleaning" and four of the regimens applied the sequence "interdental cleaning – brushing". The tools used for performing interdental cleaning included dental floss (EssentialFloss waxed/OralB, Procter & Gamble, Sulzbacher am Taunus), interdental brushes (CPS prime, Curaden Germany, D-Stutensee) with or without low abrasive Gel (Paroex toothpaste, Sunstar GUM, D-Schönau), and an elastic, metal-free interdental brush with rubber bristles (Soft-Picks Advanced, Sunstar GUM, D-Schönau). After this, the plaque was stained again using a plaque disclosing solution and the QHI and QH-API values were recorded (t1). The participants were then instructed to brush the already cleaned tooth surfaces including the gums systematically with the same (pea-sized) amount of fluoride toothpaste in rotational movements for at least one minute (=plus). Following the second brushing, the QHI and QH-API values were once again recorded after staining with the plaque disclosing solution (t2).

A cross-over design was applied in the study. Due to the cross-split-mouth design, two cleaning regimens could be evaluated together per examination appointment, thus giving rise to a total of 10 groups (Fig. 1). At the end of each examination, the teeth of the participants were professionally cleaned.

The tooth brushing tasks for all tooth surfaces were carried out by the participants themselves (hands-on brushing) and controlled by the examiner during each examination. However, the tools for cleaning the approximal surfaces were handled by the examiner himself/herself (hands-on-flossing/brushing). Thus, the interdental cleaning tools used for the approximal surfaces were used on each subject in the same way. Both approximal surfaces were cleaned with two up and down movements using dental floss. The floss was then removed as a loop out of the approximal space. When the interdental brushes and soft picks were employed, after their insertion into the approximal space, each approximal surface was cleaned using two horizontal brushing movements ("X-Technique"). The brushes were then removed obliquely out of the approximal space in an occlusal and vestibular direction. In the two groups where interdental brushes were used from vestibular and oral, the same procedure was repeated orally. Following each interdental cleaning procedure, the brushes were rinsed and cleaned under running water.

2.3. Statistical Analysis

Data analysis was performed using the statistical analysis program SPSS/PC Version 23.0 for Windows (SPSS Incorporation, Chicago, IL, USA). All the collected data were analyzed following pseudonymisation. For the clinical parameters, the mean values with standard deviations were calculated. The comparison of means between groups and time points was performed using independent sample t-tests. The level of significance was set at $p \leq 0.05$.

3. Results

Fifteen participants (7 females, 8 males) with an average age of 50.1 ± 6.5 years were included in the present study. At baseline (E0), the subjects displayed an average QHI of 2.06 ± 0.46 and an average QH-API of 3.63 ± 0.39.

Before the first brushing (t0), an average QHI of 2.85 ± 0.39 and an average QH-API of 3.79 ± 0.40 were found in all groups (Tables 1 and 2). After the first brushing (t1), both the QHI and the QH-API decreased significantly in all groups (QHI: 1.26 ± 0.46, QH API: 1.92 ± 0.65) ($p < 0.0001$). The largest QHI reduction was in the group "brushing – interdental brushing from vestibular and oral – brushing" (BI2B) (ΔQHI-t0-t1: 1.89 ± 0.30) and the lowest reduction was noted for the group "brushing – soft picks – brushing" (BSB) (ΔQHI-t0-t1: 1.36 ± 0.31). In terms of QH-API, the greatest reduction was in the group "brushing – interdental brushing from vestibular and oral – brushing" (BI2B) (ΔQH-API-t0-t1: 2.44 ± 0.45) and the smallest reduction was observed in the group "brushing – flossing – brushing" (BFB) (ΔQH-API-t0-t1: 1.37 ± 0.52) (Tables 1 and 2). On average, the subjects brushed with the manual toothbrush for 2.18 ± 0.18 minutes.

After the second brushing (t2), the QHI and QH-APIs were further significantly reduced in all groups

	QHI										
	total	**BFB**	**FBB**	**BIB**	**IBB**	**BFIB**	**FIBB**	**BSB**	**SBB**	**BI2B**	**BI2GB**
t0	2.85 ± 0.39	2.78 ± 0.45	2.85 ± 0.43	2.81 ± 0.37	2.77 ± 0.43	2.79 ± 0.42	2.87 ± 0.48	2.84 ± 0.37	2.89 ± 0.34	2.94 ± 0.30	2.97 ± 0.29
t1	1.26 ± 0.46	1.35 ± 0.45	1.13 ± 0.48	1.25 ± 0.54	1.17 ± 0.55	1.42 ± 0.45	1.26 ± 0.43	1.48 ± 0.43	1.21 ± 0.41	1.05 ± 0.47	1.26 ± 0.31
t2	0.48 ± 0.33	0.53 ± 0.34	0.47 ± 0.34	0.57 ± 0.44	0.42 ± 0.30	0.60 ± 0.40	0.48 ± 0.27	0.56 ± 0.36	0.44 ± 0.31	0.37 ± 0.21	0.42 ± 0.23
t0–t1	1.59 ± 0.38 (55.79%)	1.43 ± 0.40 (51.44%)	1.72 ± 0.38 (60.35%)	1.56 ± 0.41 (55.52%)	1.60 ± 0.40 (57.76%)	1.37 ± 0.35 (49.1%)	1.61 ± 0.43 (56.1%)	1.36 ± 0.31 (47.89%)	1.68 ± 0.27 (58.13%)	1.89 ± 0.30 (64.29%)	1.71 ± 0.30 (57.58%)
t0–t2	2.37 ± 0.38 (83.16%)	2.25 ± 0.41 (80.94%)	2.38 ± 0.42 (83.51%)	2.24 ± 0.41 (79.72%)	2.35 ± 0.31 (84.84%)	2.19 ± 0.43 (78.49%)	2.39 ± 0.44 (83.28%)	2.28 ± 0.32 (80.28%)	2.45 ± 0.25 (84.78%)	2.57 ± 0.23 (87.41%)	2.55 ± 0.36 (85.59%)

Table 1 QHI of all groups at different time points (t0, t1, t2), as well as QHI differences between t0–t1 and t0–t2.
BFB: brushing-flossing-brushing; FBB: flossing-brushing-brushing; BFIB: brushing-flossing+interdental brushing-brushing; FIBB: flossing+interdental brushing-brushing-brushing; BIB: brushing-interdental brushing-brushing; IBB: interdental brushing-brushing-brushing; BSB: brushing-soft picks-brushing; SBB: soft picks-brushing-brushing; BI2B: brushing-interdental brushing from vestibular and oral-brushing; BI2GB: brushing-interdental brushing from vestibular and oral with gel-brushing

(QHI: 0.48 ± 0.33, QH API: 1.02 ± 0.50) ($p < 0.0001$). The largest reduction of QHI was in the group "brushing – interdental brushing from vestibular and oral – brushing" (BI2B) (ΔQHI-t0-t2: 2.57 ± 0.23) and the lowest reduction was in the group "brushing – floss + interdental brushing – brushing" (BFIB) (ΔQHI-t0-t2: 2.19 ± 0.43). With respect to the QH-API values, the greatest reduction of the QH-API was in the group "brushing – interdental brushing from vestibular and oral – brushing" (BI2B) (ΔQH-API-t0-t2: 3.16 ± 0.41) and the smallest reduction was seen in the group "brushing – flossing – brushing" (BFB) (ΔQH-API-t0-t2: 2.40 ± 0.48) (Tables 1 and 2). On average, the subjects brushed 1.40 ± 0.31 minutes with the manual toothbrush during the second brushing.

3.1. Time point of approximal surface cleaning

Comparing the group "brushing – interdental cleaning" (BFB, BIB, BFIB, BSB, BI2B, BI2GB) and the group "interdental cleaning – brushing" (FBB, IBB, FIBB, SBB), there were no significant differences in the plaque index values for the smooth and approximal surfaces, neither after the first (t1) nor after the second brushing (t2) (Fig. 2).

3.2. Type of cleaning tool used

With respect to smooth surface cleaning, no significant differences in the reduction of the plaque index value were observed for the different hygiene tools, neither after the first (t1) nor after the second (t2) brushing. In the approximal area, the group "interdental brushing from vestibular and oral" (BI2B, BI2GB) showed significantly higher reductions in the plaque index value after the first brushing (t1) than the groups "dental floss" (BFB, FBB)" ($p < 0.0001$), "floss + interdental brushing" (BFIB, FIBB) ($p = 0.37$), "interdental brushing" (BIB, IBB) ($p = 0.006$) and "soft picks" (BSB, SBB) ($p < 0.0001$). Following the second brushing (t2), the group "interdental brushing from vestibular and oral" (BI2B, BI2GB) still displayed the highest reduction of the approximal plaque index value. Statistical significance, however, was achieved only when it was compared to the groups "dental floss" (BFB, FBB) ($p < 0.0001$), "interdental brushing" (BIB, IBB) ($p = 0.006$) and "soft picks" (BSB, SBB) ($p < 0.0001$). The lowest reduction of the approximal plaque index value was seen for the group "dental floss" (BFB, FBB), both after the first (t1) and after the second (t2) brushing. The lower reduction was statistically significant only after the first brushing (t1) with respect to the groups "interdental brushing vestibular and oral" (BI2B, BI2GB) ($p < 0.0001$) and "interdental brushing" (BIB, IBB) ($p = 0.036$). After the second brushing, there were no significant differences between the groups "floss" (BFB, FBB), "floss + interdental brushing" (BFIB, FIBB), "interdental brushing" (BIB, IBB) and "soft picks" (BSB, SBB) (Table 3).

A general summary of the QH-API and QHI values is presented in tables 4 and 5. The groups "floss" (BFB, FBB), "floss + interdental brushes" (BFIB, FIBB), "interdental brushes" (BIB, IBB), "soft-picks" (BSB, SBB) and "interdental brushing from vestibular and oral" (BI2B, BI2GB) are further divided with respect to the oral and vestibular surfaces of the maxilla and

QH-API											
	total	**BFB**	**FBB**	**BIB**	**IBB**	**BFIB**	**FIBB**	**BSB**	**SBB**	**BI2B**	**BI2GB**
t0	3.79 ± 0.40	3.92 ± 0.48	3.80 ± 0.50	3.88 ± 0.39	3.76 ± 0.38	3.82 ± 0.38	3.79 ± 0.47	3.86 ± 0.35	3.79 ± 0.40	3.69 ± 0.34	3.64 ± 0.30
t1	1.92 ± 0.65	2.55 ± 0.51	1.98 ± 0.57	2.04 ± 0.66	1.77 ± 0.44	2.10 ± 0.74	1.63 ± 0.57	2.33 ± 0.56	2.07 ± 0.49	1.25 ± 0.44	1.51 ± 0.47
t2	1.02 ± 0.50	1.51 ± 0.51	1.21 ± 0.47	1.13 ± 0.46	0.99 ± 0.41	0.89 ± 0.41	0.87 ± 0.46	1.35 ± 0.42	1.16 ± 0.41	0.53 ± 0.28	0.59 ± 0.27
t0–t1	1.87 ± 0.62 (49.34%)	1.37 ± 0.52 (34.95%)	1.82 ± 0.65 (47.89%)	1.84 ± 0.66 (47.42%)	1.99 ± 0.38 (52.93%)	1.72 ± 0.85 (45.03%)	2.16 ± 0.56 (56.99%)	1.53 ± 0.51 (39.64%)	1.72 ± 0.38 (45.38%)	2.44 ± 0.45 (66.12%)	2.13 ± 0.46 (58.52%)
t0–t2	2.77 ± 0.54 (73.09%)	2.40 ± 0.48 (61.22%)	2.59 ± 0.59 (68.16%)	2.75 ± 0.60 (70.88%)	2.77 ± 0.43 (73.67%)	2.93 ± 0.57 (76.7%)	2.92 ± 0.51 (77.04%)	2.51 ± 0.46 (65.03%)	2.63 ± 0.49 (69.39%)	3.16 ± 0.41 (85.64%)	3.05 ± 0.42 (83.79%)

Table 2 QH-API of all groups at different time points (t0, t1, t2), as well as QH-API differences between t0–t1 and t0–t2
BFB: brushing-flossing-brushing; FBB: flossing-brushing-brushing; BFIB: brushing-flossing+interdental brushing-brushing; FIBB: flossing+interdental brushing-brushing-brushing; BIB: brushing-interdental brushing-brushing; IBB: interdental brushing-brushing-brushing; BSB: brushing-soft picks-brushing; SBB: soft picks-brushing-brushing; BI2B: brushing-interdental brushing from vestibular and oral-brushing; BI2GB: brushing-interdental brushing from vestibular and oral with gel-brushing

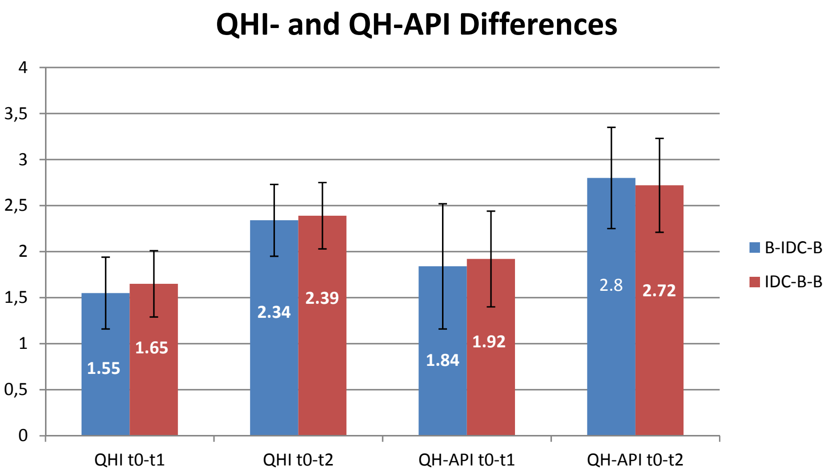
mandible. In general, after the first (t1) and second (t2) brushing, higher plaque index value reductions were observed on the vestibular smooth and vestibular approximal surfaces than on the opposing orally located ones ($p < 0.0001$). Moreover, a higher reduction of the plaque index value occurred for the upper jaw in comparison to the lower jaw ($p < 0.0001$). Comparing the plaque index values only on oral surfaces between the lower and upper jaw, greater reductions were observed for the lower jaw at both time points (t1 and t2) ($p > 0.0001$).

The group "interdental brushing from vestibular and oral" (BI2B, BI2GB) displayed the highest reduction in plaque index values for each approximal surface. In comparison to the groups "floss" (BFB, FBB) and "soft picks" (BSB, SBB), this was significantly greater in every area.

4. Discussion

The results of the present study show that the plaque index value can be significantly more reduced by second brushing as compared to one-time brushing, given that patients brush according to the instructed system. These findings are similar to the results of previous studies [13]. There could be shown that, also in approximal areas, significantly more plaque removal resulted after second brushing than after one-time brushing, even if no additional hygiene tools were used for approximal surfaces. More specifically, after the first brushing, the reduction in the plaque index value averaged 22.64 % for smooth 3.95 % for proximal surfaces. After the second brushing, a significantly higher reduction in the plaque index values was observed for both smooth (54.72 %) and approximal surfaces (24.69 %) [13]. The aim of the current study was to evaluate the effect of an additional cleaning of the proximal surfaces, using different hygiene tools in combination with a second brushing, on the reduction of the plaque index value on the smooth and approximal surfaces. Compared to the results of Günay and Meyer-Wübbold (2018), in the present study higher reductions in the plaque index values were observed on both the smooth and approximal surfaces after the first brushing, which was combined with a separate cleaning of the interdental areas with different hygiene tools. This yielded a 55.79 % and a 49.34 % reduction of plaque index value on smooth and approximal surfaces, respectively. The second brushing, which was not combined with a separate cleaning of the interdental spaces, once again significantly increased plaque reduction in the area of smooth (83.16 %) and approximal surfaces (73.09 %). These results suggest that a separate cleaning of the approximal surfaces, through the correct use of different hygiene tools, achieves an additional reduction of the plaque index value in both smooth and approximal surface areas. This effect can be further significantly increased, once again, by a second brushing.

In a review by Slot et al. [33], various studies which evaluated the effectiveness of the manual toothbrush in terms of plaque removal were presented. The article reported a reduction of the QHI by an average of 30 % [33]. Similar values were observed in a prior evaluation of second brushing, too [13]. A reduction of the plaque index value by slightly less



(Fig. 1 and 2: H. Günay and K. Meyer-Wübbold)

Figure 2 QHI and QH-API differences between t0–t1 and t0–t2 of the groups "brushing-interdental cleaning-brushing"/B-IDC-B (BFB, BIB, BFIB, BSB, BI2B, BI2GB) and "interdental cleaning-brushing-brushing"/IDC-B-B (FBB, IBB, FIBB, SBB)

than a third was observed on the smooth surfaces after the first brushing procedure in both investigated groups [13]. In the current study, on the other hand, the overall QHI after the first brushing was reduced by a little over half (difference QHI t0-t1 55.79 %). Noteworthy here is that the first brushing was combined with interdental cleaning in the present study. Thus, the higher reduction of the QHI suggests that the cleaning of the approximal surfaces using different hygiene tools also has an influence on plaque reduction in the area of the smooth surfaces.

In the present study, a reduction of the plaque index values of more than two thirds could be achieved in terms of smooth and approximal surface plaque removal after the second brushing procedure (difference QHI t0-t2 83.16 %, difference QH-API 73.09 %). It should be noted that second brushing resulted in a longer brushing time. The participants brushed the smooth surfaces with the manual toothbrush an average of 2.18 ± 0.18 minutes during the first and 1.40 ± 0.31 minutes during the second brushing procedure, respectively, resulting in a total smooth surface cleaning time of 3.58 ± 0.40 minutes. Increasing brushing time can reduce plaque removal both when using manual and electric toothbrushes [19, 37, 42]. It has been observed that 1-minute and 2-minute tooth brushing results in an average plaque reduction of 27 % and 41 %, respectively [33]. In a survey performed on a representative sample of the German population, 75 % of the respondents answered that they brushed for 2 to 3 minutes (44 % 2 minutes, 32 % 3 minutes) [44]. However, there is often a disparity between estimated and actual brushing time [28]. In order to exemplify this, one study showed that the actual average duration of a brushing session of 68.8 seconds was perceived by subjects as being 148.1 seconds, more than twice as long [28]. In light of these findings, it seems to be more effective to advise patients to brush two-times according to a certain system (e.g. CIOTIPlus), and thus indirectly increase the duration of brushing, rather than to just recommend an increase in the duration of brushing. The etiological factors contributing to tooth abrasion have been described in literature as including toothpaste abrasiveness, toothbrush hardness, toothbrush contact pressure, brushing technique, as well as the frequency or duration of brushing [2]. Although the brushing time is indeed increased by second brushing, the present study finds that the subjects did not mechanically clean the smooth surfaces with the toothbrush for an excessively long time. As mentioned before, the brushing time of the smooth surfaces was noticeably less than 5 minutes. Thus, two-times brushing should have no influence on the formation of tooth abrasion. It must also be emphasized that the CIOTIPlus-System employed in this study is not a "double" brushing in the literal sense. The addition of "Plus" does not mean that the entire brushing process is once again repeated in the same way; rather, it denotes that a same (pea-sized) amount of fluoride toothpaste is applied on all tooth surfaces, which are then brushed with a toothbrush in circular/rotating movements, which of course, this leads to a corresponding mechanical cleaning of the teeth and gums.

In the CIOTI-System, the cleaning of approximal surfaces is performed at the end after the brushing of the smooth surfaces and tongue has been completed. The aim here is to clarify to the patient that the cleaning of the approximal surfaces has to be completed separately and thus requires time and concentration. For this reason, in the present study, only the time used for smooth surface brushing was recorded, while the time used for interdental cleaning was omitted.

The cleaning of approximal surfaces using special hygiene tools, in addition to brushing with a toothbrush, results in more plaque removal in approximal surfaces than brushing alone [18, 32]. The results of the present study suggest that interdental brushes applied from vestibular and oral appear to be the most effective for reducing the plaque index value in approximal areas in comparison to other tested interdental cleaning tools. The second highest reduction of the plaque index value in the approximal area was observed in the group "dental floss + interdental brushes", followed by the groups "interdental brushes" and "soft picks". The lowest reduction in the approximal plaque index value was found in the "dental floss" group. Other studies show similar results. Slot et al. (2008) published a systematic review concerning the effectiveness of interdental brushes on plaque removal as well as their effect on various clinical parameters such as bleeding and pocket depths. Among other findings, the authors came to the conclusion that brushing teeth in

QHI and QH-API differences										
	floss (BFB, FBB)		floss + interdental brush (BFIB, FIBB)		interdental brush (BIB, IBB)		SoftPicks (BSB, SBB)		interdental brush vest. and oral (BI2B, BI2GB)	
	QHI	QH-API	QHI	QH-API	QHI	QH-API	QHI	QH-API	QHI	QH-API
t0–t1	1.57 ± 0.40	1.59 ± 0.62	1.49 ± 0.40	1.94 ± 0.74	1.58 ± 0.39	1.91 ± 0.53	1.52 ± 0.33	1.62 ± 0.46	1.80 ± 0.30	2.29 ± 0.48
t0–t2	2.31 ± 0.41	2.49 ± 0.53	2.29 ± 0.44	2.93 ± 0.54	2.29 ± 0.36	2.76 ± 0.51	2.36 ± 0.99	2.57 ± 0.47	2.56 ± 0.29	3.10 ± 0.41

Table 3 QHI and QH-API differences between t0–t1 and t0–t2 of the groups "flossing" (BFB, FBB), "flossing + interdental brushing" (BFIB, FIBB), "interdental brushing" (BIB, IBB), "soft picks" (BSB, SBB) and "interdental brushing from vestibular and oral gel" (BI2B, BI2GB)

combination with the use of interdental brushes removed more plaque than brushing teeth alone; also, interdental brushes removed more interdental plaque than dental floss or dental sticks [32]. Likewise, the current study also observed higher approximal plaque index value reductions for interdental brushes compared to dental floss. The differences were significant when the interdental brushes were used from both vestibular as well as oral. Investigations have shown that interdental brushes, which are inserted into the approximal areas only from vestibular, clean the oral surfaces of the interdental areas less effectively than the vestibular surfaces [39]. This could be confirmed in the present study as well. The use of interdental brushes from both vestibular and oral reduced approximal plaque more significantly in the vestibular and oral surface areas than interdental brushes used only from vestibular.

After the second round of brushing, there were no significant differences in the reduction of plaque index values between the groups "dental floss", "dental floss + interdental brushes", "Interdental brushes" and "soft picks", neither on smooth nor on approximal surfaces. This result suggests that any possible "deficiencies" in the area of approximal plaque control related to the use of different hygiene tools can be compensated by brushing one's teeth two-times.

Other studies also show that interdental brushes appear to be more effective than dental floss in terms of approximal cleaning performance [7]. Additionally, they find that interdental brushes are easier for patients to use. However, the use of interdental brushes can give rise to problems, which reduces user acceptance. The brushes can easily bend if they are used improperly, which not only greatly reduces their durability, but also leads to a high trauma potential of interdental soft tissues [8] or the danger of tooth hard substance damage [6]. The elastic, metal-free interdental brushes with rubber bristles, which have been on the market for some time, are intended, on the one hand, to be more user-friendly and, on the other hand, to reduce the disadvantages of interdental brushes with metal cores. Studies could show that metal-free interdental brushes with rubber bristles were similarly effective in plaque removal as compared to interdental brushes with metal-cores and nylon bristles over an observation period of 3 to 4 weeks [1, 15]. However, in a one-time application, Abouassi et al. (2014) observed significantly higher plaque reduction when using interdental brushes with metal cores and nylon bristles as compared to the metal-free interdental brushes with rubber bristles, which is in conformance with the results of the present study; the reductions in the approximal plaque index values were found to be higher for interdental brushes than for soft picks. After 4 weeks of use, Abouassi et al. (2014) found no significant differences in the plaque reduction between the two types of brushes. The authors account for these difference in the one-time application to be related to patient compliance. In a survey, the authors found out that the patients preferred the metal-free interdental brushes with rubber bristles over metal-core interdental brushes with nylon bristles; this lead them to the conclusion that the participants had consequently used metal-core interdental brushes for home-based oral hygiene less frequently [1]. Interdental space size varies not only between patients, but also within a dentition. This implies that for an effective cleaning of the interdental space, interdental hygiene tools should be individually selected beforehand, not only taking into consideration the shape and size of the interproximal surfaces, but also user skill and acceptance.

In literature, there are no recommendations or indications with regards to whether the interdental cleaning should be carried out before or after smooth surface brushing. A cleaning of the interdental spaces before smooth surfaces could have the advantage that one already displaces the adhering plaque in the area with the tools for interdental space cleaning and this dislocated plaque could then be better removed with a toothbrush. Additionally, it could also be assumed that the brushing of smooth surfaces prior to interdental cleaning may be contra productive because an incorrect usage of the toothbrush has the potential to press even more plaque into the interdental area, thus making it more difficult to remove after. In the present study, after the first cleaning in the area of the ap-

QHI-API difference												
	total		floss (BFB, FBB)		floss + interdental brush (BFIB, FIBB)		interdental brush (BIB, IBB)		SoftPicks (BSB, SBB)		interdental brush vest. and oral (BI2B, BI2GB)	
	t0–t1	t0–t2	t0–t1	t0–t2	t0–t1	t0–t2	t0–t1	t0–t2	t0–t1	t0–t2	t0–t1	t0–t2
UJ vest.	2.86 ± 0.94	3.73 ± 0.75	2.65 ± 0.93	3.6 ± 0.65	2.78 ± 1.08	3.81 ± 0.85	3.11 ± 0.98	3.82 ± 0.87	2.53 ± 0.73	3.45 ± 0.61	3.24 ± 0.79	3.99 ± 0.67
UJ pal.	0.87 ± 0.74	1.71 ± 0.75	0.54 ± 0.55	1.46 ± 0.67	0.87 ± 0.86	1.89 ± 0.76	0.81 ± 0.66	1.62 ± 0.81	0.72 ± 0.61	1.53 ± 0.66	1.41 ± 0.71	2.06 ± 0.71
LJ vest.	2.47 ± 0.94	3.32 ± 0.72	1.99 ± 1.05	2.85 ± 0.84	2.67 ± 0.99	3.61 ± 0.52	2.58 ± 0.89	3.33 ± 0.69	2.33 ± 0.79	3.19 ± 0.71	2.81 ± 0.79	3.59 ± 0.58
LJ lin.	1.29 ± 0.83	2.33 ± 0.89	1.14 ± 0.86	2.15 ± 0.93	1.33 ± 0.77	2.33 ± 0.89	1.19 ± 0.73	2.27 ± 0.85	1.02 ± 0.76	2.12 ± 0.85	1.76 ± 0.86	2.77 ± 0.85

Table 4 QH-API differences between t0–t1 and t0–t2 of the groups "flossing" (BFB, FBB), "flossing + interdental brushing" (BFIB, FIBB), "interdental brushing" (BIB, IBB), "soft picks" (BSB, SBB) and "interdental brushing from vestibular and oral gel" (BI2B, BI2GB) divided into the vestibular and oral surfaces of the upper jaw (UJ) and lower jaw (LJ)

proximal and the smooth surfaces, slightly higher reductions in the plaque index value were in fact observed in the groups that performed interdental cleaning before smooth surface brushing. However, this was statistically significant only when dental floss was used in approximal areas. Similar results were reported by Mazhari et al. (2018). The authors were able to show that significantly more plaque could be reduced, both approximally and overall, in the group where floss was first used before tooth brushing as compared to the group in which brushing was first performed and then followed by flossing [21]. Nonetheless, the results of the present study lead to the general conclusion that the sequence of the cleaning procedure is not clearly relevant for plaque reduction in the interdental areas.

Not all of the participants in the present study used interdental hygiene tools as part of their home-based oral hygiene and they were therefore not equally adept in using these tools. Preliminary examinations showed that there were big differences in the ability to use interdental hygiene tools between individuals. Thus, it could be determined that the participants were not able to independently reach all approximal surfaces. A standardized use of the hygiene tools through patient self-use would not have been possible, as this would have produced distorted results in the evaluation of the cleaning performance of each hygiene tool. Winterfeld et al. (2014) assessed the brushing behavior and use of floss of 101 young adults using video surveillance. The authors found that, although almost half used floss, only 2 of the adults used it adequately (vertical movements) and only one reached all approximal surfaces [43]. They support the claim made by Sambunjak et al. (2011), in that, often an inadequate flossing technique is employed, resulting in insufficient cleaning of approximal surfaces [27, 43]. In order to be able to circumvent these disadvantages and to create equal conditions, the cleaning of the approximal surfaces was performed by the examiner in the present study. Moreover, the examiner always employed each type of hygiene tool in the same way for each subject. The aim of this pilot study was primary to evaluate which interdental cleaning tool has the potential to lead to the highest possible reduction of the plaque index value, given the circumstances that they are applied correctly in combination with second brushing. The present study design simulates "ideal conditions" with regard to interdental cleaning. The use of interdental brushes from vestibular and oral not only requires a certain degree of skill, but also attention towards the design of the interdental brushes. Due to the user's limited visibility from oral, interdental brushes with a longer, more ergonomically-shaped handle would certainly permit better viewing conditions as well as an easier insertion of brushes into the interdental area from oral. Further investigations are needed in order to evaluate the implementation of home-based, self-responsible oral hygiene.

In the present investigation, a "split-mouth design" was used. This design was chosen to minimize the number of examination appointments, while still testing a maximum number of brushing regimens. The often described disadvantage of a "carry-across effect" [16] does not apply to the results of the current study, given that only a mechanical cleaning was performed and a subsequent evaluation of the plaque indices. This one-time mechanical cleaning has no systemic effect, which could lead to a "carry-across effect". Another disadvantage with a "split-mouth design" lies in the missing barrier between the jaw halves. In

QHI difference												
	total		floss (BFB, FBB)		floss + interdental brush (BFIB, FIBB)		interdental brush (BIB, IBB)		SoftPicks (BSB, SBB)		interdental brush vest. and oral (BI2B, BI2GB)	
	t0–t1	t0–t2	t0–t1	t0–t2	t0–t1	t0–t2	t0–t1	t0–t2	t0–t1	t0–t2	t0–t1	t0–t2
UJ vest.	2.76 ± 0.74	3.30 ± 0.69	2.80 ± 0.82	3.39 ± 0.72	2.58 ± 0.80	3.12 ± 0.78	2.76 ± 0.81	3.20 ± 0.74	2.65 ± 0.66	3.22 ± 0.57	3.01 ± 0.54	3.54 ± 0.55
UJ pal.	0.56 ± 0.49	1.36 ± 0.55	0.51 ± 0.45	1.22 ± 0.58	0.40 ± 0.40	1.33 ± 0.55	0.54 ± 0.50	1.33 ± 0.57	0.62 ± 0.53	1.47 ± 0.51	0.71 ± 0.55	1.47 ± 0.51
LJ vest.	2.17 ± 0.72	2.81 ± 0.99	2.08 ± 0.82	2.85 ± 0.66	2.12 ± 0.68	2.56 ± 0.84	2.10 ± 0.59	2.76 ± 0.47	2.15 ± 0.70	2.85 ± 0.67	2.37 ± 0.78	3.03 ± 0.63
LJ lin.	0.96 ± 0.66	1.96 ± 0.71	0.97 ± 0.61	1.82 ± 0.69	0.88 ± 0.71	1.88 ± 0.70	0.98 ± 0.72	1.90 ± 0.66	0.82 ± 0.59	1.92 ± 0.76	1.15 ± 0.66	2.28 ± 0.66

Table 5 QHI differences between t0–t1 and t0–t2 of the groups "flossing" (BFB, FBB), "flossing + interdental brushing" (BFIB, FIBB), "interdental brushing" (BIB, IBB), "soft picks" (BSB, SBB) and "interdental brushing from vestibular and oral gel" (BI2B, BI2GB) divided into the vestibular and oral surfaces of the upper jaw (UJ) and lower jaw (LJ) (Tab. 1–5: H. Günay und K. Meyer-Wübbold)

the present study, this disadvantage was irrelevant because the mesial approximal surfaces of the central incisors were not included in the assessment, and hence, did not affect the results. All participants were right-handed. In general, it is assumed that the right half of the jaw is more difficult for right-handed people to clean than the left side. A "cross-split-mouth design" was thus intentionally chosen in order to avoid any possible distortions of the results. For each participant, the right upper jaw and left lower jaw were combined together and evaluated separately with respect to the left upper jaw and right lower jaw.

Already in 1948 Bass recommended the use of a system for tooth brushing [5]. In particular, the oral surfaces of mandibular teeth often have more hard and soft plaque than the other tooth surfaces and are neglected during home-based oral hygiene [22]. For this reason, it was recommended that tooth brushing should begin with the inside surfaces of teeth [22, 24]. However, studies have shown that patients predominately brush the vestibular surfaces first [21]. Van der Sluijs et al. (2018) found that there was no significant difference in the reduction of plaque across the dentition, regardless of whether patients initially brushed the oral or vestibular surfaces first [36]. The patients achieved a plaque reduction of 55 % when they started brushing the inside surfaces of the teeth and 58 % when they began with outside surfaces [36]. However, for the lingual surfaces, it was determined that the plaque index could be reduced more if brushing was started from lingual; the authors thus observed a reduction of the plaque index by 73 % when brushing was initially performed from lingual and 67 % when it began from vestibular. However, this difference was not statistically significant [36]. In the current study, the teeth were brushed according to the CIOTI-System. The brushing of the chewing surfaces preceded the brushing of the inside surfaces because, on the one hand, patients find it easier to begin brushing on the chewing surface, and on the other hand, the toothpaste gets the chance to be distributed evenly in the mouth concomitantly with occlusal brushing. In the present investigation, despite prior brushing of the inside surfaces, a notable lower plaque index value reduction was achieved orally in comparison to vestibular after the first brushing, for both the smooth and proximal surfaces; this is consistent with the findings of other studies. Van der Sluijs et al. also reported a smaller plaque reduction for the oral surfaces (67–73 %) compared to the vestibular surfaces (82–83 %) [36]. However, the second brushing procedure applied in this study noticeably reduced this difference. Hence, second brushing seems to have the potential to reach the "problematic areas" associated with home-based oral hygiene.

5. Conclusion

Interdental brushes used from vestibular and oral appear to be the most effective for reducing the plaque index value in approximal surfaces when compared to other interdental cleaning tools. The time point of interdental cleaning (before or after the brushing of smooth surfaces) has no great influence on the reduction of the plaque index value. Furthermore, interdental cleaning should be performed separately and requires time, which is why specifying a general time for home-based oral hygiene is not effective. Second brushing achieves a higher reduction of the plaque index value than one-time brushing for both the smooth and approximal surfaces, regardless of which type of hygiene tool is used for interdental cleaning. Regarding the approximal cleaning, second brushing can compensate for cleaning “deficiencies” owing to the use of different hygiene tools. It also seems to have the potential to reach the “problematic areas” during home-based oral hygiene, as well as the oral surfaces.

Conflicts of interest:

The authors declare that there is no conflict of interest within the meaning of the guidelines of the International Committee of Medical Journal Editors.

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Validation of a questionnaire for the recognition of dental anxiety in adolescents

Introduction:
In a clinical prospective pilot study, the hierarchic anxiety questionnaire (HAF) by Jöhren was tested for its applicability to identify dental fear in adolescents. Self-disclosure by completing a questionnaire requires certain – age-related – intellectual and cognitive skills. Thus, it gives rise to the question whether the HAF is applicable to adolescents.

Materials and methods:
In order to answer this question, an investigation including 210 adolescent test subjects was conducted. They were distinguished by age (12–14 years, 15–17 years) and sex. The HAF consists of 11 questions, from which the anxiety classifications can be drawn: slightly anxious (≤ 30 points), moderately anxious (31–38 points) and extremely anxious (possibly phobic) (> 38 points). In addition to a review of the internal validity via test and retest (t0, t1), the HAF was externally validated by comparing results of similar tools of self-information and a behavioral evaluation (dental anxiety scale, modified dental anxiety scale and visual analogue scale).

Results:
More than half of all test subjects declared to be slightly anxious (distribution across different survey procedures and points in time: 54–68 %) and 7–12 % said to be extremely anxious. The reliability of the information regarding the level of anxiety was confirmed using Cronbach's α (always > 0.9 = "excellent") for both t0 and t1. Specifically, the answers "moderate" to "good" corresponded to the 11 questions (Cohen's kappa metric). The consistency of HAF-Results and other methods to validate externally provided a high Spearman correlation (at least r > 0.7). Bland-Altman analyses further confirmed, that all techniques determining the subject's degree of fear at t0 and t1 were interchangeable. Moreover, their compliance was substantiated by at least "good" kappa values. The anxiety evaluation that was additionally carried out by the treating dentist and his assistant produced "good" to "very good" Kappa values. Age (correlation coefficient at t0 r = 0.290; at t1 r = 0.285) and sex (bei t0 r = 0.097; bei t1 r = 0.130) had no impact on the applicability of the HAF. However, in the group of the younger adolescents (12–14 years old), the questionnaire was filled out incorrectly in 14 cases.

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Conclusion:
This pilot study has shown that the HAF in its existing form is generally very applicable to adolescents. It is suggested that younger adolescents (12–14 years old) do not fill out the forms without guidance. In addition, further studies on the applicability of the HAF in adolescents are recommended in consideration of their education.

Keywords: adolescents; dental anxiety; hierarchic anxiety questionnaire

1. Introduction

Today, there are multiple options in dentistry to carry out nearly painless dental treatment.

Despite these possibilities, dental fear is a common phenomenon in our society, regardless of social status and level of education of people affected. A visit to the dentist is a burden for every second person in the population, which can lead to psychological, social and dental problems. About 10 % of the population avoid a visit to the dentist completely. Therefore, dental anxiety is one of the greatest obstacles in achieving optimal dental health in the population [3, 7, 11, 20]. From the dentist's perspective, the treatment of anxiety patients leads to an increased burden and stress reactions. Additional costs following appointment cancellations are not uncommon. This phenomenon of dental anxiety impacts the entire health care system: Treatments are delayed, made more difficult or cancelled. If phobic patients are treated psychotherapeutic, additional costs arise due to these interventions [7, 17, 30].

Anxiety before dental treatment can have various different causes (bad experiences, model learning, disposition, etc.) and shows different manifestations, even up to anxiety disorders with pathological significance, for example dental phobia [14, 20]. Usually, the origin of dental phobia can be due to bad experiences in one's childhood or adolescence. Öst [27] asserts the average age for a beginning dental phobia to be 13 years old. The behavior of a child is further modulated by endogenous (constitutional, hereditary) and exogenous (educational, environmental) impacts [16, 32]. But also the development of anxiety during the process of detachment from parents or rather development of the own personality (puberty), a normal phenomenon, is described. Nevertheless, these fears can enhance dental anxiety [31, 33]. Therefore it is important, to give dentists the opportunity to recognize dental anxiety in kids and adolescents, in order to adapt to the situation and adequately prepare the patient [12, 40].

For these reasons, it is important to recognize and classify an existing dental anxiety when compiling the medical history [11, 18, 29], as well as offering appropriate techniques for prevention or reduction [27, 28]. Anxiety questionnaires are popular for patients to assess themselves (e.g. Corah's dental anxiety scale, Jöhren's hierarchic anxiety questionnaire). The visual analogue scale is used as well. These methods are considered to be easily applicable, cost-effective and nevertheless reliable means for a diagnosis of dental anxiety. Especially the hierarchic anxiety questionnaire has proven to be a reliable screening instrument due to its hierarchic design [1, 7, 10, 14].

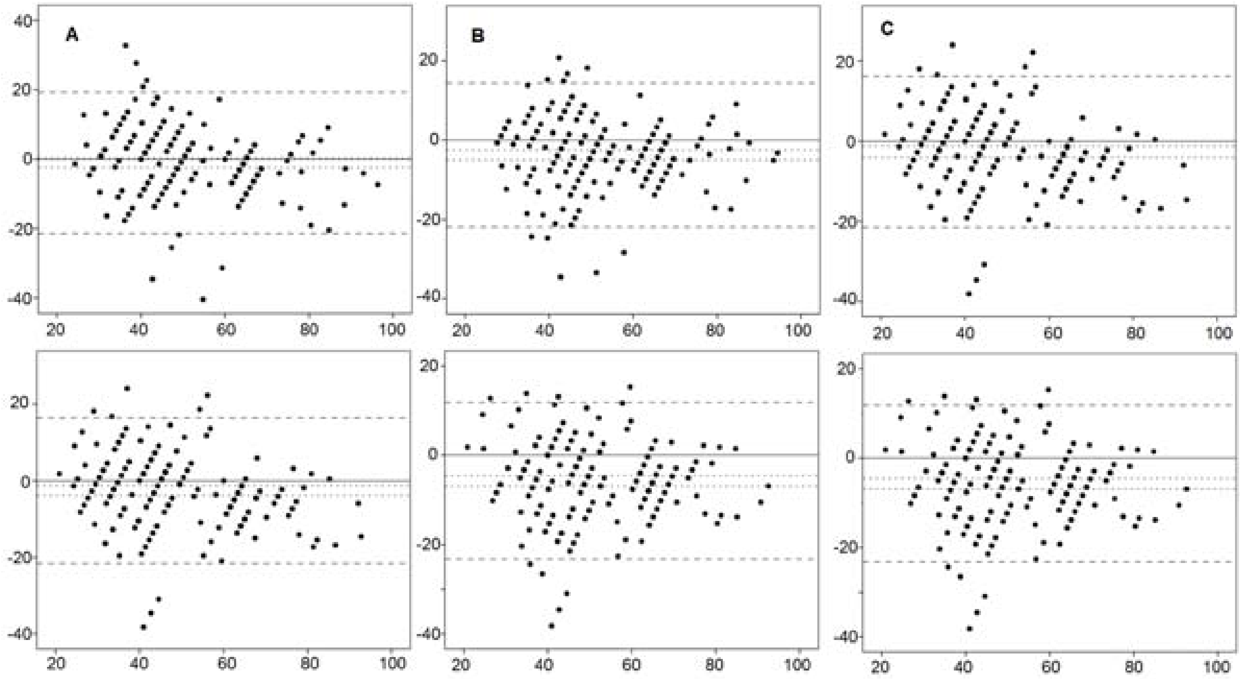
The methods mentioned above were developed empirically and validated in adult subjects. In pediatric dentistry these methods have not been sufficiently investigated and therefore are not applicable. This is because questionnaires and analogue scales require specific intellectual and cognitive skills, which are well-developed in adults and at best in adolescents [24, 40]. For children, the assessment in regard to dental anxiety is done by the treating dentist [4, 39]. For older children up to 13 years old, visual and textually simplified anxiety questionnaires were developed [21]. The question remains unanswered if the method of self-assessment that was used in adults [15] is also suitable for teenage adolescents. Contents of the questionnaire could possibly not be understood fundamentally or extensively. In this content, it is problematic that adolescent imagination is not fully matured and lacking experience. Further, it could lead to false declarations, possibly in consequence of a sense of shame or lack of cooperation due to immaturity [33, 34].

The present pilot study examines the applicability of questionnaires in detecting and determining the extent of dental anxiety in male and female adolescents from ages 12 to just under 18. The investigation is aimed to evaluate the applicability of the HAF (hierarchic anxiety questionnaire) in consideration of a comparison with the DAS (dental anxiety questionnaire as well as the modified form MDAS) and the VAS (visual analogue scale) in adolescents and to validate it via behavioral evaluation.

2. Materials and methods

The present prospective pilot study was conducted between March and September 2012 in a private dental practice in Breckerfeld (Ennepe-Ruhr-Kreis, North Rhine-Westphalia). The study design was previously examined and authorized by the ethics committee of the University Witten/Herdecke (Nr. 05/2012).

The total sample size included 224 students participating voluntarily and was based on earlier comparable studies [e.g. 10, 40]. In 14 cases (6.25 %) the questionnaire was filled out incorrectly (t0 = 9, t1 = 5); all of these 6 male and 8 female participants were under the age of 14. Of the remaining 210 subjects, 94 were male and 116 female. According to the usual classification of development psychology [6], 2 groups were defined: 12–14 year-olds and 15–17 year-olds (meaning



(Fig. 1: N. Weifenbach)

Figure 1 Bland-Altman plots for (A) HAF/DAS, (B) HAF/MDAS and (C) HAF/VAS at different points in time (t0 in the upper row, t1). The X-axis refers to the mean, the Y-axis refers to the difference (see Table 2). The longer, dashed lines mark the limits of agreement, and the short stippled lines mark the 95 % confidence interval of the difference of the total scores.

that the 15th or 18th year has not been completed, respectively). The group mentioned first included 37 males and 50 females, the second group included 57 males and 66 females.

2.1 Utilized survey procedures

Corah's dental anxiety scale (DAS) [2] and its modification (MDAS) [9]: DAS is the most frequently used "anxiety scale" in dentistry internationally [15, 22]. It consists of 4 questions with 5 answer possibilities each. Patients are asked to imagine themselves in different situations and to check the answer possibility that corresponds to their feelings (regarding the specific situation). Patients were asked to imagine themselves in different situations and check response options that represent their current sensation (with regard to the respective situation). The DAS intends the score distribution from 4 to 20 in 3 classifications (12 points: slightly anxious; 13–14: moderately anxious; 15 and higher: extremely anxious) [2, 25]. The MDAS has been extended to include a question on local anaesthesia and has a points distribution from 5–25 (< 16 points: slightly anxious; 16–18: moderately anxious; > 18: extremely anxious) [9].

Jöhren's hierarchic anxiety questionnaire (HAF) [10]: The HAF builds on top of the DAS and in addition contains different treatment situations, which were taken from an anxiety hierarchy of Gale's investigation [5], and that depicts situations causing anxiety in patient treatment [10, 13]. The HAF consists of 11 questions, where 5 different anxiety manifestations can be selected (from not at all anxious" to "sick with fear"), therefore a points score from 11 to 55 is possible. Thus, the patients can be divided in 3 categories (≤ 30 points: slightly anxious; 31–38 points: moderately anxious; > 38 points: extremely anxious) [10]. The diagnosis dental phobia can be deduced from the HAF, when a point value of more than 38 is reached with simultaneous prevention of dental treatment for more than 2 years in the medical history [10, 14]. The questionnaire was validated and checked on its reliability. It yielded a high correlation to DAS with a coefficient of 0.88 and a good correlation to STAI ("State Trait Anxiety Inventory" of Spielberger et al. [36]) with a coefficient of 0.66 [10].

Self-assessment using the visual analogue scale (VAS) [1]: This test consists of a scale with 2 defined endpoints (0–100 mm). The patients were asked to mark their anxiety with a line on this scale, where 0 corresponds to total fearlessness and the value 100 is maximum anxiety before a treatment. This test is an easy way to determine if dental anxiety exists and how profound it is [14, 15]. Before it was asked if the VAS can serve as an initial screening instrument, it was validated using the HAF. This resulted in the VAS being a suitable, fast and simple (and therefore easily applicable in everyday dental practice) measure of tendency to obtain clarity in what methods in diagnosing anxiety could possibly be applied. However, VAS results alone tempt overinterpretation [1].

The methods presented to self-assess are depicted in Annex 1.

2.2 Study procedure

Test and retest: The questioning of every person was conducted using HAF, MDAS, DAS and VAS (presented in random order). Additionally, all

Anxiety	HAF	DAS	MDAS	VAS	Dentist	Assistant
t0						
Slightly anxious	136 (64.6)	141 (67.14)	144 (68.57)	133 (63.33)	116 (55.24)	115 (54.76)
Moderately anxious	58 (27.62)	50 (23.81)	50 (23.81)	58 (27.62)	70 (33.33)	69 (32.86)
Extremely anxious (possibly phobic)	16 (7.62)	19 (9.05)	16 (7.62)	19 (9.05)	24 (11.43)	26 (12.38)
t1						
Slightly anxious	138 (65.71)	142 (67,62)	140 (66,67)	133 (63.33)	No data was collected	
Moderately anxious	55 (26.19)	49 (23.33)	53 (25.24)	57 (27.14)		
Extremely anxious (possibly phobic)	17 (8.1)	19 (9.05)	17 (8.10)	20 (9.52)		

Table 1 Absolute distribution and (in parentheses) the percentage of anxiety classification of the questionnaires HAF (hierarchic anxiety questionnaire), DAS (dental anxiety scale), MDAS (modified dental anxiety scale), and the VAS (visual analogue scale), as well as the dentist's and assistant's assessment (n = 210). In order to compare the methods, scores were standardized to 100 %.

			t0	t1
HAF–DAS	Mean		-1.073	-2.584
	95 %-mean confidence interval	Minimum	-2.456	-3.875
		Maximum	0.309	-1.294
	Standard deviation		10.162	9.4841
HAF–MDAS	Mittelwert		-3.778	-5.737
	95 %- mean confidence interval	Minimum	-5.013	-6.928
		Maximum	-2.544	-4.545
	Standard deviation		9.076	8.759
HAF–VAS	Mittelwert		12.579	11.596
	95 %- mean confidence interval	Minimum	10.851	9.984
		Maximum	14.307	13.208
	Standard deviation		12.703	11.848

Table 2 Statistical description of data at t0 and t1 used to create Bland-Altman plots (Figure 1) (n = 210).

subjects were assessed regarding their state of anxiety by the dentist and his assistant. The assessment has been carried out based on the behavioral scale of Frankl et al. [4]. Out of the 4 anxiety classifications, the two middle ones were combined so that the subjects could be assessed as: extremely cooperative, conditionally cooperative and slightly cooperative. The 3 anxiety classifications were equated with Corah's anxiety classifications [2]: slightly anxious, moderately anxious and extremely anxious.

	HAF–DAS (t0)	HAF–DAS (t1)	HAF–MDAS (t0)	HAF–MDAS (t1)	HAF–VAS (t0)	HAF–VAS (t1)
Median	-1.136	-3.182	-3.273	-5.818	14.591	12.909
Interquartile range	11.02	11.36	9.82	10.64	15.45	13.59
Minimum	-40.45	-38.18	-34.55	-38.18	-27.09	-26.09
Maximum	32.73	24.09	20.73	15.27	38.55	37.27
p-value	**0.367**	**0.002**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**

Table 3 Results of Bland-Altman analyses for the differences of the total scores and of respective sign tests of HAF and each one of the other dental anxiety methods at t0 and t1 (n = 210). Significant values are bold and in italics.

In order to verify the repeatability of the collected data, all subjects were questioned for a second time (t1) in different intervals, but at least 2 weeks after the first questioning (t0) using HAF, DAS, MDAS and VAS (retest).

Inclusion criteria: The following characteristics were applied for subject selection:

- Boys and girls between 12 and under 18 years of age;
- Full command of the German language;
- Attendance of secondary school;
- Visit to a dental practice with (at least) one parent (or guardian) at time t0 and the voluntary participation in a consultation on the study followed by giving written consent;
- No dental treatment was necessary until retest (t1).

2.3 Statistical analysis

All analyses were conducted using SPSS (Statistical Package for the Social Sciences), Version 19.

Internal validation: In order to determine the test-retest reliability of the HAF, Cronbach's α for time t0 and t1 was calculated. Additionally, it was shown if response items were possibly misunderstood or not kept apart correctly using the Kappa coefficients. With an interval-inclusion test (confidence interval method) the sets of data were tested for equivalence in regard to both points in time. The difference of the total scores (which were previously standardized to 100 %) for t0 and t1 were calculated.

External validation: In order to check the validity of the HAF results using DAS, MDAS and VAS, the scores of mentioned survey methods were standardized to 100 % first to facilitate comparison. Afterwards, a Bland-Altman-analysis was conducted with Bland-Altman-plots for the HAF and for another method mentioned above. In addition to the plot method, sign tests (dependent samples, continuous data) were calculated to detect differences in the calculated total scores of the HAF and DAS, MDAS and VAS, respectively. A statistical difference means, that the subjects would have responded significantly different at both times of investigation. Only after the degree of accordance was determined, it makes sense to investigate how the results of HAF and DAS, MDAS and VAS correlate: a high correlation alone says nothing about the congruence. With the parameter free correlation test by Spearman, the correlation coefficient was calculated for the HAF and each respective method. After this investigation of the correlation in general, the correlation of different survey methods for the 3 classifications of anxiety (slightly anxious, moderately anxious, extremely anxious) was examined separately using kappa values.

Comparison of the HAF results and the assessment of the dentist and his assistant: In order to evaluate the possible difference between HAF results and the personal assessments of competent professionals (only at time t0), the McNermar-Bowker-test was considered along with appropriate cross tables. In addition, the Kappa value was calculated and considered as measure of congruence.

The impacts of age and sex on the applicability of the HAF: In order to determine the impact of age (12–14 years, 15–17 years) and sex (male, female) on the HAF results, Spearman's correlation coefficient was secondarily calculated for these parameters, respectively. Additionally, it was tested on differences using the Wilcoxon-test.

3. Results

With 54 %-68 %, more than half of the 210 subjects declared to be slightly anxious for test and retest and all survey procedures. Subjects stating to be extremely anxious (possibly phobic) made up mostly less than 10 %, with a maximum of 12 % (Table 1). The consideration of the degree of anxiety based on age and sex yields, that younger, female subjects tended to be the most anxious (data not shown).

3.1 Internal Validation

The reliability of the first HAF-interview (t0) was checked using a retest (t1) and the following determination of Cronbach's α. The values were stable over the course of both times of investigation. At t0 and t1, $\alpha = 0.92$ and for t0 + t1, $\alpha = 0.96$, which signified an "excellent" correlation of test and retest. The calculation of kappa coefficients showed a "good" correlation (0.633–0.739) in 4 out of 11 HAF questions, and a "moderate" correlation (0.460–0.591) at both points in time. The conducted interval-inclusion-test illustrates, that the responses of test and retest were the same and the median difference (50.0–47.27 = –3.63) was within the ± 5 % equivalence range (95 % confidence interval: –3.63; –1.82).

3.2 External Validation

Figure 1A-C depicts Bland-Altman-Plots for the interview via HAF in comparison with DAS, MDAS und VAS for the points in time t0 and t1, based on the values in Table 2.

The plotted values (mean values versus difference of the total scores using two methods) for the most part scatter within the defined limits of agreement, respectively, this also applies for the 95 % confidence interval of difference of total scores. This means that the questionnaires are interchangeable. The 95 % confidence interval excludes a value of zero for HAF/MDAS and HAF/VAS (Figure 1B, C), so that significances of the respective methods differed. The additional sign tests conducted on differences in the total scores of HAF and DAS, MDAS and VAS, respectively, revealed that the intra-individual deviations were low (Table 3).

Calculation of Spearman's correlation coefficient consistently yielded a high correlation of the 3 methods with HAF, respectively: HAF/DAS–r = 0.771 (t0), r = 0.798 (t1); HAF/MDAS–r = 0.780 (t0), r = 0.795 (t1); HAF/VAS–r = 0.829 (t0), r = 0.838 (t1). Table 4 showed a correlation (kappa value) between different survey methods with regard to the frequency of 3 defined anxiety classifications: slightly anxious, moderately anxious and extremely anxious (possibly phobic). The correlations were consistently "good" to "very good". Only in one case (MDAS/dentist's assistant) it was "moderate".

	HAF	DAS	MDAS	VAS
HAF		0.44	0.883	0.896
DAS	0.903		0.961	0.876
MDAS	0.872	0.890		0.915
VAS	0.915	0.895	0.865	
Dentist	0.675	0.665	0.675	0.713
Assistant	0.607	0.605	0.583	0.646

Table 4 Determination of the kappa value regarding the correlation of 2 dental anxiety survey methods at t0 (underlined) and t1 (n = 210). Significant values are bold and in italics.

3.3 Differences in classification (dentist, assistant)

Table 5 and 6 compare the HAF results (only at time t0) with the assessment of the dentist and assistant, respectively, regarding the subjects' anxiety. It is shown, that the HAF and competent professionals both classify the anxiety nearly identically. However, McNemar-Bowker-Tests showed, that the HAF results and assessments of the dentist or assistant differed statistically. For HAF/dentist and HAF/assistant the differences were significant ($p < 0.01$), respectively. For dentist/assistant, the difference was not significant ($p = 0.587$). A consistently "good" to "very good" correlation of responses with the respective assessments was shown using Kappa values: HAF/dentist–0.675; HAF/assistant –0.607; dentist/assistant –0.842.

3.4 Impact of age and sex on the anxiety scale, measured using the HAF

The Spearman correlation coefficient of total scores of the HAF with both age groups yielded a low correlation: t0 r = 0.290; t1 r = 0.285. The same applies for sex: t0 r = 0.097; t1 r = 0.130. Impact of age and sex on the degree of anxiety can therefore not be proven. This is shown by the conducted Wilcoxon test for sex (t0: $p = 0.161$; t1: $p = 0.59$), but not for age, where the results were significant (t0; t1: $p < 0.001$).

4. Discussion

4.1 Evaluation of results

The self-assessment of patients on determining the level of anxiety is considered a quick, cost-effective and not-invasive method to recognize and assess dental anxiety. This is with the help of adequate guidelines – for adults in form of the HAF – an appropriate, reliable and widely accepted resource for anxiety diagnosis in the context of dental treatment [8, 15]. Recognizing dental anxiety and determining its level before a dental procedure is crucial for coordinating the dental therapy and the methods calming anxiety [8]. When dental anxiety is suspected, the therapy of choice would be behavioral therapy [38]. Even treatment under general anesthesia can be indicated in individual cases [13, 14]. The described methods regarding diagnosis and therapy of dental anxiety and dental phobia have primarily been investigated in adult patients so far [15]. Dental anxiety with pathological value manifests itself often during the beginning of puberty [27, 33]. In order to avoid bad experiences in the dental practice, it is important to receive reliable information in young patients regarding the level of anxiety before a dental procedure [40]. For children up to 13 years old, customized methods that specifically suit their development were devised, which achieve very good results [40], such as the questionnaire to measure dental anxiety in children (FEZ-Ki) [21]. But what measuring instruments are suitable for older adolescents? Are questionnaires appropriate, that base their complexity on adults and the knowledge/understanding needed in order to answer

			Assessment of dentist regarding degree of anxiety			Total
			Slightly anxious	Moderately anxious	Extremely anxious, phobic	
HAF-Classification regarding degree of anxiety	Slightly anxious	Number	111	24	1	136
		Percentage of total	52.9 %	11.4 %	0.5 %	64.8 %
	Moderately anxious	Number	5	46	7	58
		Percentage of total	2.4 %	21.9 %	3.3 %	27.6 %
	Extremely anxious, phobic	Number	0	0	16	16
		Percentage of total	0 %	0 %	7.6 %	7.6 %
Total		Number	116	70	24	210
		Percentage of total	55.2 %	33.3 %	11.4 %	100 %

Table 5 Quantitative comparison of the answers (cross tables, not shown) of the HAF (Hierarchic anxiety questionnaire) and the assessment of the dentist at t0.

truthfully [10]? This published pilot study investigates this question and examines the suitability of the HAF in adolescents from the age of 12.

In all of the survey methods used in the present study, it was consistently shown that a large part of the adolescent subjects was slightly anxious. The extremely anxious (possibly phobic) subjects made up the lowest percentage, approximately one tenth. The results correspond with those of the investigated adult patients, which show, that increased anxiety with regard to dental treatment constitutes a serious problem for about 10 % of the population [3, 10]. Furthermore, it appears from the collected data, that boys seemed less anxious than girls and that older adolescents (15–17 years old) seemed less anxious than younger adolescents (12–14 years). Even though this is consistent with the socially assigned gender roles and the normal intellectual maturation [e.g. 26], the examination of the effect of age and sex yielded somewhat, that age could play a role. Also, in investigations of dental anxiety in adults, the women declare more anxiety than men [10].

The internal validity, investigated using Cronbach's α through test and retest was "excellent" (> 0.9). Consequently, a high measure of stable relations between the interviews and the different points of time (t0, t1) can be assumed. Despite this very good internal consistency, an item-wise test (McNemar-Bowker-Tests) produced, that the participants' responses of all 11 questions of the HAF at both points in time differed significantly.

These differences were consistently not highly significant. In accordance with this, the kappa values showed an item-wise comparison of test and retest, so that the correlation of the 1st and 2nd interview was at least "moderate", in 4 out of 11 questions even "good". The results of the interval-inclusion-test suggest an equivalent significance at t0 and t1 (95 % confidence interval within the defined area of equivalence) and therefore support the interval validity. The lack of experience of young subjects could possibly have an impact, because it can be assumed, that examined adolescents have little experience in general visiting a dental practice. At least the first test conducted in this research project solely took place during a dental check-up; even following this no dental procedure was carried out (until the retest).

For the external HAD-validity using Spearman's correlation test, the data was examined using Bland-Altman-analyses. These showed, that the HAF results strongly correlated with the DAS, MAS and VAS.

However, it must be noted, that the other questionnaires used for external validity for adolescents was not examined and validated expressis verbis, let alone translated from English into German for this group and checked appropriately. Such investigations exist for diagnosing anxiety in adults, for example for the DAS [37]. Most international studies deal with dental anxiety in adults and include adolescents of 15 years or older from time to time, without pointing this out separately or discussing it. So far, it was always rather differentiated between children and adults. In this study, it is investigated explicitly, if the HAF is a suitable instrument in 12–14 year old adolescents. The results of the present investigation show that in spite of all previous scepticism, the HAF is a suitable instrument to diagnose anxiety in adolescents.

Although adolescents are considered "uncooperative", especially

			Assessment of assistant regarding degree of anxiety			Total
			Slightly anxious	Moderately anxious	Extremely anxious, phobic	
HAF- Classification regarding degree of anxiety	Slightly anxious	Number	107	27	2	136
		Percentage of total	51.0 %	12.9 %	1.0 %	64.8 %
	Moderately anxious	Number	8	42	8	58
		Percentage of total	3.8 %	20 %	3.8 %	27.6 %
	Extremely anxious, phobic	Number	0	0	16	16
		Percentage of total	0 %	0 %	7.6 %	7.6 %
Total		Number	115	69	26	210
		Percentage of total	54.8 %	32.9 %	12.4 %	100 %

Table 6 Quantitative comparison of the answers (cross table, not shown) of the HAF (hierarchic anxiety questionnaire) and the assessment of the dentist's assistant at t0. (Tab. 1–6: N. Weifenbach)

when transitioning to puberty, and possibly tend to make false statements due to a sense of shame [6, 33, 34, 40], these results show that adolescents had no difficulties handling the questionnaire. This is particularly true for older adolescents, which is in line with the fact that questionnaires filled out incorrectly solely occured in the group of 12–14 year old subjects. In order to achieve clear results and recognize uncertainties in younger adolescents handling the questionnaires, it is recommended that a follow-up study examines the completion of the HAF questionnaire under the guidance of competent staff.

4.2 Methodological critique

The study presented exhibits pilot character because the sample size is based on the HAF study in adults from 1999 [10] and other diagnostic studies [1, 40]. Follow-up studies with larger number of participants are in the planning stage. Additionally, the social, cultural and spatial distribution of participating students were not taken into account. They attended different types of schools, which could have an impact given the expected variation in level of education [cf. 23]. The same applies for possible effects of cultural barriers such as effects, that potentially result from time or length of study, even though this cannot be expected according to the authors' assessment. Furthermore, in this pilot study, the participants' origins were not subjected to any geographic dispersion with regard to the entire country of Germany, and all participants of this investigation visited the same dental practice. Unlike Margraf and Poldrack [19], who explicitly compared East and West Germany, the present pilot study only reproduces a selective situation. However, regardless of degree of education and individual level of development, no questionnaire was filled out incorrectly in the group of 15–17 year olds.

Although the results presented contribute to closing the knowledge gaps in dentistry and are important for the clinical approach, it must not be overlooked, that a comprehensive and final evaluation at the current degree of the knowledge process has not been given.

5. Conclusion

This pilot study shows, that the HAF in its existing form is applicable in adolescents of both sexes between the ages of 15 and 18. Regarding the applicability of younger adolescents between 12 and 14 years old, difficulties in dealing with the questionnaire emerged. Further studies have to show the impact of social, cultural and regional aspects and how adolescents can be supported most appropriately in filling out this anxiety questionnaire, so that the HAF can be justified for this target group in the daily dental practice.

Conflict of interest:

Authors state, that there is no conflict of interest within the meaning of the International Committee of Medical Editors.

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Annex 1

Hierarchic anxiety questionnaire (HAF)

Please imagine yourself in the following situations and specify:

	Relaxed (1 Point)	Uneasy (2 Points)	Tense (3 Points)	Anxious (4 Points)	Sick with fear (5 Points)
How do you feel at the thought of having to go see the dentist tomorrow?					
You are sitting in the waiting room and waiting to be called up. How do you feel?					
Imagine entering the treatment room and smelling the typical odor.					
You are in the dentist's chair and the dentist enters the room.					
You take a look at the X-Ray image together and discuss what has to be done.					
How do you feel when it is explained to you, that tartar is about to be removed?					
The dentist explains that you have a cavity, and that he wants to treat it right now.					
He adjusts the position of the chair and prepares a syringe.					
Imagine hearing the typical noise of the drill, how do you feel?					
The dentist explains to you, that the caries is too deep and that the tooth has to be extracted.					
A wisdom tooth has to be removed and the injection was already given. The dentist picks up the scalpel.					

Patient questions on DAS (Questions 1 to 4)

1. Imaging having to go see a dentist tomorrow. How do you feel right now?

I quite enjoy going to the dentist.	1
I don't mind, it doesn't bother me.	2
I feel a little uneasy.	3
I am worried, that it will be painful and uncomfortable	4
I am very afraid and am very worried what the dentist is going to do with me.	5

2. Imagine sitting in the waiting room at the dentist. How do you feel?

relaxed	1
a little uncomfortable	2
tense	3
anxious	4
so anxious, that I am sweating and feeling downright sick	5

3. Imagine sitting in the dentists' chair. The dentist prepares the drill to work on your teeth. How do you feel?

relaxed	1
a little uncomfortable	2
tense	3
anxious	4
so anxious, that I am sweating and feeling downright sick	5

4. Imagine sitting in the dentists' chair to have tartar removed. While you wait, the dentist prepares the instruments he will use to scrape off tartar in the gingival area. How do you feel?

relaxed	1
a little uncomfortable	2
tense	3
anxious	4
so anxious, that I am sweating and feeling downright sick	5

MDAS: Extension of DAS by 1 question

5. Imagine having to receive an injection into your gums above a posterior molar. How do you feel?

relaxed	1
a little uncomfortable	2
tense	3
anxious	4
so anxious, that I am sweating and feeling downright sick	5

Self-evaluation on a visual analogue scale (VAS) by the patient

How do you evaluate the strength of the anxiety? Please mark the subjective feeling with a vertical line on the scale.

No fear

Such intense fear, that one believes one must die

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