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Effectiveness of CIOTIPlus depending on different toothbrushes on approximal cleaning

Introduction: Oral health awareness has increased significantly in recent years and the self-responsible home-based oral hygiene has been given a high priority in the prevention of tooth decay and periodontitis. A large number of different toothbrush systems for plaque removal are available to the patients. However, since many patients are still affected by caries and inflammatory periodontal diseases, the quality of home-based plaque removal appears to be rather inadequate. The aim of the present pilot study with cross-over design was to investigate the cleaning effect on the approximal areas by brushing twice in accordance with the CIOTIPlus system using different toothbrushes.

Methods: Fifteen participants (7 female, 8 male, mean age 50.1 ± 6.5 years) were included in this study with split-mouth design. Four toothbrushes (electric toothbrush [ETB], sonic toothbrush [STB], manual toothbrush1 [MTB1] and manual toothbrush2 [MTB2]) were each evaluated in combination with dental floss and interdental brushes in 4 separate appointments, following a plaque accumulation phase of 72 h. 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 3 times after plaque staining to assess the plaque reduction: before first brushing (t0), after first brushing (t1), and after second brushing (t2).

Results: At t1, a significant reduction of the QHI and QH-API was observed in all groups compared to t0. The highest reduction of QHI was found in group „MTB1 and interdental brush" (Bm1IB) (ΔmQHI-t0-t1: 1.7 ± 0.3) and the lowest reduction was found in group „STB and dental floss" (BsFB) (ΔmQHI -t0-t1: 1.3 ± 0.3). The highest reduction of the QH-API was detected in group „ETB and interdental brushes" (BeIB) (ΔQH-API-t0-t1: 1.9 ± 0.5) and the lowest reduction of QH-API was found in group BsFB (ΔmQH-API-t0 -t1: 1.3 ± 0.3). After the second brushing (t2), the QHI and QH-API were significantly reduced further in all groups (QHI: 0.6 ± 0.4, QH-API: 1.1 ± 0.4) ($p < 0.0001$). The highest reduction of QHI was found in group BeIB (ΔmQHI-t0-t2: 2.5 ± 0.3) and the lowest reduction of QHI was found in the groups „MTB2 and interdental brush" (Bm2IB) (ΔmQHI-t0-t2: 2.2 ± 0.4) and „MTB2 and dental floss" (Bm2FB) (ΔmQHI-t0-t2: 2.3 ± 0.4). The highest reduction of the QH-API was detected in group BeIB (ΔQH-API-t0-t2: 3.0 ± 0.5) and the lowest reduction was found in group „MTB1 and dental floss" (Bm1FB) (ΔmQH-API-t0 -t2: 2.1 ± 0.5).

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Conclusion: The second brushing using the systematic oral hygiene approach "COITIPlus" leads to a higher plaque reduction on smooth and interproximal surfaces compared to the one-time brushing, regardless of what kind of toothbrush is used.

Keywords: CIOTIPlus system; plaque reduction; interdental cleaning; two time brushing

1. Introduction

Oral health awareness in the German population has increased significantly over the last few years. In the Fifth German Oral Health Study (DMS V), 85.5 % of questioned younger adults were convinced that they could contribute "much" or "a lot" in order to maintain or improve their oral health [13]. The patients seem to be aware that plaque-/biofilm removal as part of their home-based oral hygiene routine is of great importance in caries and periodontitis prevention. However, since a number of patients are still affected by caries and inflammatory periodontal diseases, the quality of home-based plaque removal seems still to be insufficient.

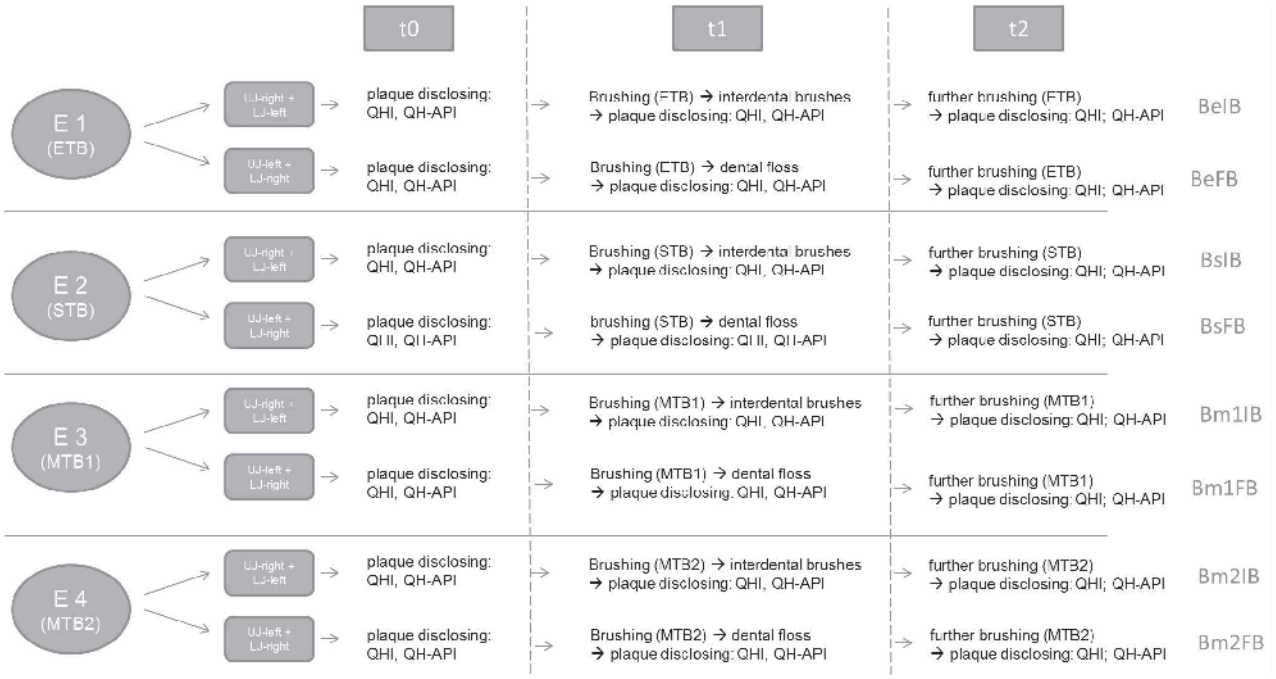
For plaque removal on smooth surfaces, a number of different toothbrush systems are available to patients in their home-based oral hygiene routine. Generally, a distinction between manual and electric toothbrushes is made. Zimmer and Lieding (2014) determined in a representative sample of the Republic of Germany, that 53 % of respondents use a manual toothbrush as part of their home-based oral hygiene routine [32]. 38 % stated, that they only used an electric toothbrush [32]. A reliable cleaning of smooth surfaces can be achieved when using a manual or an electric toothbrush correctly [27]. However, there is some indication that electric toothbrushes are superior to manual toothbrushes regarding plaque removal and gingivitis prophylaxis. In a review article it was summarized that 11 % (observation period 1–3 months), or 21 % (observation period > 3 months) more plaque can be removed and 6 % (observation period 1–3 months) or 11 % (observation period > 3 months) of gingivitis can be reduced using electric toothbrushes in comparison to manual toothbrushes [27]. Electric toothbrushes are distinguished between brushes with rotating-oscillating or sonically activated motion patterns. In literature, there is more evidence regarding the efficacy of rotating-oscillating brushes [26, 27].

The toothbrushing technique recommended most by dentists is the "bass technique", or its modification [28]. However, investigations have shown that this technique is rarely implemented by patients as part of their oral hygiene routine [4]. Also, there are no published study results that show the superiority of the bass technique in comparison to other techniques. There is a common understanding that when using manual or electric toothbrushes, the compliance with the system of plaque removal is more important than the technique itself [5, 8, 17].

Not only the cleaning of smooth surfaces, but also the effective cleaning of interdental space is important in gingivitis and caries prophylaxis, because the tooth surfaces below interproximal contact is a predilection site for caries and gingivitis [18]. Because these areas are insufficiently reached [22] when using a manual or electric toothbrush, and biofilm or food residues can oftentimes not be removed adequately, further tools are recommended [7, 21]. The cleaning of approximal area is often neglected during home-based oral hygiene. According to DMS V, 61.3 % of women and only 35.5 % of men stated, that they clean interdental area with floss [13]. Zimmer and Lieding (2014) reported similar results [32]. Out of 1025 respondents, 59 % stated that they used certain tools to clean interdental spaces, with the women's value being higher at 67 % than the men's at 51 % [32]. Most respondents stated, that they used floss followed by interdental brushes for interdental cleaning [32].

In previous examinations it was shown, that a simple modification of home-based oral hygiene in the form of brushing twice while complying to the "CIOTIPlus" system significantly reduced the formation of root surface and crown margin caries in older people and improved, or rather stabilized the periodontal conditions [9, 10]. The second brushing achieves a larger reduction in the plaque index value of smooth and interproximal surfaces in comparison to brushing once [9–11]. The choice of additional tools used for interdental cleaning is less important. This gives the "CIOTIPlus" system the potential to balance out possible deficits in interproximal cleaning [11]. When using this system the patient cleans the **c**hewing surfaces first, followed by **i**nside and **o**utside surfaces. Next the **t**ongue and **i**nterdental areas are cleaned using the respective tools. Following the cleaning process, the patient cleaned all tooth surfaces systematically for around 1 minute in circulating/rotating motions using a same amount (pea-sized) of flouride toothpaste ("**plus**") [9].

The aim of the present "cross-over" pilot study was to investigate the cleaning effect of different toothbrushes in combination with tools for approximal cleaning (interdental brushes and floss) when brushing



(Fig. 1, Tab. 1–9: K. Meyer-Wübbold, H. Günay)

Figure 1 Clinical approach
ETB: electric toothbrush; STB: sonic toothbrush; MTB1: manual toothbrush 1; MTB2: manual toothbrush 2
BeIB: brushing (electric toothbrush) – interdental brushes – brushing (electric toothbrush); BeFB: brushing (electric toothbrush) – floss – brushing (electric toothbrush); BsIB: brushing (sonic toothbrush) – interdental brushes – brushing (sonic toothbrush); BsFB: brushing (sonic toothbrush) – floss – brushing (sonic toothbrush); Bm1IB: brushing (manual toothbrush 1) – interdental brushes – brushing (manual toothbrush 1); Bm1FB: brushing (manual toothbrush 1) – floss – brushing (manual toothbrush 1); Bm2IB: brushing (manual toothbrush 2) – interdental brushes – brushing (manual toothbrush 2); Bm2FB: brushing (manual toothbrush 2) – floss – brushing (manual toothbrush 2)

twice according to the CIOTIPlus system.

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 the participation in this project was a remaining dentition of 20 teeth in the absence of any crown restaurations, a patient age between 35–64 years and a Periodontal Screening Index (PSI) < 2. Exclusion criteria included any physical disabilities that make adequate oral hygiene more difficult, a history of radiotherapy in the head and neck region, heavy smokers (> 10 cigarettes per day) and drug intake that could result in false clinical values (e.g. anticoagulants).

Project participation was voluntary and could have been revoked at any time without stating reasons. A positive vote was issued by the ethics committee of the Hannover Medical School (vote number: 1054–2011).

2.2 Study design and collected parameters

All investigations were carried out by a practitioner with the support of an assistant. In the initial examination (E0), the anamnesis and periodontal screening index (PSI) was gathered from all participants. The dental plaque was visualized with the aid of a plaque disclosing solution (Mira-2-Ton, Hager & Werken, Duisburg). Afterwards, the Turesky's modified Quigley-Hein plaque index (QHI) [24] and a modified plaque index similar to the Quigley-Hein-Index, in order to assess the extent of approximal plaque (modified QH-API) [10], were determined using a magnifying loupe (2.5-fold, Orascoptic Lupensysteme, Sigma Dental, D-Handewitt). The tooth brushing system "CIOTIPlus" was explained, demonstrated and practiced. The chewing, inside and outside surfaces of the teeth are cleaned first for 2 minutes, which is then followed by the cleaning of the tongue and the approximal area (CIOTI). At the end, the previously cleaned surfaces and gums are cleaned again for 1 minute with circular/rotating motions using a same (pea-sized) amount of fluoride containing toothpaste (Plus).

Additionally, the sizes of the interdental brushes used during the examinations that followed were determined for every respective approximal area for every participant (IAP-probe, Fa. Curaprox). During the initial examination, the different toothbrushes were shown to all participants, and their use was demonstrated and practiced. In order to create uniform starting conditions, all participants received a professional tooth cleaning that included the cleaning and polishing of the smooth and approximal tooth surfaces.

Four follow-up examinations (E1-E4) ensued, 6each of which was preced by a 72-hour plaque accumulation phase (no home-based oral hy-

	QHI								
	total	BeIB	BeFB	BsIB	BsFB	Bm1IB	Bm1FB	Bm2IB	Bm2FB
t0	3.0 ± 0.4	3.0 ± 0.3	3.0 ± 0.3	3.0 ± 0.4	3.1 ± 0.4	3.0 ± 0.3	3.0 ± 0.3	2.8 ± 0.4	2.8 ± 0.5
t1	1.5 ± 0.5	1.4 ± 0.5	1.6 ± 0.4	1.6 ± 0.6	1.8 ± 0.5	1.3 ± 0.4	1.4 ± 0.4	1.2 ± 0.5	1.3 ± 0.5
t2	0.6 ± 0.4	0.5 ± 0.3	0.6 ± 0.4	0.6 ± 0.4	0.7 ± 0.4	0.5 ± 0.3	0.6 ± 0.2	0.6 ± 0.4	0.5 ± 0.3
t0-t1	1.5 ± 0.4	1.6 ± 0.4	1.5 ± 0.4	1.4 ± 0.4 [a]	1.3 ± 0.3 [b]	1.7 ± 0.3 [a]	1.6 ± 0.2 [b]	1.6 ± 0.4	1.5 ± 0.4
t0-t2	2.4 ± 0.4	2.5 ± 0.3 [a]	2.5 ± 0.4	2.3 ± 0.5	2.3 ± 0.3	2.5 ± 0.4	2.4 ± 0.3	2.2 ± 0.4 [a]	2.3 ± 0.4

Table 1 QHI of all groups at different times (t0, t1, t2), as well as QHI differences t0-t1 and t0-t2. Values with the same letters are significant between them in the horizontal direction.

BeIB: brushing (electric toothbrush) – interdental brushes – brushing (electric toothbrush); BeFB: brushing (electric toothbrush) – floss – brushing (electric toothbrush); BsIB: brushing (sonic toothbrush) – interdental brushes – brushing (sonic toothbrush); BsFB: brushing (sonic toothbrush) – floss – brushing (sonic toothbrush); Bm1IB: brushing (manual toothbrush 1) – interdental brushes – brushing (manual toothbrush 1); Bm1FB: brushing (manual toothbrush 1) – floss – brushing (manual toothbrush 1); Bm2IB: brushing (manual toothbrush 2) – interdental brushes – brushing (manual toothbrush 2); Bm2FB brushing (manual toothbrush 2) – floss – brushing (manual toothbrush 2)

0	QH-API								
	total	BeIB	BeFB	BsIB	BsFB	Bm1IB	Bm1FB	Bm2IB	Bm2FB
t0	3.7 ± 0.4	3.7 ± 0.3	3.7 ± 0.2	3.6 ± 0.4	3.6 ± 0.3	3.6 ± 0.3	3.6 ± 0.3	3.9 ± 0.4	3.9 ± 0.46
t1	2.1 ± 0.5	1.8 ± 0.4	2.2 ± 0.3	1.8 ± 0.5	2.3 ± 0.4	1.8 ± 0.2	2.3 ± 0.3	2.0 ± 0.4	2.5 ± 0.6
t2	1.1 ± 0.4	0.7 ± 0.35	1.0 ± 0.3	0.9 ± 0.3	1.3 ± 0.4	1.0 ± 0.2	1.5 ± 0.3	1.1 ± 0.4	1.5 ± 0.5
t0-t1	1.6 ± 0.5	1.9 ± 0.5	1.5 ± 0.3 [ab]	1.8 ± 0.4	1.3 ± 0.3 [a]	1.8 ± 0.3	1.3 ± 0.3 [a]	1.9 ± 0.7	1.4 ± 0.6
t0-t2	2.6 ± 0.5	3.0 ± 0.5 [ab]	2.7 ± 0.5 [cd]	2.7 ± 0.4 [a]	2.3 ± 0.4 [c]	2.6 ± 0.4 [b]	2.1 ± 0.5 [d]	2.8 ± 0.6	2.4 ± 0.6

Table 2 QH-API of all groups at different times (t0, t1, t2), as well as QH-API differences t0-t1 and t0-t2. Values with the same letters are significant between them in the horizontal direction.

BeIB: brushing (electric toothbrush) – interdental brushes – brushing (electric toothbrush); BeFB: brushing (electric toothbrush) – floss – brushing (electric toothbrush); BsIB brushing (sonic toothbrush) – interdental brushes – brushing (sonic toothbrush); BsFB: brushing (sonic toothbrush) – floss – brushing (sonic toothbrush); Bm1IB: brushing (manual toothbrush 1) – interdental brushes – brushing (manual toothbrush 1); Bm1FB: brushing (manual toothbrush 1) – floss – brushing (manual toothbrush 1); Bm2IB: brushing (manual toothbrush 2) – interdental brushes – brushing (manual toothbrush 2); Bm2FB: brushing (manual toothbrush 2) – floss – brushing (manual toothbrush 2)

giene, no use of oral or dental hygiene products, or sweets or chewing gum containing menthol). Every examination appointment was followed by a "wash-out phase" of at least 2 days, where participants went back to using their regular dental hygiene products. After this, the next 72-hours plaque accumulation phase began. At every examination appointment the dental plaque was visualized and the Turesky's modified QHI [24] and the modified QH-API [10] were determined (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.

After this the patients were instructed to brush their teeth systemically for at least 2 minutes. The cleaning of the smooth surfaces was always carried out following the same system (first the chewing surfaces, then the inside and finally the outside surfaces and the tongue – system: CIOTI). A different toothbrush was used at every appointment. All participants once again received a demonstration and instruction regarding the use of every respective toothbrush. At E1, an electric toothbrush with rotating-oscillating motion patterns was used (ETB) (Braun/OralB Pro 6000, head: Oral-B Precision Clean Sensitive, Fa. Braun/OralB). At E2, a sonic toothbrush was used (STB) (Hydrosonic CHS 100 with brush head Hydrosonic smart BIW 259, level „Intensive" with 32.000 motions per minute, Fa. Curaprox), and at E3 a manual toothbrush (MTB1) (Curaprox 5460, Fa. Curaprox). At E4, also a manual toothbrush was used (MTB2) (1–2–3 Classic Care, Fa. OralB). Additionally, a toothpaste with medium abrasiveness (Elmex Sensitive Professional Repair & Prevent, CP-GABA GmbH) was used. The cleaning of the approximal area was done using interdental brushes (CPS prime, Fa. Curaprox) in the right maxilla and left mandible, and using floss (EssentialFloss,

waxed, Fa. OralB) in the left maxilla and right mandible.

After this 1. cleaning process, plaque was visualized using disclosing solution and the QH and QH-API was determined (t1). Afterwards, the participants were instructed to brush the previously cleaned tooth surfaces and gums with systematic circular/rotation motions for at least 1 minute using a same (pea-sized) amount of flouride containing toothpaste and the same toothbrushes that were used during the first brushing (System: CIOTIPlus). After this 2. cleaning process, the QHI and QH-API was determined after visualizing the plaque with a disclosing solution (t2).

A "cross-over" design was chosen for this study. Due to the "cross-over-split-mouth design", 2 tools for approximal cleaning could be evaluated together per examination appointment, resulting in a total of 8 groups (Fig. 1).

After every examination appointment, the smooth and approximal surfaces of every participant were cleaned and polished professionally. At every appointment, the cleaning of all tooth surfaces was carried out by the participants themselves and controlled by the examiner ("hands-on-brushing"). The tools to cleaning approximal areas were handled by the investigator himself/herself ("hands-on-flossing/brushing").

Every tool was used on every participant in the same way, a total of 5 times per interproximal space. Both interproximal surfaces were cleaned using floss in 2 up-and-down movements, followed by removing the floss formed to a loop towards the vestibular. A new piece of floss was used for every approximal area. When using interdental brushes, both interproximal surfaces were cleaned with two horizontal brushing motions after insertion to the interproximal space (X-Technique). The brushes were then removed obliquely out of the approximal space in an occlusal and vestibular direction.

2.3 Statistical Analysis

The data analysis was performed using the statistical analysis program SPSS/PC Version 23.0 for Windows (SPSS Incorporation, Chicago, IL, USA). All collected data were evaluated pseudoanonymously. In descriptive statistics, the median, standard deviations and statistical frequencies were calculated. The variation analysis of the collected data was used for repeated measurements within the group of paired t-tests. The means comparison of ΔQHI and QH-API between the two groups was done using unpaired t-tests. If plaque values before toothbrushing differed significantly within a group, an analysis of covariance was conducted. The statistical level of significance was determined to be $p < 0.05$.

3. Results

Fifteen participants (7 female, 8 male) with a median age of 50.1 ± 6.5 years were included in the study. During the initial examination (E0) the participants showed an average QHI of 2.1 ± 0.5 and an average QH-API of 3.6 ± 0.4. 53.33 % of the participants previously used a manual toothbrush and 46.67 % previously used an electric toothbrush as part of their home-based dental hygiene. No participant had previously used a sonic toothbrush for home-based oral hygiene.

Before the first brushing (t0) all groups showed an average QHI of 3.0 ± 0.4 and an average QH-API of 3.7 ± 0.4 (Table 1 and 2).

After the 1. brushing (t1) the QHI as well as the QH-API was decreased significantly in all groups (QHI: 1.5 ± 0.5; QH-API: 2.1 ± 0.5) ($p < 0.0001$). The largest reduction of the QHI was seen in the group "brushing (brushing (MTB1) – interdental brushes – brushing (MTB1)" (Bm1IB) (ΔmQHI-t0-t1: 1.7 ± 0.3) and the lowest reduction was seen in the group "brushing (STB) – floss – brushing (STB)" (BsFB) (ΔmQHI-t0-t1: 1.3 ± 0.3). The largest reduction of the QH-API was seen in the group "brushing (ETB) – interdental brushes – brushing (ETB)" (BeIB) (ΔQH-API-t0-t1: 1.9 ± 0.5) and the lowest reduction was seen in the group BsFB (ΔmQH-API-t0-t1: 1.3 ± 0.3) (Tab. 1 and 2).

After the second brushing (t2) the QHI and QH-API was further reduced significantly in all groups (QHI:

	Average cleaning time (minutes)	
	1. cleaning process	2. cleaning process
ETB	2.4 ± 0.2	1.7 ± 0.3
STB	2.4 ± 0.1	1.6 ± 0.3
MTB1	2.3 ± 0.2	1.5 ± 0.3
MTB2	2.2 ± 0.1	1.3 ± 0.2

Table 3 Average tooth brushing time of the subjects with the different toothbrushes

	QHI	
	interdental brush	floss
t0	2.9 ± 0.4	3.0 ± 0.4
t1	1.4 ± 0.5	1.5 ± 0.5
t2	0.5 ± 0.3	0.6 ± 0.4
t0-t1	1.5 ± 0.4	1.5 ± 0.4
t0-t2	2.4 ± 0.4	2.4 ± 0.4

Table 4 QHI at different times (t0, t1, t2), as well as QHI differences t0-t1 and t0-t2 of the groups "interdental brushes" (BeIB, BsIB, Bm1IB, Bm2IB) and "dental floss" (BeFB, BsFB, Bm1FB, Bm2FB)

	QH-API	
	interdental brush	floss
t0	3.7 ± 0.4	3.7 ± 0.5
t1	1.9 ± 0.5	2.3 ± 0.4
t2	0.9 ± 0.3	1.3 ± 0.4
t0-t1	1.8 ± 0.5	1.4 ± 0.4
t0-t2	2.8 ± 0.5	2.4 ± 0.5

Table 5 QH-API at different times (t0, t1, t2), as well as QH-API differences t0-t1 and t0-t2 of the groups "interdental brushes" (BeIB, BsIB, Bm1IB, Bm2IB) and "dental floss" (BeFB, BsFB, Bm1FB, Bm2FB)

0.6 ± 0.4; QH-API: 1.1 ± 0.4) ($p < 0.0001$). The largest reduction of the QHI was recorded in the group BeIB (ΔmQHI-t0-t2: 2.5 ± 0.3) and the lowest reduction of the QHI was recorded in the groups "brushing (MTB2) – interdental brush – brushing (MTB2)" (Bm2FB) (ΔmQHI-t0-t2: 2.3 ± 0.4). The largest reduction of the QH-API was seen in the group BeIB (ΔQH-API-t0-t2: 3.0 ± 0.5) and the lowest reduction in the group "brushing (MTB1) – floss- brushing (MTB1)" (Bm1FB) (ΔmQH-API-t0-t2: 2.1 ± 0.5) (Tab. 1 and 2). The average brushing time for the first and second cleaning process for the respective toothbrushes can be gathered from table 3.

3.1 Comparison between floss and interdental brushes

In the area of smooth surfaces, a higher reduction of the plaque index was shown in the group "interdental brushes" (BeIB, BsIB, Bm1IB, Bm2IB) after the first as well as the second brushing when compared to the "floss" group (BeFB, BsFB, Bm1FB, Bm2FB), which emerged as not statistically significant (Table 4).

In the approximal area, a higher significant reduction of the plaque index value ($p < 0.0001$) was seen in the group "interdental brushes" (BeIB, BsIB, Bm1IB, Bm2IB) compared to the "floss" group (BeFB, BsFB, Bm1FB, Bm2FB) after the first and second brushing (Table 5).

3.2 Comparison between toothbrushes

In the groups that used interdental brushes, it was shown that after the first brushing the smooth surfaces of group Bm1IB showed the largest reduction and the group BsIB the lowest reduction of plaque index (Table 1). In approximal areas after the first brushing, the largest reduction of plaque index was seen in the group BeIB and the lowest reduction was seen in the group Bm1IB (Table 2). After the second brushing, the group BeIB showed the largest and the group Bm2IB showed the lowest reduction of plaque index on smooth surfaces (Table 1). In the approximal areas the largest reduction of plaque index was seen in group BeIB and the lowest reduction in group Bm1IB after the second brushing (Table 2).

In the groups that used floss, it was shown that after the first brushing, the smooth surfaces of the group Bm1FB showed the largest reduction and the group BsFB the lowest reduction of plaque index (Table 1). In approximal areas after the first brushing, the largest reduction of plaque index was seen in the group BeFB and the lowest reduction was seen in the group BsFB (Table 2). After the second brushing, the group BeFB showed the largest and the group Bm2FB showed the lowest reduction of plaque index on smooth surfaces (Table 1). In the approximal areas the largest reduction of plaque index was seen in group BeFB and the lowest reduction in group Bm1FB after the second brushing (Table 2).

Tables 6–9 show the results of the QH-API and QHI of all groups divided into oral and vestibular surfaces of maxilla and mandible. In total, higher reduction of plaque index values were found after the first and second brushing on the vestibular smooth surfaces and vestibular approximal area when compared to the oral regions ($p < 0.0001$), where a reduction in vestibular plaque index values was higher in the maxilla than in the mandible ($p < 0.0001$). At both points in time, a higher reduction of plaque index values was found on the oral surfaces of the mandible compared to the oral surfaces of the maxilla ($p > 0.0001$).

4. Discussion

The results of this study show, that two-time brushing in combination with approximal cleaning using interdental brushes and floss according to a system can lead to significantly lower plaque index values on smooth and approximal surfaces in instructed patients when compared to a single cleaning. In literature, electric toothbrushes are described as more effective than manual toothbrushes [26, 27]. This could not be fully confirmed in the present investigation. It was shown, that the tested "manual toothbrush 1 – MTB1" led to the largest reduction of the plaque index value on smooth surfaces after the first brushing in comparison to all other toothbrushes. The second largest reduction of plaque index values was seen in the electric toothbrush with rotating-oscillating motion pattern (ETB), followed by the tested "manual toothbrush 2 – MTB2" and the sonic toothbrush (STB). After the second brushing, the result changed slightly. The ETB showed the largest reduction of plaque index value, followed by MTB1, STB, and MTB2. In approximal spaces, the largest reduction in plaque index values was seen in ETB, followed by MTB2, STB and MTB1 after the first and second brushing. The larger reduction of plaque index value was statistically significant in comparison to STB and MTB1.

The manufacturer of MTB1 did not use nylon brushes, but rather "curen filaments". Specific details on these components could not be found, neither from the manufacturer nor in literature. According to the manufacturer, the material absorbs less water than nylon and remains stable even in wet conditions, which is why filaments with a finer thickness are usually used for the head of toothbrushes. Because of this, the total amount of filaments per brush head can be maximized. In MTB1, more than 5400 individual fibres with rounded ends and a 0.1 mm diameter, arranged in a classic flat "multi-tufted", densely packed 5 rows of 39 tufts. The results of this investigation suggests, that the large number of fibres in classic flat, multitufted, densely packed tufts are advantageous in cleaning smooth surfaces. However, a lower reduction of the plaque index value was registered in approximal spaces using this manual toothbrush. This could possibly be because of the flat bristle field. It could be seen that an optimal alignment to the surface of the tooth can only be achieved when the flat bristles are angled at around 45° [3]. If the bristles are placed vertically onto the tooth surface, like in the "scrubbing- or fones technique", the bristles contact only the prominent area of the oral and vestibular smooth surfaces of the tooth surface [3].

Furthermore, a so-called "blocking effect" is observed in flat bristles

	Difference QHI (interdental brush)							
	BeIB		BsIB		Bm1IB		Bm2IB	
	t0-t1	t0-t2	t0-t1	t0-t2	t0-t1	t0-t2	t0-t1	t0-t2
UJ vest.	2.8 ± 0.8	3.7 ± 0.6	2.3 ± 0.6	3.4 ± 0.6	2.9 ± 0.7	3.4 ± 0.6	2.7 ± 0.8	3.1 ± 0.8
UJ oral	0.6 ± 0.4	1.4 ± 0.7	0.7 ± 0.5	1.4 ± 0.7	0.6 ± 0.3	1.4 ± 0.6	0.6 ± 0.5	1.4 ± 0.5
LJ vest.	2.1 ± 0.6	2.9 ± 0.6	1.8 ± 0.8	2.7 ± 0.7	2.1 ± 0.7	2.9 ± 0.5	2.1 ± 0.6	2.7 ± 0.5
LJ oral	1.0 ± 0.7	2.3 ± 0.7	0.9 ± 0.6	2.2 ± 0.7	1.2 ± 0.7	2.2 ± 0.7	1.0 ± 0.8	1.9 ± 0.7

Table 6 QHI differences t0-t1 and t0-t2 of the group "interdental brushes" (BeIB, BsIB, Bm1IB, Bm2IB) divided into the vestibular and oral surfaces of the upper jaw (UJ) and lower jaw (LJ)

	Difference QH-API (interdental brush)							
	BeIB		BsIB		Bm1IB		Bm2IB	
	t0-t1	t0-t2	t0-t1	t0-t2	t0-t1	t0-t2	t0-t1	t0-t2
UJ vest.	3.2 ± 0.8	4.1 ± 0.7	3.0 ± 0.8	4.1 ± 0.7	3.1 ± 0.7	3.8 ± 0.6	2.9 ± 1.2	3.7 ± 1.0
UJ oral	0.8 ± 0.4	1.6 ± 0.7	0.6 ± 0.4	1.2 ± 0.6	0.6 ± 0.4	1.2 ± 0.5	1.0 ± 0.7	1.9 ± 0.8
LJ vest.	2.7 ± 0.7	3.5 ± 0.4	2.5 ± 0.7	3.3 ± 0.7	2.4 ± 0.7	3.1 ± 0.5	2.3 ± 1.0	3.2 ± 0.8
LJ oral	1.2 ± 0.6	2.8 ± 0.7	0.9 ± 0.6	2.2 ± 0.6	1.0 ± 0.3	2.3 ± 0.5	1.1 ± 0.9	2.4 ± 1.0

Table 7 QH-API differences t0-t1 and t0-t2 of the group "interdental brushes" (BeIB, BsIB, Bm1IB, Bm2IB) divided into the vestibular and oral surfaces of the upper jaw (UJ) and lower jaw (LJ)

with filaments arranged parallely, which describes that filaments impede each other when advancing into tapered down areas, such as interdental spaces [3]. The disadvantages of flat bristles can be avoided with the bristle's angle to the tooth surface of around 45°, as described in the "bass technique". The manufacturer of the "manual toothbrush 1" recommends to place the bristles slightly diagonally in a 45° angle to the gingiva and to clean the tooth surface in small circulating movements. The "bass technique" is most recommended by dentists, however, it is difficult to learn and is hardly implemented by patients [4]. Rather, during examinations more circulating or horizontal brushing motions were found [4]. All patients were instructed on the correct application of each toothbrush defined by the respective manufacturers. It was observed that many participants fell back into familiar technique during the cleaning process, which could explain the lower reduction of plaque index values when using MTB1 in approximal spaces.

The sonic toothbrush used in the present investigations achieved lower reduction of plaque index values in smooth and interproximal areas than the manual toothbrushes tested. This contradicts other examinations, in which effective plaque removal with sonic toothbrushes when compared to manual toothbrushes were observed [1, 16, 31]. The manufacturer of the sonic toothbrush used in the present study recommends an angle of 45° to the tooth surface for optimal cleaning of the gingival margin, similar to MTB1. The bristles should be placed onto the tooth surface lightly and without pressure. The user should remain 2–3 seconds per tooth and then carry out a tilting motion without pressure [source: manual and instruction video Hydrosonic, Curaprox]. As previously mentioned, the patients of the present investigation were instructed on the application of each respective toothbrush in the beginning. It cannot be excluded that the manufacturer's predetermined technique was not fully implemented. The technique provided by the manufacturer is very similar to the "bass technique" and was therefore possibly difficult to implement by participants. Additionally, it was being seen that the short motionless remaining of the brush head on the tooth was difficult to do for the patients. The examined patients grew impatient quickly, which was possibly connected to the feeling of being "under surveillance". Patients using a STB often fall back into the motion pattern of a manual toothbrush during its use. They were also not used to clean their teeth with as little pressure as possible. The sonic toothbrushes used in this study did not come with pressure control and it cannot be excluded that patients applied too much pressure, which possibly lowered the cleaning performance of the sonic toothbrush. Different experiences with different toothbrushes should also be considered when interpreting the results.

	Difference QHI (floss)							
	BeFB		BsFB		Bm1FB		Bm2FB	
	t0-t1	t0-t2	t0-t1	t0-t2	t0-t1	t0-t2	t0-t1	t0-t2
UJ vest.	2.5 ± 0.6	3.5 ± 0.6	2.1 ± 0.7	3.2 ± 0.6	2.7 ± 0.4	3.4 ± 0.5	2.7 ± 0.8	3.3 ± 0.7
UJ oral	0.7 ± 0.4	1.7 ± 0.5	0.5 ± 0.3	1.5 ± 0.4	0.4 ± 0.3	1.2 ± 0.4	0.4 ± 0.3	1.2 ± 0.5
LJ vest.	2.0 ± 0.7	3.0 ± 0.5	1.7 ± 0.6	2.8 ± 0.3	2.4 ± 0.6	3.0 ± 0.5	1.9 ± 0.9	2.8 ± 0.7
LJ oral	0.9 ± 0.5	2.2 ± 0.7	0.8 ± 0.4	2.0 ± 0.8	0.9 ± 0.5	2.2 ± 0.6	0.8 ± 0.6	1.7 ± 0.7

Table 8 QHI differences t0-t1 and t0-t2 of the group "dental floss" (BeFB, BsFB, Bm1FB, Bm2FB) divided into the vestibular and oral surfaces of the upper jaw (UJ) and lower jaw (LJ)

	Difference QH-API (floss)							
	BeFB		BsFB		Bm1FB		Bm2FB	
	t0-t1	t0-t2	t0-t1	t0-t2	t0-t1	t0-t2	t0-t1	t0-t2
UJ vest.	2.4 ± 0.5	3.6 ± 0.5	2.0 ± 0.6	3.0 ± 0.8	2.1 ± 0.6	2.7 ± 0.8	2.4 ± 0.9	3.6 ± 0.6
UJ oral	0.8 ± 0.5	1.9 ± 0.7	0.4 ± 0.3	1.3 ± 0.6	0.4 ± 0.4	1.1 ± 0.6	0.6 ± 0.5	1.5 ± 0.7
LJ vest.	2.1 ± 0.7	3.2 ± 0.6	1.8 ± 0.7	2.8 ± 0.5	1.9 ± 0.5	2.6 ± 0.7	1.6 ± 0.9	2.7 ± 0.7
LJ oral	1.0 ± 0.5	2.3 ± 0.9	0.8 ± 0.3	1.8 ± 0.5	0.8 ± 0.4	2.1 ± 0.7	1.0 ± 0.7	2.1 ± 0.9

Table 9 QH-API differences t0-t1 and t0-t2 of the group "dental floss" (BeFB, BsFB, Bm1FB, Bm2FB) divided into the vestibular and oral surfaces of the upper jaw (UJ) and lower jaw (LJ)

The participants used different toothbrushes as part of their home-based oral hygiene routine. 53.3 % of participants stated that they used a manual toothbrush and 46.67 % stated they used an electric toothbrush with rotating-oscillating motion patterns. No participant had used a sonic toothbrush in their home-based oral hygiene routine. This could also explain the lower reduction of plaque index values for the group STB.

Ganss et al. (2018) observed participants during the brushing process with an electric and manual toothbrush in a video [6]. Regardless of the type of toothbrush used, the authors found that vestibular surfaces were cleaned sufficiently, however, oral surfaces were reached insufficiently [6]. This was confirmed in the present study, where regardless of the toothbrush used, plaque index value reduction was higher on vestibular compared to oral surfaces. Furthermore, Ganss et al. (2018) noticed numerous changes between areas when using electric and manual toothbrushes during the cleaning process [6]. Identical motion patterns (horizontal and circulating cleaning motions) were registered with both toothbrushes. Only 50.5 % of participants allowed "passive motions" (positioning of brush head on the tooth with less than 2 motions) when using the electric toothbrush. This "passive brushing" took less than 10 % of total brushing time [6]. In order for electric toothbrushes to achieve optimal cleaning performance a "passive motion" is quite useful. The electric toothbrushes with rotating-oscillating motion patterns used in this study were not found to be superior compared to other toothbrushes, as previously described in literature. This could also be attributed to possible incorrect application despite previous instruction.

In the present study, the cleaning time for the first brushing was not limited. In the second cleaning process, it was made sure that patients do not exceed a 2 minute brushing time. However, the average cleaning processes did not differ in duration with different brushes in the first and second process from one another (Table 3), so that the differences of plaque index value reduction cannot be attributed to varying cleaning processes. The total cleaning duration is increased by brushing twice. In the present investigation, the participants brushed the smooth surfaces with different toothbrushes for an average of 2.3 ± 0.1 minutes in the first cleaning process and 1.5 ± 0.1 minutes in the second cleaning process. In total, an average cleaning time of 3.9 ± 0.2 minutes results. By increasing brushing time, more plaque can be reduced with manual and electric toothbrushes [15, 25, 29]. It was observed that 27 % of plaque reduction can be achieved with one-minute brushing and 41 % with two-minute brushing. In a survey of a representative sample of the Republic of Germany, 75 % stated to brush for 2–3 minutes (44 % 2 minutes; 32 % 3 minutes) [32].

There is often a discrepancy between estimated and real cleaning period [20]. An examination showed that the real cleaning process averaged 68.8 seconds, but was perceived by patients to be more than twice as long (148.1 seconds) [20]. Because of that it seems expedient to recommend that patients brush twice following a specific system (e.g. CIOTIPlus) and increase brushing time indirectly, instead of solely increasing brushing time.

Studies have shown that more plaque can be removed in the approximal area when using certain tools for approximal cleaning in addition to brushing teeth with a toothbrush [14, 22]. Interdental brushes seem to be more effective than floss regarding interproximal cleaning [2]. This was confirmed by the results of this study. Regardless of the type of toothbrush, the groups that used interdental brushes shows significantly larger plaque reduction than groups that used floss in approximal surfaces after the first and second brushing process.

In different investigations, it could be determined that floss is often not adequately used and a sufficient cleaning of approximal area can therefore not occur [19, 30]. In the present study, not all participants used additional tools for approximal cleaning in their home-based oral hygiene process, and were therefore not equally practiced in their application. It was shown in preliminary investigations that there are big differences between individuals when applying tools for approximal cleaning, and that not all participants were able to reach and clean all approximal spaces themselves. A standardized application of these tools could not have been possible by self-application, which is why a distortion of results would have occurred during evaluation of the cleaning performance. In order to avoid these disadvantages and create similar conditions, the investigator took charge of cleaning the approximal spaces himself, applying the tools in the same way for every participants.

In the present investigation a „split-mouth-design“ was used. This design was chosen to maintain a low number of examination appointments. The commonly described disadvantage of the „carry-across“-effect [12] does not apply according to the results of the study, because solely the mechanical cleaning was carried out evaluated through collecting plaque indices. The one-time mechanical cleaning has no systemic effect on how a “carry-across-effect” could be formed. Another disadvantage in the “split-mouth-design” is the missing barrier between the jaw segments. In this study, mesial approximal surfaces for middle incisors were not included in the evaluation, which means that this disadvantage was also not relevant in this study. All participants were right-handed. In general it is assumed that the right half of the jaw is more difficult to clean for right-handed people than the left half of the jaw. In order to avoid possible distortion of the results, the „cross-over-split-mouth-design“ was chosen on purpose. For the test subjects, the right maxilla and left mandible, as well as left maxilla and right mandible, were summarized and valued respectively.

It was not evaluated in the present study if the differences in reduction of plaque index value are of clinical relevance in respect to caries and periodontitis prevention when using different toothbrushes. Further long-term investigations are necessary, where participants use different toothbrushes over a longer period of time in their home-based oral hygiene routine and data on caries and periodontitis prevalence are collected.

5. Conclusion

A higher reduction of plaque index value can be achieved by brushing the smooth and approximal surfaces twice than with single brushing, regardless the type of toothbrush used. The usage of interdental brushes for approximal plaque reduction seems more effective than floss in the present patient population. Electric toothbrushes do not necessarily lead to a higher reduction of the plaque-index-value when compared to manual toothbrushes. In order to achieve optimal plaque reduction when using manual or electric toothbrushes, a thorough instruction and an intensive training by dental professionals should have occurred.

Conflicts of interest:
The authors state, that there is no conflict of interest in terms of the guidelines of the International Committee of Medical Journal Editors.

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