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Mechanische Wirkung von in der Schweiz marktführenden Zahnpasten auf Dentin: Untersuchung der Reinigungs-, Abrasions- und Anrauhungpotentials

Mechanical effects of different Swiss market-leading dentifrices on dentin: evaluation of cleaning potential, relative dentin abrasion and surface roughening

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Summary

In order to estimate the potential of dentifrices to harm exposed dentin, the mechanical properties of 15 dentifrices available in the Swiss market were investigated.

A total of 120 bovine dentin samples were irradiated and analyzed for relative dentin abrasion (RDA). To investigate subsequent increases in surface roughness (Ra), dentin specimens (n = 180) were analyzed profilometrically at baseline and after brushing with test slurries. The cleaning efficacy (Ce) was determined using artificially stained tooth specimens (n = 180). The available fluoride content of the dentifrices was measured in respective slurries using an ion-selective electrode. The results of the mechanical analyses were categorized into 4 or five groups for each parameter. Four potential user groups were defined according to individual problem specifications and user demands. The results were compared to those of an earlier investigation of dentifrices published in 1998.

The RDA results exceeded the values declared by the manufacturers and correlated significantly with the results of the Ra measurements. A significant positive correlation of RDA and Ce values was also shown. The measured fluoride content often exceeded the fluoride declaration by the manufacturers. Only a few of the tested dentifrices qualified as suitable for all potential user groups.

Major differences were observed between the mechanical properties found in the present study compared to those found in 1998. These changes in the properties of dentifrices during the past decade should be considered with respect to providing adequate recommendations for individual user demands.

(1644 keystrokes)

Key words: dentifrice, relative dentin abrasion, surface roughness, cleaning efficacy, fluoride

Introduction

There are still controversies on how to explain the decline in caries incidence observed in many Western countries over the past 3 decades. In many regions and cities of Switzerland, the reduction in the caries incidence of school children reached very high levels (MENGHINI et al. 2010, STEINER et al. 2010). There is general consensus on the positive effect of the use of fluoride dentifrice since the 1950's, but the influence of other factors remains disputed, such as the impact of new dental products, different diet regimens and the increasingly common health consciousness (BRATTHALL et al. 1996). The market responds with a broad selection of toothbrushes, dental floss and mouth rinses and a great variety of differently colored and flavored dentifrices, which floods the market with its increasing demand for improvement and simplification of oral hygiene. The increasing range of products complicates decision-making of consumers and patients, as well as professional advice by dentists and oral hygienists (FRANSCISCO et al. 2013). Cury and Tenuta (2014) highlighted the importance of accurate, evidence-based recommendations on dentifrice in order to benefit from their application. Attention is mainly focused on the therapeutic substances contained in dentifrices, above all on fluoride content. However, the mechanical properties of the dentifrices should equally be taken into consideration with respect to patients' needs (SCHLUETER et al. 2012). The abrasion of sound dental hard tissues depends mainly on the effect of dentifrices, while the influence of toothbrushes seems rather negligible (ADDY & HUNTER 2003). Effects of toothbrushes on dental wear were only found with eroded enamel and dentin (ADDY & HUNTER 2003, WIEGAND et al. 2008, WIEGAND et al. 2009, WIEGAND et al. 2013). The analysis of the abrasion potential (relative dentin abrasion, RDA) of dentifrices has been either based on the measurement of radioactive dentin release or dentin surface profile changes after brushing procedures with dentifrices (GONZALES-CABEZAS et al. 2013). The radiotracer method is a useful tool to determine the relative abrasion level of dentifrices. However, RDA values differ according to the laboratory where

the measurements are performed. So, comparisons of RDA values measured in different laboratories should be avoided (DOERFER 2011). Besides, RDA values alone do not fully represent the multifactorial etiology of dental wear. For evidence-based individual recommendations on dentifrices or toothbrushes, consideration of the patient's objective needs as well as his or her subjective demands appear inevitable. Given the compelling advertising of the benefits of dentifrice by dentifrice manufacturers, adequate guidance and advice seems necessary. Details about the mechanical properties of dentifrices should be available to facilitate allocation according to individual needs (GONZALES-CABEZAS et al. 2013). Information about the ingredients should equally be provided by the manufacturers and verified independently on a regular basis to ensure better standards (CURY & TENUTA 2014). The last study about the mechanical effects of different market-leading dentifrices in Switzerland was presented more than 10 years ago (IMFELD et al. 1998), which highlights the need for data actualization and verification.

The aim of the present study was to evaluate the mechanical properties and fluoride content of popular dentifrices in Switzerland (n = 15). To this end, the relative dentin abrasion of bovine samples was analyzed after brushing using a sandwich technique, which has been described in detail by IMFELD (2010). Additionally, the resulting surface roughness (Ra) was measured profilometrically, and the cleaning efficacy (Ce) of the dentifrices was determined by comparing standardized photographic images at baseline and after brushing. Moreover, the fluoride content of the dentifrices was determined using an ion-selective electrode. The results of the respective mechanical analyses were categorized into four Ce groups and five RDA groups. Also, four potential user groups were defined according to objective problem specifications and subjective demands of patients to simplify advice. The results were compared to those of a previous study (IMFELD et al. 1998).

Materials and Methods

Specimen preparation and dentifrices

Fifteen popular dentifrices were purchased in drug stores of the agglomeration of Zurich in January 2014 (Fig. 1, Tab. I). A standard slurry was freshly prepared for all experiments. This standard slurry consisted of silica (Sident®, Evonik Degussa GmbH, Essen, Germany) mixed with carboxymethylcellulose, glycerol, silicone anti-foam (Sigma Aldrich Chemie GmbH, Buchs, Switzerland) and and a saliva substitute of similar buffer capacities to human saliva. Brushing was performed with a standard manual toothbrush (Paro M43, Esro AG, Thalwil, Switzerland). Due to the advantage of bovine teeth having larger sizes and flatter surfaces compared to human teeth, dentin samples of 120 bovine tooth roots were assessed for RDA. The experimental validity of substituting bovine roots for human roots has been shown in comparative studies (IMFELD 2001, WEGEHAUPT et al. 2010). Bovine incisors were used to prepare dentin specimens, as described in a previous study (IMFELD 2010). The crowns were removed with a disc. Polishing of the roots followed using Sof-Lex Pop-on discs (light blue, 15 µm; light yellow, 3 µm) (International Dental Supply, Hialeah, FL, USA) for two minutes each at a load of 40–60 g using a pressure gauge (8600A Digital Multimeter Specifications, Kontron Electronic AG, Zurich, Switzerland).

For the Ra and Ce assays after brushing, 360 roots from extracted human canines, incisors, or premolars without any root recesses were used. These extracted teeth were collected in unlabeled tubes to anonymize their origin. Donation was voluntary and patients were informed verbally about the use of the extracted teeth for research purposes only. The roots were cleaned from soft tissue using dental scalers and the crowns were removed using a diamond disc under constant water cooling. The root surfaces were polished using Sof-Lex Pop-on discs (light blue, 15 µm; light yellow, 3 µm) (International Dental Supply) for two minutes each at a load of 40–60 g, leading to a substance loss of approximately 100 µm. The total fluoride content of the test dentifrices was determined using an ion-selective electrode

after addition of sodium chloride and hydrochloric acid to the test slurries. Ionized fluoride content was measured using TISAB buffer with a pH of 5.1 and EDTA (modified protocol of BUSHEE et al. 1971). For validation, two samples of each test dentifrice were used to analyze the total amount of fluoride and two samples of each dentifrice to determine the ionized fluoride. An overview of the study design (Fig. 1) has been provided to give a better overall picture of the applied methodology.

Relative dentin abrasion (RDA)

The bovine specimens (n = 120) as well as synthetic apatite specimens for standardization underwent a neutron bombardment at the Atomic Institute of Vienna, Austria. The exposure to a neutron flow of 1.7 neutrons/cm^2·s converts ^{31}P of hydroxyapatite within the specimens to radioactive ^{32}P. After irradiation at a maximum temperature of 55°C and reshipment in special containers to a B-laboratory, the root specimens were embedded in methyl methacrylate using a custom Teflon mold and a positioning caliper to ensure a surface positioning 1 mm above the surface of the embedding material. To prevent root dentin dehydration, the molds were kept under water during polymerization. The specimens were then stored in water until handled further.

Eight irradiated root samples were allocated to each of the 15 test groups and the respective standard ISO abrasion material. The relative dentine abrasion of the 15 toothpastes was then determined after brushing the specimens using a sandwich technique, previously described by IMFELD (2010). The abrasivity of the dentifrices was calculated based on the ratio relative to a reference abrasive (standard slurry). To determine the reference abrasivity, specimens were first brushed with a standard slurry, then with a slurry of the test dentifrice and then again with standard slurry. For each brushing sequence, Paro M43 manual toothbrushes (Esro AG) were moved for 25 min over the roots in 30 mm excursions at a rate of 60 cycles/minute at 2.5 N. Specimens were positioned in an automated 8-place cross-brushing machine, enabling

simultaneous testing of seven testing slurries and one standard slurry (V-8 Cross Brushing Machine, Sabri Enterprises Inc., Downers Grove, IL, USA). Each chamber was filled with 65 g of the respective testing slurry or the standard slurry. The experimental slurries contained the respective toothpaste mixed with saliva substitute, bi-distilled water and sodium bicarbonate. After each brushing sequence, samples of the slurry were removed for analysis. Prior to the next brushing sequence, the chamber was cleaned with ionized water. For analysis, three 0.5 g samples were taken from each slurry after each brushing sequence to measure the ^{32}P radiation activity over 24 h (Phosphor-Imager®, Molecular Dynamics, Sunnyvale, CA, USA). The measured ^{32}P activity in counts per minute (cpm) was converted into decays per minute (dpm)/mg by comparison with the results of a ^{32}P standard (Amersham Pharmacia Biotech, Vienna, Austria). The data obtained from the two brushing sequences with standard slurry served as a reference and were averaged and normalized to the value 100. The relative dentin abrasion of the test dentifrices (processed in between standard slurry runs) was expressed as a percentage of this standard value.

Surface roughness (Ra)

For each experimental product and for three standard controls in total, 10 human root specimens per group were used to determine the surface roughness after brushing (n = 180). The root specimens were embedded in rectangular brushing chambers between two glass bars to simulate the outlines of adjacent teeth. Embedding was performed with silicone material (President®, Coltène/Whaledent AG, Altstätten, Switzerland). The chambers were weighed prior to brushing and 1 g of the experimental slurry or standard slurry, respectively, was pipetted into the flasks. The specimens were then placed into a 6-place cross-brushing machine and a new manual toothbrush (Paro M43, Esro AG) with a 2.5 N load was used for each specimen. Each cycle in the cross-brushing machine consisted of one standard control and five test dentifrices, leading to three separate runs with three values for the standard slurry

(standards 1–3). This was then repeated 10 times, to include all 180 specimens. Surface roughness was determined at baseline and after 25 min of brushing (1 reciprocating motion per second, 32 mm one way). Five parallel baseline profiles (Ra = 3 mm) at distances of 0.5 mm were recorded for each sample using a mechanical contact profilometer oriented perpendicular to the brushing movements (cut-off Lc 0.25 mm, cut-off Ls 0.0025 mm) (Talysurf-50, Rank Tayler Hobson Limited, Leicester, UK). Profiles started 1 mm from the cementoenamel junction. The specimens were stored and measured under wet conditions to ensure stable profilometric readings (ATTIN et al. 2009). After brushing, the profiles of the same regions were analyzed again.

Cleaning efficacy (Ce)

Ten root specimens were used per slurry and per standard slurry as described above (n = 180). The root surfaces were stained for 17 h in 8 ml of tea solution in combination with gentle agitation at 37°C (Lipton Black Tea Yellow Label, The Indian Tea Company, Epping, UK, pH 4). Baseline images were obtained after embedding the specimens with silicone material in brushing chambers between two glass bars, as described above. Digital images of each stained specimen and a scale bar were obtained using a Tessovar (Pentax K20D, Pentax AG, Wallisellen, Switzerland). The specimens were then placed in a 6-place cross-brushing machine, enabling the testing of five test slurries and a standard slurry during each run. This resulted in three runs and three separate values for the standard slurries (standard 1–3). To include all specimens, this was repeated 10 times. To facilitate the acquisition of standardized digital images after brushing, the brushing borders were marked using a dental scalpel on the dentin. Brushing was performed as described above, for 25 min with 2.5 N of surface pressure. After 1500 brushing cycles and a washing step with water (1 reciprocating motion per second as adjusted for the surface roughening experiments), standardized images were obtained and analyzed planimetrically. Stain-free areas were expressed as a percentage of the

whole brushed area. The cleaning efficacy of each standard and each experimental slurry was determined by averaging the percentages calculated for the 10 respective specimens.

Fluoride content and pH measurement

The total amount of fluoride in each dentifrice was analyzed based on hydrolysis of the fluoride after binding to sodium chloride. Measurements were performed directly using an ion-selective electrode. A total of 12.5 g of each dentifrice was weighed, placed into a plastic tumbler and homogenized with 50 ml of distilled water for 1 h with a magnetic stirrer. The slurry was transferred to a 250 ml volumetric flask and mixed. After 6 h, a total of 5 ml of the supernatant was pipetted into a 500 ml volumetric flask. Then, for hydrolysis of bound fluoride, 20 ml of 37% hydrochloric acid and 29 g of sodium chloride were added and filled up to the mark (resulting in 500 ml of a 5.8% NaCl solution). An analysis of the solution was possible after 16 h. To this end, 40 ml of the solution was transferred to a 50 ml flask and agitated gently with a measuring chain. The mV value was measured twice for every solution. Measurements of ionized fluoride content were performed using an ORION-720-A measurement device with a combined fluoride electrode 9609 BN (Orion-Europe, Cambridge, Great Britain) according to a modified protocol published by BUSHEE et al. (1971). The mV value of each dentifrice was tested twice. The mV values were converted to ppm of fluoride using a regression analysis.

The pH for each test slurry was assessed with a pH meter twice (Methrom-827 meter and electrode 6.0210.100, Methrom AG, Herisau, Switzerland) using a standardized laboratory protocol (CIBA-GEIGY AG 1984.

Ranking of the measurements

The measured values of the mechanical experiments were allocated to four or five arbitrarily graded categories within each mechanical experiment. The ranking went from favorable

results for the dentifrices (i.e. RDA-1, Ra-1 and Ce-1, respectively) to less favorable results (i.e. RDA-5, Ra-5 and Ce-4, respectively) based on the categorization proposed by IMFELD et al. (1998).

Ranking for the RDA values:

- RDA-1: Very low abrasion, RDA <20
- RDA-2: Low abrasion, RDA 20–40
- RDA-3: Moderate abrasion, RDA 41–60
- RDA-4: Strong abrasion, RDA 61–80
- RDA-5: Very strong abrasion, RDA >80

Ranking for the surface roughness:

- Ra-1: Very low roughening, Ra <0.1 µm
- Ra-2: Low roughening, Ra 0.1–0.5 µm
- Ra-3: Moderate roughening, Ra 0.6–1.0 µm
- Ra-4: Strong roughening, Ra 1.1–1.5 µm
- Ra-5: Very strong roughening, Ra >1.5

Ranking for the cleaning efficacy:

- Ce-1: Very good cleaning, Ce >70%
- Ce-2: Good cleaning, Ce 41–70%
- Ce-3: Sufficient cleaning, Ce 21–40%
- Ce-4: Poor cleaning, Ce 0–20%

Categorization of patient's requirements

In order to facilitate a comparison of the studies, four potential user groups were defined according to the classification proposed by IMFELD et al. (1998).

User group 1: Persons without exposed dentin surfaces and without stained teeth; cleaning and polishing can be achieved using dentifrices exhibiting sufficient cleaning efficacy and RDA values are not crucial.

User group 2: Persons without exposed dentinal surfaces, but with stained teeth surfaces due to smoking, consumption of coffee, tea, wine and certain other foods; high cleaning efficacy becomes important, but RDA values are not crucial.

User group 3: Persons with exposed dentin surfaces, but without stained teeth; dentifrices with very low or low abrasion should be recommended, while Ce values are not critical.

User group 4: Persons with a combination of exposed dentin surfaces and stained teeth; low abrasion dentifrices with good cleaning efficacy are required.

Data analysis

Statistical analysis was performed with StatView (Version 5.0.1, Abacus Concepts Inc., Berkeley, CA, USA). Correlations between measured RDA values and the results of the surface roughness measurements, as well as the cleaning efficacy were analyzed. Differences between the declared and measured fluoride concentration were calculated. The threshold for statistical significance was set at $\alpha < 0.05$.

Results

The results for relative dentin abrasion, surface roughness and cleaning efficacy are summarized in Tables II and III. The dentifrice Signal White System achieved the best cleaning efficacy, however, it also produced the strongest roughening and strong abrasion on dentin. A significant correlation was found in all dentifrices between the abrasion potential (RDA) and the results of the surface roughness measurements ($p = 0.0258$, $|R| = 0.572$). The RDA values were also shown to significantly correlate with the cleaning efficacy of the tested

dentifrices ($p = 0.0049$, $|R| = 0.684$). The highest RDA values were measured for Candida White Micro-Crystals, Signal Anti-Caries, Signal White System and Colgate Total Original. The cleaning efficacy of these dentifrices were categorized from "very good" to "good." Most of the tested dentifrices achieved different rankings depending on the parameter analyzed. Only Candida Parodin Professional, Elmex Sensitive plus and Colgate Fresh Gel ranked low in all three parameters. The fluoride concentration measured in the tested slurries differed from the manufacturer´s declarations by an average of 121 ppm. Six of the dentifrices contained up to 100 ppm less than the declared fluoride content (Table I). The toothpaste Elmex Kariesschutz showed the maximum deficit between declared and measured fluoride content, while Candida White Micro-Crystals exhibited an excess of approximately 40 ppm. Only seven of ten dentifrices tested by IMFELD et al. (1998) were also tested in the present study (Candida Fresh Gel, Candida Peppermint, Colgate Total Original, Colgate Dentagard Original, Elmex Sensitive plus, Elmex Kariesschutz and Meridol).

The RDA values measured in the 1998 study were lower for all seven dentifrices that were also tested in the present study (Table II). An increase in cleaning efficacy compared to the 1998 study was observed in four dentifrices of the present study and correlated with an increase in surface roughness for the respective dentifrices (Table III). Only Candida Peppermint, Colgate Total Original and Colgate Dentagard Original showed reduced cleaning efficacy compared to the 1998 study. Candida Peppermint and Colgate Dentagard Original, however, also showed a decrease in surface roughness compared to the 1998 study. Colgate Total Original showed reduced cleaning efficacy compared to 1998, but surface roughness and dentin abrasion were increased compared to 1998.

Discussion

Many experts have underscored the positive effect of the use of fluoride dentifrice on caries decline, which has reached a general consensus (BRATTHALL et al. 1996, PETERSSON & BRATTHALL 1996). A great impact has also been attributed to oral health education and its implementation in oral hygiene regimens that have led to better brushing techniques and more frequent exposure of oral hard tissues to dentifrice. Despite the undisputed benefits of mechanical cleaning, still to be supported by dentists and dental hygienists, it is imperative to pay attention to cumulative tooth damage that may be generated by dentifrices.

The hidden properties and favored attributes of dentifrices should be examined carefully. In general, adequate dentifrices should clean (cleaning efficacy) and polish (surface roughness) the teeth, but at the same time produce minimal dentin abrasion (relative dentin abrasion). Appropriate fluoride reservoirs should also be available in a soluble state. Accessible and reliable details on composition should be given to customers. The mechanical properties of the dentifrices tested in the present study were assessed and compared using a standardized "ordinary" manual toothbrush with a plane bristle type. Cross-brushing machines were used and simulated a reciprocating scrubbing motion, which is not the recommended motion for application but is widely used by the average consumer and helpful for the standardization of experiments. Recommendations on suitable brushing techniques for optimal plaque removal are still controversially discussed (HARNACKE et al. 2012, SCHLUETER et al. 2013). While the use of adequate toothbrushes and/or brushing techniques might reduce tooth wear, they are not likely to influence the ranking of the tested dentifrices within the investigated parameters. Three mechanical effects of dentifrices were evaluated separately based on a former investigation by IMFELD et al. (1998). At that time, cleaning efficacy, surface roughness and relative dentin abrasion of 12 Swiss market-leading dentifrices were assessed. A ranking was determined according to the tested parameters and then the dentifrices were recommended for specific user groups (4 to 5 groups; Table III). The present study aimed to update the data on the mechanical properties of currently available dentifrices and to review

the manufacturers' data on RDA and fluoride content (Table I). In most cases, the declared RDA values differed noticeably from the measured data. Five of eight dentifrices with declared RDA values were found to have considerably higher RDA values than that stated in the product information. Four dentifrices revealed as much as 50% higher RDA values than described by the manufacturers. In two dentifrices, the declared values matched the measured RDA values (Table III). However, discrepancies between declared RDA and measured RDA values might be explained either by the biological variations in the dentin substrate or by the laboratory set-up where the values were measured. The tests of the fluoride content revealed differences between the declared amount of fluoride and the amount determined in the present study of 100 ppm and more in seven of the tested dentifrices. In two cases, a reduced amount of fluoride compared to the declared amount of up to approximately 450 ppm was observed (Table I). To validate the data, not only the total fluoride content but also the ionized fluoride was determined two times. As expected, the ionized fluoride revealed concentrations according to the declared type of fluoride. Dentifrices containing sodium monofluoride phosphate were found to have only a small amount of ionized fluoride (43-569 ppm). It is known that the fluoride uptake in enamel and the formation of a protective calcium fluoride-like precipitate on an enamel surface depends not only on the concentration of the applied fluoride. The amount of fluoride in enamel increases with duration and frequency of application and with a decrease in pH (SAXEGAARD & RÖLLA 1988). The measured pH values ranged from pH 4.4 (Meridol) to pH 9.5 (Signal White System). Dentifrices containing amine fluoride were found to have pH values below pH 5.0 (Elmex Sensitive plus, Elmex Kariesschutz, Meridol). Obviously, both the pH and type of fluoride should be considered.

The discrepancies between declared and measured fluoride content highlight the necessity of conducting regular verifications of marketed products and submitting requests for revision of the declarations to maintain the proposed standards.

The results of the assessment of mechanical properties are summarized in Table IV. In accordance with the results of IMFELD et al. (1998), only a few dentifrices showed favorable results for all tested parameters. While some dentifrices were ranked favorably with respect to cleaning efficacy (i.e., up to 83%), their results for RDA and surface roughness were ranked unfavorably. To simplify a ranking of the properties of the respective dentifrices, the results of the tested parameters were grouped as described above (Table IV).

None of the tested dentifrices were graded as having very low abrasion (RDA-1) or very low roughening values (Ra-1). In comparison to the previous investigation in 1998, four dentifrices exhibited very strong abrasion potential (RDA-5) and seven showed very strong surface roughening after brushing (Ra-5). These products are mostly whitening dentifrices for stain removal and are not recommended for use on a daily basis. A comparison between the dentifrices examined in 1998 and those of the present study highlights a shift towards higher abrasion and surface roughening potentials for the dentifrices in the present study.

Similarly to the categorization of the mechanical parameters, consumers and patients were split into different user groups according to individual requirements and dental conditions. This provides the ability to assign adequate dentifrices to the respective consumer groups.

A successful allocation of appropriate dentifrices to the described user groups might be beneficial in the light of a cost-benefit analysis. Demands of the consumers and patients, such as proper cleaning results, are considered a benefit, while abrasion and surface roughening represent costs incurred by the user.

Along these lines, user group 1, whose members were defined as without exposed dentinal surfaces and no stained teeth, might be recommended to use dentifrices with sufficient or good cleaning efficacy. Adequate dentifrices for people who fit in this group are listed in Table IV. Categories Ce-3 and Ce-2 must equally fulfill the criteria of the RDA-2/RDA-3 and Ra-2/Ra-3 categories. Therefore Candida Parodin Professional, Elmex Sensitive plus, Colgate

Fresh Gel and Candida Peppermint represent adequate dentifrices for this user group. Use of Meridol leads to high abrasion and cannot be recommended for this group.

Patients of user group 2, who are defined as having discolored teeth but no exposed dentin surfaces, require dentifrices with higher cleaning potentials. Dentifrices of category Ce-2 with no higher RDA and Ra values than in RDA-2/RDA-3 and Ra-2/Ra-3 are recommended. Candida Peppermint, Candida Parodin Professional, Colgate Fresh Gel and Elmex Sensitive plus present adequate dentifrices for this group. In contrast, use of Colgate Total Original, Candida Multicare 7 in 1, Candida White Micro-Crystals and Signal Micro-Granuli induced very strong surface roughening and should be avoided by this user group.

User group 3, characterized by exposed dentin and no staining, requires dentifrices with gentle cleaning such as Ce-3 or Ce-2, and RDA and Ra values on the level of RDA-2 and Ra-2. Only Candida Parodin Professional, Colgate Fresh Gel and Elmex Sensitive plus can be recommended. The dentifrice Elmex Sensitive professional has a low abrasion potential, but it exhibits a strong surface roughness value and is therefore not suitable for this user group.

Patients of user group 4, who have a combination of stained teeth and exposed dentin, should only use dentifrices categorized as Ce-2, RDA-2 and Ra- 2. Only Candida Parodin Professional, Colgate Fresh Gel and Elmex Sensitive professional can be recommended for this group. These dentifrices show properties suitable for all described user groups due to their good cleaning efficacy and only slight abrasion and surface roughening. Within this group of dentifrices, and considering the outcomes of the fluoride measurements, Colgate Fresh Gel exhibited the best ranking in all parameters. The highest cleaning efficacies were achieved with Signal White System and Signal Anti-Caries, as well as Candida Fresh Gel. However, these dentifrices have strong to very strong surface roughening and RDA values and should not be used on a daily basis.

The allocation of the dentifrices described above is based on mechanical parameters only and can be amended by the fluoride content. Looking at the three top performers, only Colgate

Fresh Gel conforms to its declared fluoride supply of 1450 ppm (measured 1423 ppm). Candida Parodin Professional contained 1043 ppm (declared 1490 pm), Elmex Sensitive plus had 1194 ppm (declared 1400 ppm) and Elmex Kariesschutz contained only 957 ppm (declared 1400 ppm).

Overall, major changes were found in the mechanical properties of dentifrices when compared to the study performed 12 years ago. Also, most of the measured values of the mechanical properties differed noticeably from the declared values. The observed changes in mechanical properties should be taken into account when making recommendations to individual users.

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Zusammenfassung

Um die zu Putzschäden führenden Eigenschaften von Zahnpasten zu evaluieren wurden 15 Zahnpasten des Schweizer Marktes auf ihre mechanischen Eigenschaften und den Fluoridgehalt überprüft. Hundertzwanzig bovine Dentinproben wurden für die Untersuchung der relativen Dentinabrasion (RDA) bestrahlt und nach 25-minütigem Bürstvorgang mit den jeweiligen Test-Zahnpasten unter Verwendung einer Bürstmaschine analysiert. Um die Oberflächenrauigkeit (Ra) zu ermitteln, wurden hundertachzig menschliche Zahnproben profilometrisch vor und nach dem Bürstvorgang mit den jeweiligen Test-Slurries untersucht. Für die Evaluation der Reinigungswirkung (Ce) wurden hundertachzig bovine Dentinproben zunächst in einer Teelösung gelagert, um eine Verfärbung des Dentins zu erreichen. Anschließend wurden die Proben vor und nach dem Bürsten mit den Test-Zahnpasten standardisiert fotografiert und planimetrisch ausgewertet. Der verfügbare Fluoridgehalt der Zahnpasten wurde unter Verwendung einer ionenselektiven Elektrode nach Natriumzugabe gemessen. Die Ergebnisse der mechanischen Analysen wurden in Gruppen innerhalb der untersuchten Parameter eingeteilt (RDA-1 bis RDA-5, bzw. Ra-1 bis Ra-5 und Ce-1 bis Ce-4). Zur Veranschaulichung der Anwendung wurden vier potenzielle Benutzergruppen mit verschiedenen objektiven Bedürfnissen und subjektiven Wünschen definiert. Die Ergebnisse der mechanischen Untersuchungen wurden mit denjenigen einer früheren Untersuchung von Zahnpasten des Schweizer Marktes verglichen (IMFELD et al. 1998).

Insgesamt qualifizierten sich nur sehr wenige der getesteten Zahnpasten für alle potenziellen Benutzergruppen (Candida Parodin Professional, Colgate Fresh Gel and Elmex Sensitive professional). Hiervon wies nur Colgate Fresh Gel den angegebenen Fluoridgehalt auf, während Candida Parodin Professional und Elmex Sensitive plus ein Defizit über 200 ppm aufwiesen. Es wurden weitestgehend Abweichungen im Vergleich zur deklarierten Fluoridmenge gefunden. In sieben der untersuchten Zahnpasten wurden Konzentrationsunterschiede von 100 ppm und mehr festgestellt. In einigen Fällen wurde ein

Defizit von nahezu 450 ppm ermittelt (Candida Parodin Professional und Elmex Kariesschutz). Sieben Zahnpasten aus der Untersuchung marktführender Schweizer Zahnpasten von IMFELD et al. (1998) konnten in der vorliegenden Studie wieder geprüft werden. All diese wiesen 2014 ein höheres Abrasionspotential auf und dies war statistisch signifikant mit einer verstärkten Oberflächenrauigkeit korreliert. Auch die Reinigungswirkung korrelierte signifikant mit steigendem Abrasionspotential. Nur Colgate Total Original wies trotz erhöhtem RDA-Wert und erhöhter Oberflächenrauigkeit eine reduzierte Reinigungswirkung auf. Insgesamt wurde ein Trend in Richtung zu abrasiveren Zahnpasten festgestellt. Für individuelle Empfehlungen von Zahnpasten sind die in den letzten zehn Jahren veränderten Eigenschaften der untersuchten Zahnpasten je nach den individuellen Bedürfnissen der Anwender zu berücksichtigen.

(369 Wörter)

Résumé

Pour évaluer les dommages occasionnés par le brossage des dents avec dentifrice, 15 dentifrices suisses ont été testés sur leurs propriétés mécaniques et leur teneur en fluorure.

120 dents bovines ont été irradiées pour étudier leur érosion relative (RDA) puis analysées après 25 minutes de brossage avec différent dentifrices et en utilisant une machine de brossage. Pour déterminer la rugosité superficielle (Ra) 150 échantillons de dents humaines ont été examinés avec un profilomètre avant et après leur brossage avec les dentifrices. Pour évaluer l'effet de nettoyage (Ce) 150 échantillons de dents bovines ont été immersés dans une solution de thé pour obtenir une coloration du tissu dentaire. Ensuite les échantillons ont été photographiés de manière standardisée et évalués planimétriquement avant et après leur brossage avec les dentifrices testées. La teneur en fluorure des dentifrices a été mesurée à l'aide d'une électrode ionique recherchant l`ajout de sodium. Les résultats des analyses mécaniques ont été ensuite répartis en groupes pour chaque paramètre étudié (de RDA-1 à RDA-5, de Ra-1 à Ra-5 et Ce-1 à Ce-5). Pour simplifier, 4 groupes d`utilisateur potentiels ont été définis selon leurs problèmes spécifiques et les buts recherchés. Les résultats de ces tests ont été comparés aux tests d'une enquête sur les dentifrices suisses effectuée en 1998 (IMFELD et al, 1998).

En tout très peu de dentifrices testés se sont qualifiés pour tous les groupes des utilisateurs potentiels (Candida Parodin Professional, Colgate gel frais et Elmex Sensitive professional). Parmi eux seul Colgate Fresh Gel avait la teneur en fluorure indiquée tandis que Candida Parodin Professional et Elmex Sensitive plus montraient un déficit supérieur à 200 ppm (tableau I). De très grandes variation on été trouvées par rapport au montant de fluorure indiqué. Des différences de concentration de 100ppm et plus ont été trouvées dans 7 dentifrices testés. Dans certains cas un déficit de presque 450 ppm a été déterminé (Candida Parodin Professional et Elmex Kariesschutz). Par rapport aux études des dentifrices suisses de

IMFELD et al. (1998), 7 dentifrices ont pu être comparés directement entre eux (tableau II & III). Tous révélaient une augmentation du potentiel abrasif et statistiquement en corrélation avec une augmentation significative de la rugosité superficielle des dents. L'effet de nettoyage est en corrélation avec une augmentation du potentiel d'abrasion. Seul Colgate Total Original malgré une valeur RDA et une rugosité superficielle en hausse, s'est démarqué par une réduction du degré de nettoyage. Dans l'ensemble une tendance abrasive des dentifrices a été déterminée en hausse. Pour une recommandation appropriée des dentifrices, les propriétés variables des dentifrices testés doivent être considérés en fonction des besoins individuels des utilisateurs.

(428 words)

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Figure and table caption

Figure I: Present study design

Table I: Brand names, manufacturers, types of fluoride, declared and measured fluoride content, and measured pH values of the 15 tested dentifrices.

Table II: Declared and determined RDA values in comparison to the results of IMFELD et al. (1998).

Table III: Measured cleaning efficacy and surface roughness of all 15 tested dentifrices in comparison to the results of IMFELD et al. (1998).

Table IV: Relative dentin abrasion (RDA), surface roughness (Ra) and cleaning efficacy (Ce) of the experimental dentifrices after 25 min brushing. Ranking according to increasing RDA, Ra and decreasing Ce-values.

Figure 1

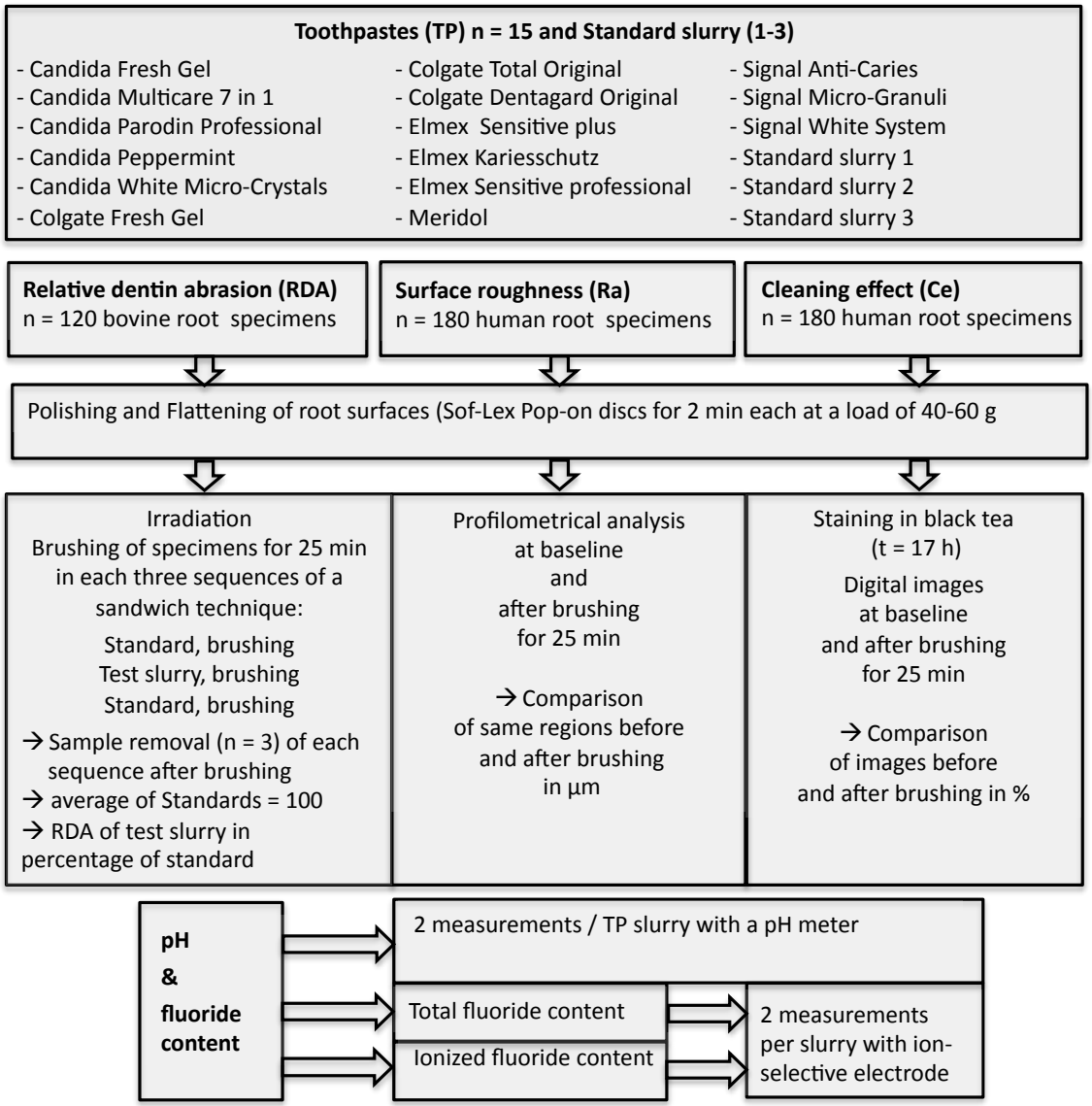
Toothpastes (TP) n = 15 and Standard slurry (1-3)
- Candida Fresh Gel
- Candida Multicare 7 in 1
- Candida Parodin Professional
- Candida Peppermint
- Candida White Micro-Crystals
- Colgate Fresh Gel
- Colgate Total Original
- Colgate Dentagard Original
- Elmex Sensitive plus
- Elmex Kariesschutz
- Elmex Sensitive professional
- Meridol
- Signal Anti-Caries
- Signal Micro-Granuli
- Signal White System
- Standard slurry 1
- Standard slurry 2
- Standard slurry 3
Relative dentin abrasion (RDA)
n = 120 bovine root specimens
Surface roughness (Ra)
n = 180 human root specimens
Cleaning effect (Ce)
n = 180 human root specimens
Polishing and Flattening of root surfaces (Sof-Lex Pop-on discs for 2 min each at a load of 40-60 g
Irradiation
Brushing of specimens for 25 min in each three sequences of a sandwich technique:
Standard, brushing
Test slurry, brushing
Standard, brushing
→ Sample removal (n = 3) of each sequence after brushing
→ average of Standards = 100
→ RDA of test slurry in percentage of standard
Profilometrical analysis at baseline and after brushing for 25 min
→ Comparison of same regions before and after brushing in µm
Staining in black tea (t = 17 h)
Digital images at baseline and after brushing for 25 min
→ Comparison of images before and after brushing in %
pH & fluoride content
2 measurements / TP slurry with a pH meter
Total fluoride content
Ionized fluoride content
2 measurements per slurry with ion-selective electrode

Table I

toothpaste	manufacturer	declared fluoride	declared ppm F	total F* ppm F	ionized F ppm F	pH
Candida Fresh Gel	a	MFP	1300	1091	43	7.6
Candida Multicare 7 in 1	a	MFP/NaF	1300	1242	569	6.8
Candida Parodin Professional	a	MFP	1490	1043	62	6.7
Candida Peppermint	a	MFP	1490	1452	71	7.1
Candida White Micro-Crystals	b	NaF	1350	1392	1389	7.7
Colgate Fresh Gel	b	NaF	1450	1423	1467	5.9
Colgate Total Original	b	NaF	1450	1485	1401	6.9
Colgate Dentagard Original	c	NaF	1450	1449	1477	7.0
Elmex Sensitive plus	c	AMF	1400	1194	1208	4.7
Elmex Kariesschutz	c	AMF	1400	957	979	4.7
Elmex Sensitive professional	d	MFP	1400	1283	122	9.0
Meridol	d	AMF/SnF_2	1400	1230	1225	4.4
Signal Anti-Caries	e	NaF	1450	1349	1374	7.2
Signal Micro-Granuli	e	NaF	1450	1436	1439	6.2
Signal White System	e	MFP	1450	1382	164	9.5

total F= bound and ionized fluoride after hydrolysis; MFP = sodium monofluoride phosphate, NaF = sodium fluoride, AMF = amine fluoride, SnF_2 = stannous fluoride
a = Mibelle AG Cosmetics, Buchs, Switzerland
b = Colgate-Palmolive, Swidnica, Poland
c = GABA International AG, Swidnica, Poland
d = GABA International AG, Lörrach, Germany
e = Unilever Schweiz GmbH, Thayngen, Switzerland

Table II

toothpaste	declared RDA	measured RDA 2014 (mean ± stdev)	measured RDA 1998** (mean ± stdev)
Candida Fresh Gel	50	75 ± 12	51 ± 18
Candida Multicare 7 in 1	50	80 ± 3	-
Candida Parodin Professional	25	24 ± 4	-
Candida Peppermint	20	43 ± 3	20 ± 3
Candida White Micro-Crystals	75	90 ± 10	-
Colgate Fresh Gel	n/a	33 ± 6	-
Colgate Total Original	n/a	121 ± 7	51 ± 13
Colgate Dentagard Original	n/a	78 ± 5	41 ± 9
Elmex Sensitive plus	n/a	28 ± 4	12 ± 11
Elmex Kariesschutz	n/a	65 ± 3	38 ± 9
Elmex Sensitive professional	n/a	38 ± 3	-
Meridol	n/a	65 ± 7	39 ± 5
Signal Anti-Caries	50	108 ± 6	-
Signal Micro-Granuli	37	44 ± 4	-
Signal White System	110	110 ± 14	-

* RDA values declared by manufacturers or printed on toothpaste tubes

**IMFELD et al. 1998

Table III

toothpaste	cleaning efficacy (%) 2014 (mean ± stdev)	cleaning efficacy (%) 1998* (mean ± stdev)	Ra (µm) 2014 (mean ± stdev)	Ra (µm) 1998* (mean ± stdev)
Candida Fresh Gel	66 ± 8	50.9 ± 11.1	5.52 ± 1.09	0.313 ± 0.112
Candida Multicare 7 in 1	52 ± 14	-	2.44 ± 1.13	-
Candida Parodin Professional	44 ± 15	-	0.12 ± 0.04	-
Candida Peppermint	46 ± 10	52.3 ± 19.6	0.35 ± 0.09	0.701 ± 0.654
Candida White Micro-Crystals	50 ± 9	-	3.12 ± 0.93	-
Colgate Fresh Gel	42 ± 11	-	0.25 ± 0.12	-
Colgate Total Original	55 ± 16	63.5 ± 15.1	2.07 ± 1.05	0.409 ± 0.382
Colgate Dentagard Original	53 ± 13	63.3 ± 21.0	0.62 ± 0.30	0.636 ± 0.591
Elmex Sensitive plus	40 ± 14	2.8 ± 2.1	0.18 ± 0.07	0.078 ± 0.031
Elmex Kariesschutz	45 ± 11	35.9 ± 16.0	0.71 ± 0.31	0.282 ± 0.134
Elmex Sensitive professional	42 ± 10	-	1.01 ± 0.70	-
Meridol	28 ± 13	20.9 ± 18.7	0.44 ± 0.29	0.345 ± 0.116
Signal Anti-Caries	67 ± 14	-	2.22 ± 0.81	-
Signal Micro-Granuli	44 ± 9	-	3.42 ± 0.81	-
Signal White System	83 ± 12	-	9.70 ± 0.83	-
Standard 1	46 ± 14	46.9 ± 16.0	2.74 ± 1.70	1.565 ± 1.509
Standard 2	55 ± 15	63.9 ± 11.7	4.00 ± 1.83	1.418 ± 1.157
Standard 3	50 ± 16	40.5 ± 14.9	4.95 ± 1.65	2.047 ± 1.070

*IMFELD et al. 1998

Table IV

RDA-values (in % standard deviation)		Ra-values (increase of average roughness in µm)		Ce-values (% cleaned surface)	
RDA-1: RDA 0-20 (rarely abrasive)		**Ra-1: Ra 0.0-0.1 (rarely roughening)**		**Ce-1: Ce > 70 (very good cleaning)**	
				Signal White System	83 ± 12
				Signal Anti-Caries	67 ± 14
				Candida Fresh Gel	66 ± 8
RDA-2: RDA 20-40 (slightly abrasive)		**Ra-2: Ra 0.1-0.5 (slight roughening)**		**Ce 40-69 (good cleaning)**	
Candida Parodin Professional	24 ± 4	Candida Parodin Professional	0.12 ± 0.04	Colgate Total Original	55 ± 26
Elmex Sensitive plus	28 ± 4	Elmex Sensitive plus	0.18 ± 0.07	Colgate Dentagard Original	53 ± 13
Colgate Fresh Gel	33 ± 6	Colgate Fresh Gel	0.25 ± 0.12	Candida Multicare 7 in 1	52 ± 14
Elmex Sensitive professional	38 ± 3	Candida Peppermint	0.35 ± 0.09	Candida White Micro-Crystals	50 ± 9
		Meridol	0.44 ± 0.29	Candida Peppermint	46 ± 10
				Elmex Kariesschutz	45 ± 11
				Signal Micro-Granuli	44 ± 9
				Candida Parodin Professional	44 ± 15
				Colgate Fresh Gel	42 ± 11
				Elmex Sensitive professional	42 ± 10
				Elmex Sensitive plus	40 ± 14
RDA-3: RDA 40-60 (medium abrasive)		**Ra-3: Ra 0.5-1.0 (medium roughening)**		**Ce-3: Ce 20-39 (sufficient cleaning)**	
Candida Peppermint	43 ± 3	Colgate Dentagard Original	0.62 ± 0.30	Meridol	28 ± 13
Signal Micro-Granuli	44 ± 4	Elmex Kariesschutz	0.71 ± 0.31		
RDA-4: RDA 60-80 (strong abrasive)		**Ra-4: Ra 1.0-1.5 (strong roughening)**		**Ce-4: Ce 0-19 (sparse cleaning)**	
Elmex Kariesschutz	65 ± 3	Elmex Sensitive professional	1.01 ± 0.70		
Meridol	65 ± 7				
Candida Fresh Gel	75 ±12				
Colgate Dentagard Original	78 ± 5				
Candida Multicare 7 in 1	80 ± 3				
RDA-5: RDA >80 (very strong abrasive)		**Ra-5: Ra >1.5 (very strong roughening)**			
Candida White Micro-Crystals	90 ± 10	Colgate Total Original	2.07 ± 1.05		
Signal Anti-Caries	108 ± 6	Signal Anti-Caries	2.22 ± 0.81		
Signal White System	110 ± 14	Candida Multicare 7 in 1	2.44 ± 1.13		
Colgate Total Original	121 ± 7	Candida White Micro-Crystals	3.12 ± 0.93		
		Signal Micro-Granuli	3.42 ± 0.81		
		Candida Fresh Gel	4.52 ± 1.09		
		Signal White System	9.70 ± 0.83		
Standard	100	Standard 1	2.74 ± 1.70	Standard 1	46 ± 14
		Standard 2	4.00 ± 1.83	Standard 2	55 ± 15
		Standard 3	4.95 ± 1.65	Standard 3	50 ± 16