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COMPARATIVE ANALYSIS OF MODERN DENTAL PREVENTION TECHNIQUES IN PERIODONTAL THERAPY AND THEIR INTEGRATION INTO eHEALTH

PhD thesis

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List of abbreviations

MMP-8	matrix-metalloproteinase-8
WHO	World Health Organization
BOB	bleeding on brushing
FMPS	full-mouth plaque score
FMBS	full-mouth bleeding score
PMN-leukocytes	polymorphonuclear-leukocytes
IFMA	immunofluorometric assay
ELISA	enzyme-linked immunosorbent assay
PPD	periodontal probing depth
DMFT-index	decayed, missing, filled teeth-index
AC	alveolar bone crest
CEJ	cementoenamel junction
GCF	gingival crevicular fluid
SBI	sulcus bleeding index
ICT	Information and Communication Technologies

1. Introduction

1.1. Definition and clinical effects of dental biofilm

The World Health Organization (WHO) has declared periodontitis is a chronic inflammatory disease that shares social determinants and risk factors with other systemic diseases, such as cardiovascular diseases or diabetes mellitus. According to the International Workshop for the Classification of Periodontal Diseases and Conditions, gingivitis has two forms: plaque-induced gingivitis and non-plaque-induced gingivitis. Plaque-induced gingivitis, which is associated with inflammation of the gum, has clinical symptoms, such as redness, swelling, and bleeding. Inflammatory disease that affects periodontal tissues causes periodontal tissue destruction. Periodontitis is the sixth most common human disease [1].

The evidence-based clarification of the aetiology and pathomechanism of periodontal disease can be traced back to a study by Herald Löe in 1965 [2]. It was demonstrated that test subjects with healthy gingiva at baseline developed gingivitis within three weeks of stopping mechanical tooth cleaning. (Figure 1)

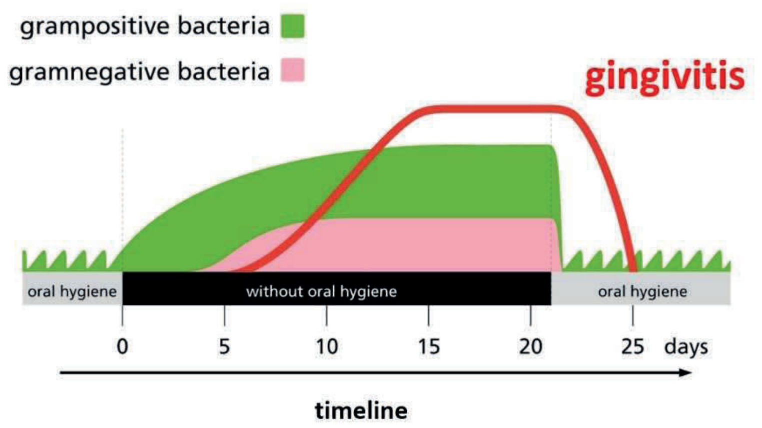

Figure 1: Demonstration of development of gingival inflammation. Figure of Ralf Petersen based on the article by Löe at al. from 1965 [2].

The first clinical sign of inflammation was bleeding. At the same time, it was proven that gingivitis was cured by restoring mechanical plaque control. The study proved that the accumulation of dental biofilm triggers an inflammatory gingival response in almost all

test subjects. After regular biofilm removal, patients would be cured. It was believed that an increase in dental plaque alone is sufficient to cause gingivitis, and without biofilm removal, periodontitis would eventually develop [3].
This formed the foundation of the non-specific plaque hypothesis; however, this paradigm was subsequently revised in the light of research conducted in the 1970s and 1980s. Advances in periodontal microbiology during this period demonstrated that only particular periodontopathogenic bacteria are implicated in the progression of the destructive periodontal process, leading to the specific plaque hypothesis [4], which was re-evaluated after it was confirmed that a significant amount of anaerobic, Gram-negative bacteria are present even in individuals with clinically healthy periodontium. The first breakthrough also challenged the question by a follow-up study by Löe et al., who pointed out that periodontal disease occurred in severe cases among tea plantation workers who did not perform mechanical tooth brushing, never received dental treatment, and lived in primitive, isolated communities [5]. This rate was no worse than in the Scandinavian society, which had an advanced prevention approach at that time, where, despite all prevention programmes, 10-15% of the adult population faced destructive periodontal disease. This prompted the need to search for other systemic risk factors, which led to first epidemiological and later randomised clinical trials focusing on the important role of acquired and genetic factors. It can be said that dental plaque is a necessary and sufficient causal factor in the development of gingivitis; however, mature biofilm alone is not a sufficient causal factor in the pathogenesis of destructive periodontal disease [6]. Furthermore, in the light of the epidemiological data above, less than 20% of adult patients with periodontitis belong to this complex risk group, while 80% of cases are primarily the result of neglected oral hygiene. Mature dental biofilm, calculus accumulation and inadequate dental care lead to gingivitis or periodontitis. This suggests that in 80% of the adult population without genetic or systemic diseases, timely prevention programmes, whether group or individual, can effectively prevent the development and progression of these inflammatory diseases [7].
However, Scandinavian studies of the 1970s proved that although group programmes led to significant improvements in oral hygiene habits and oral health of the population in the first few months, they failed to maintain good oral hygiene in patients in the long term [8].

It became clear that proper oral hygiene could only be maintained with individual motivation, professional oral hygiene treatment, and regular professional supportive treatment repeated up to four times a year, depending on the skill and possible risk factors of the patient.

One of the first evidence-based clinical proofs of this was provided by Axelsson and Lindhe in a Swedish closed community professional oral hygiene programme [9].

In a Swedish community of approximately 600 people, the population aged between 18 and 45 years was randomly divided into two groups. At baseline, everyone underwent a thorough dental screening and professional oral hygiene treatment. The test group had four check-ups a year and one additional professional oral hygiene treatment, whereas the control group had one check-up a year, without professional oral hygiene treatment. Follow-up examinations at year 6 revealed a significant difference between the two groups. A detectable attachment loss was registered in the control group, while a minimal attachment loss was registered in the test group. For ethical reasons, the study of the control group could not be continued, and the two groups were pooled and subjected to four sessions of professional oral hygiene treatment, regular education and motivational training. In the light of the results of the 30-year study, it was clear that attachment loss was minimal in approximately 300 people aged 50 to 80 years who remained within the study, and the number of teeth lost due to periodontal causes was reduced to a few teeth during the entire period. These studies and individual programmes proved that chairside education, motivation and regular recall are the only effective means of both preserving a healthy periodontium and reducing the rate of progression in this high-risk group [10].

Research has predominantly focused on interproximal regions, as it has been demonstrated that neither the most effective manual nor electric toothbrushes achieve adequate cleaning efficacy in these areas. Regular flossing is recommended for young people, and the use of individually sized proximal toothbrushes for older people or those with open interdental spaces.

“Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” [11]. In contrast to this definition by the World Health Organization, dental health should be defined as the state free from an inflammatory process. Periodontal health can be assessed both histologically and clinically. Biofilm-induced inflammation has replaced the original delicate vascular network by loop configurations of gingival capillaries, while clinically, signs of inflammation may not be detected. Even in clinically healthy gingiva, a small inflammatory cell infiltrate can be histologically characterised. It indicates polymorphonuclear leukocyte surveillance. The term clinical health means no attachment loss, no BoP, no sulcular probing more than 3 mm, no redness and no edema. Clinically healthy gingiva demonstrates the absence of visible clinical symptoms of inflammation. Gingivitis is defined as a nonspecific inflammatory reaction to a nonspecific accumulation of plaque that is confined to the gingival tissue, without underlying destruction of the attachment apparatus [12, 13].

Gingivitis is defined, based on the latest evidence and the latest classification, as the normal natural immune response to supragingival biofilm accumulation that exceeds individual thresholds [14]. An increase in periodontal bacteria leads to elevation of cellular transduction and secretion of pro-inflammatory mediators, while the complement system is activated. As long as the natural immune response is manifested in the gingival sulcus, the gingiva remains clinically healthy, although minimal polymorphonuclear leukocyte (PMN-leukocytes) aggregation can be detected histologically in the free gingival margin, and the immune response takes place in the sulcus fluid. Lysosomal enzymes released during phagocytosis, such as matrix metalloproteinase-8 (MMP-8), are discharged into the oral cavity with the sulcus fluid and no tissue damage occurs. When this defence mechanism is exhausted and gingivitis develops, phagocytosing cells penetrate into the tissues of the free gingival margin, collagen degradation processes may begin, the collagen content of the gingiva gradually decreases and the inflammatory exudate increases [15].

Cellular activation can lead to changes in connective tissue and bone metabolism, causing periodontal destruction. The intercellular connections of junctional epithelium are destroyed and bacteria and their metabolic products can penetrate into blood vessels and deeper tissues. Periodontal pockets may form based on the degree of penetration. (Figure 2)

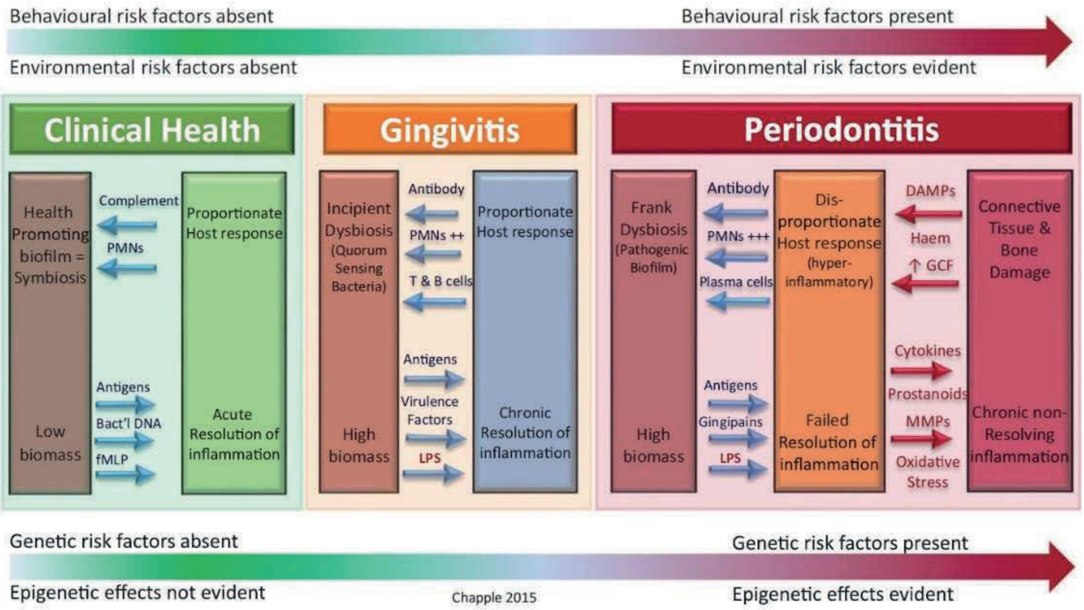

Figure 2: Molecular aspects of the pathogenesis of periodontitis [15].

The diagnosis of gingivitis or periodontitis is based on clinical examination and radiographic assessments of periodontal tissues. Disease-specific biomarkers in saliva as complements to regular clinical and radiographic examinations are of interest in clinical patient care. Saliva contains biomarkers, which raises the possibility of using saliva as a diagnostic tool to detect periodontal disease [16].

When the full mouth plaque score (FMPS) is under 10%, gingiva is considered clinically healthy. Gingivitis is only clinically detectable in over 10%, and above 30%, it is generalised gingivitis [17]. To treat clinically detectable gingivitis, dental health professionals should encourage patient motivation, provide oral hygiene education and perform professional mechanical plaque removal. Below a plaque score of 10%, dental professionals cannot detect gingival inflammatory progresses clinically, but a natural immune response has already occurred and minimal PMN-leukocyte aggregation can be detected histologically in the free gingival margin. During this period, matrix metalloproteinases (MMPs) are heavily involved as they begin to break type I collagen down. Thus, collagenolysis is already taking place in this phase, but clinical signs of gingivitis are not yet visible. The detection of matrix metalloproteinases in saliva, prior to clinical signs, allows for the early diagnosis of inflammatory processes. This may lead to the possibility of starting dental treatment at an early phase in order to reduce the inflammatory process even before the clinical signs appear [13, 17].

1.2. New approaches in clinical diagnostic methods for dental and periodontal destructive processes

The two most prevalent diseases in the oral cavity caused by dysbiosis are caries and periodontitis. The presence of bacteria is constant, but the diseases can only be diagnosed after symptoms have developed [18].

When gingivitis is present or has already progressed to periodontitis, secondary prevention aims to prevent disease recurrence [19].

The most productive indicator for monitoring health, gingivitis or periodontal destruction is the parameter of BoP, which can assess the condition of the gingiva and periodontal tissues. Each tooth is tested at six points using a PCP-UNC 15 periodontal probe at a pressure of 0.25 Ncm. In case of inflammation, bleeding from the sulcus at the probed point is visible after a few seconds. The BoP is used to calculate the full mouth bleeding score (FMBS), which is the ratio of 100 times the total tooth surface area divided by six times the number of teeth:

$$\mathrm{FMBS} = \frac{\text{Total bleeding sites on all teeth}}{\text{Number of teeth} \times 6} \times 100$$

However, BoP is usually measured as a clinical parameter, with histological features of gingival tissues associated with a significantly increased percentage of cell-rich and collagen-reduced connective tissue. Moreover, clinical and histological data suggest that bleeding is an earlier sign of gingivitis than visual signs of inflammation (redness and swelling).

Radiographic assessment forms are a critical component of the periodontal examination. Radiographic features of an anatomically intact periodontium would include an intact lamina dura, no bone loss in furcation areas, and the attachment level is 1.0-3.0 mm from the most coronal level of the alveolar bone crest (AC) to the cementoenamel junction (CEJ) [1]. (Figure 3)

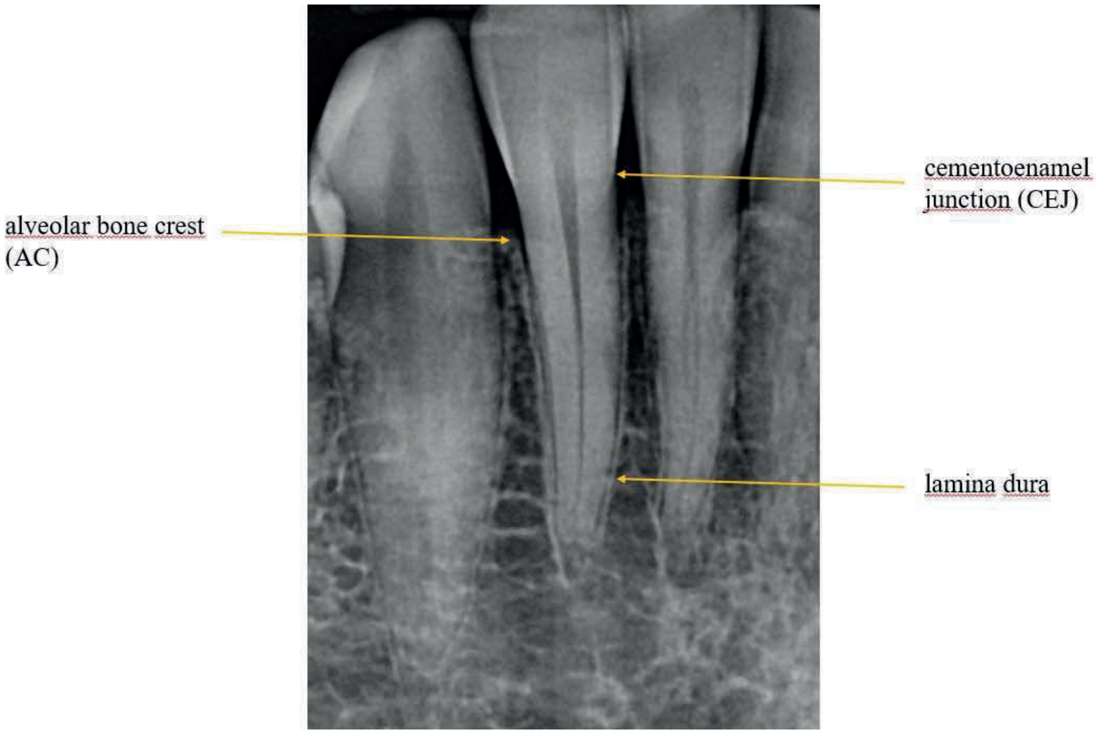

Figure 3: Radiographic findings of lower front teeth from a case of Fanni Simon.

For clinical and radiological examinations, there are a number of imaging options, such as bitewing radiography, fiber optic transillumination (FOTI), digital imaging fiber-optic transillumination (DIFOTI) and quantitative light-induced fluorescence (QLF).
Although these tests are suitable for the diagnosis of developed cariogenic lesions in proximal dental surfaces, they are not suitable for the early diagnosis of lesions to prevent the pathological development [20, 21].

1.2.1. Matrix metalloproteinases-8 (MMP-8)

There are new aspects of clinical examinations that can detect gingival infiltrate as a host inflammatory response even before clinical signs.
With increasing knowledge of the pathophysiology of gingivitis, specific biomarkers have been detected in oral fluids that may help to define inflammatory processes. Among the

most promising biomarkers are inflammatory cytokines, indicators of the inflammatory host response, which can be recovered from gingival crevicular fluid (GCF) and saliva. Saliva is a hypotonic aqueous solution that contains proteins, lipids, hormones, peptides, enzymes, sugars, growth factors and a variety of other compounds. (Figure 4)

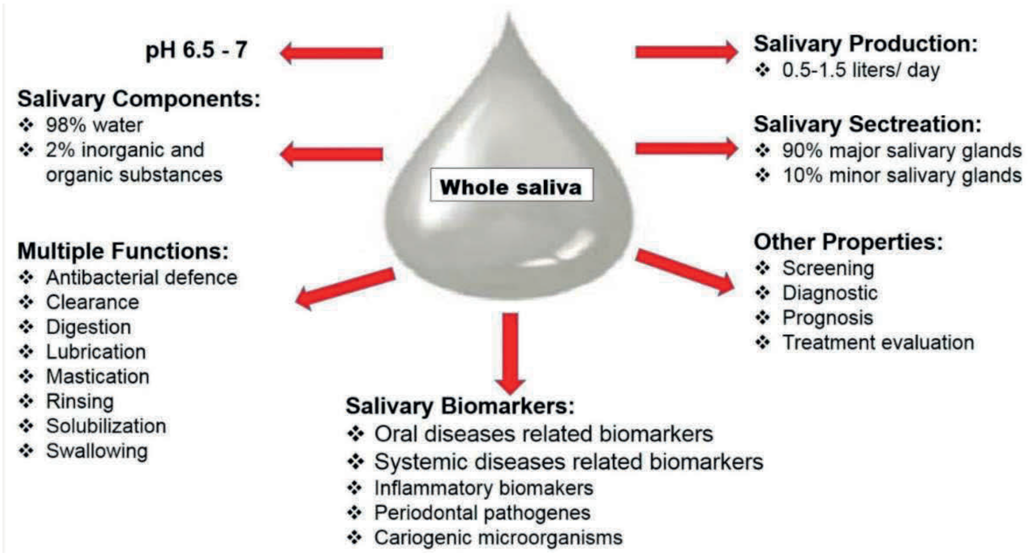

Figure 4: Functions and roles of the saliva [13].

The challenge in dental practice is to detect destructive progression at an early stage. Saliva has the advantage of being an easy and non-invasive way to diagnose periodontal destructive processes. These salivary diagnostics can be performed by biomarker detection, which is easily accessible and economically advantageous. Inflammatory biomarkers such as matrix metalloproteinases (MMPs) are produced in saliva in response to bacterial invasion. MMPs are calcium-dependent, zinc-containing endopeptidases that may play an important role in pathological periodontal processes. MMPs are produced in different forms, in latent, non-active proforms, and are activated extra- or intracellularly, depending on the structure of the MMP molecules.

At present, different forms of MMPs can only be measured under laboratory conditions using tests such as ELISA, Western blotting, immunofluorometric assay (IFMA). With the exception of activeMMP-8 (aMMP-8), which plays a major role in periodontal inflammatory processes and can be measured with chair side technique, this has opened up the possibility of using this measurement method in clinical diagnostics. (Figure 5)

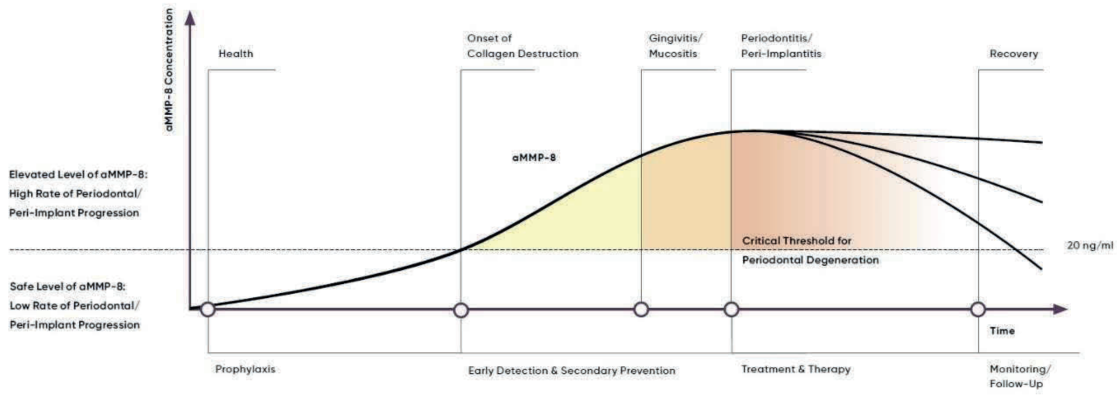

Figure 5: Active MMP-8 level and its role in periodontal processes and therapy [22].

Previous studies have shown that salivary MMP-8 level is associated with loss of attachment in periodontitis [12, 16, 22].

Type I collagen represents the vast component of periodontal extracellular matrix. The activity of collagenases in gingival crevicular fluid is mainly derived from MMP-8 [13, 23]. (Figure 6)

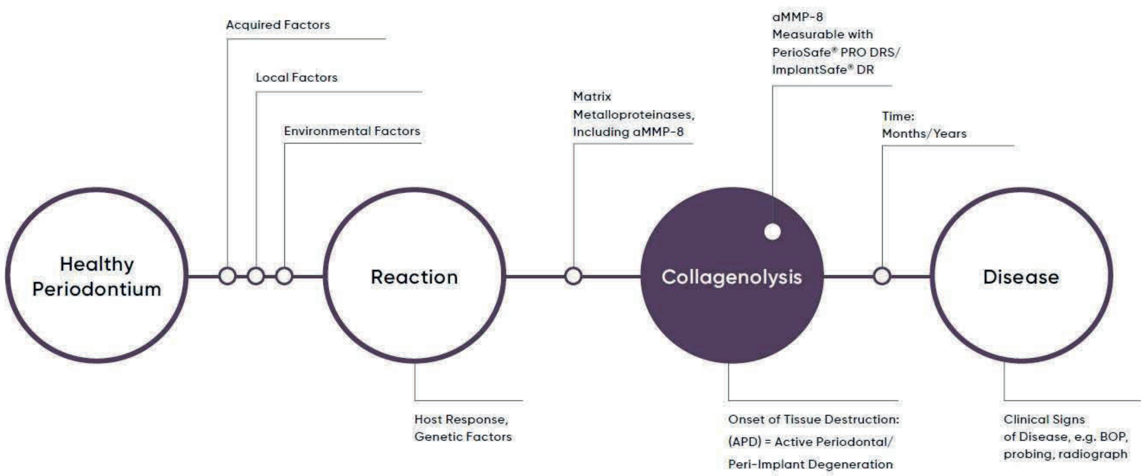

Figure 6: Early detection of collagenolysis [24].

1.2.2. Bleeding on Brushing (BOB)

A variety of periodontal indices have been defined. One such index is the Sulcus Bleeding Index (SBI), which was introduced in 1971 by Muehlemann & Son. The most common index is the BoP, which is designated to detect subgingival bleeding associated with periodontal probing. As the periodontal probe penetrates into healthy tissues and is stopped by the avascular junctional epithelium, it should not induce bleeding. In periodontitis, the probe can indicate bleeding and assess the depth of the periodontal pockets [25, 26].

There are limitations in the diagnosing inflammation in interdental spaces by probing. Most indices do not accurately reflect the state of the col area. Several indices have been developed to assess interproximal inflammation. The first was the Eastman Interdental Bleeding Index (EIBI), which diagnosed the interdental area by horizontal insertion of a wooden stick into the space, leading to trauma of the papillae. Consequently, Hofer et al. opted to use interdental brushes instead of wooden sticks to assess interdental gingivitis. However, as interdental spaces vary in size, standard interdental brushes were often less effective or caused trauma, making it difficult to clearly detect bleeding [27]. Interdental areas are difficult to access by standard diagnostic tools, making the col area susceptible to oral diseases at an early age. BOB presents a solution to this problem by providing valuable information on potentially pathogenic processes in the interproximal area. BOB can become a suitable index for measuring and detecting gingival inflammation. A straightforward and dependable screening method has been developed to identify early pathological changes in interproximal spaces. The BOB-probe, a specialised conical interdental brush, allows for the measurement of interdental areas of varying sizes using a single diagnostic tool. This brush can be gently inserted buccally into the interproximal spaces until slight resistance is felt. After a few seconds, any bleeding in these areas is recorded. The technique of buccally inserting the conical interdental brush into the interdental space, placing it under the contact point and maneuvering with it between the teeth with a jiggling motion, is referred to as the “feather effect”. Bleeding is recorded for each interdental site. The Bleeding on Brushing index can be calculated by determining how much bleeding occurred in the interdental spaces examined.

Due to its conical shape, the BOB-probe is suitable for assessing BOB in most interproximal areas and is less traumatic than a periodontal probe. The results of Rosenauer at al. confirm the superiority of interdental brushes in assessing bleeding indices. Plaque indices usually fail to assess the interdental condition [28]. It has also been emphasised that in young patients with papillae filling the interdental spaces, dental floss is the only tool that can be used to reach in. However, this statement cannot be supported at present. With the basic information (bleeding = inflammation; no bleeding = healthy), intent and outcome could be easily explained to study participants. Interdental hygiene with interdental brushes of sizes appropriate for each individual is superior to flossing. Preventive dentistry should focus on encouraging patients to perform consistent interproximal hygiene in addition to conventional toothbrushing [28].

1.3. Modern dental prevention techniques

In oral health, the goal is to achieve a high quality of life, so the primary aim in dental prevention is to establish a regenerative balance. Dentists generally focus on treating symptoms of developed diseases instead of strengthening primary prevention. Individual and professional prevention is a neglected topic. Dental treatments can cause traumatic experiences that lead to low patient compliance [29, 30].

Both in prevention and treatment, the home behavior and daily routine of patients are essential, which means regular mechanical biofilm removal. For effective tooth cleaning, manual, electric or sonic toothbrushes are suitable for cleaning buccal and oral surfaces. Interdental brushes and dental floss are required for interdental cleaning. Interdental brushes have cylindrical bristles and are available in different widths. Before use, it is essential for dental health workers to select the appropriate size and instruct patients on its correct use. Interdental brushes can remove dental biofilm from the col area and the brushes can penetrate into even the smallest interdental space diameter. Techniques are only effective if dental professionals provide appropriate explanations, individual instructions and practical exercises, which patients then follow. Dental prevention requires a patient-centred approach, and behavioral changes in education. Professional mechanical plaque removal is the responsibility of dental professionals, involving debridement and polishing of tooth surfaces [31].

The use of toothbrushes and electric or sonic toothbrushes is similar to that of small brooms for cleaning smooth surfaces. In contrast, toothbrushes are not suitable for cleaning convex surfaces, fissures, interdental spaces and gingival sulcus. If patients wish to clean convex surfaces only with toothbrushes, they may damage the sulcular area of the clinical crowns of the teeth or the gingiva, e.g., by causing gingival recessions. Our patients were taught the modified Bass technique for toothbrushing [32, 33, 34].

Since the 1960s, numerous studies have shown that dental treatments combined with preventive programmes can enhance dental health and reduce the need for restorative procedures [35, 36].

A 15-year longitudinal study by Axelsson et al. in 1991 indicates that regular recalls every two or three months are essential to maintain effective oral hygiene and patient motivation. The absence of consistent follow-ups significantly contributes to the increase in decayed tooth surfaces and periodontal pockets [37, 38].

1.3.1. SOLO concept (Prophylaxis Concept)

The SOLO concept identifies the bacterial cause of two oral diseases - dental caries and periodontal disease - and provides a therapeutic solution to eliminate them. It also supports long-term control through regular patient education to maintain a high standard of oral hygiene [28].

The Prophylaxis Concept places utmost importance on cleaning the interdental areas and the cervical zone. To achieve this, it offers patients special tools, as well as a theoretical background, to help them achieve individualised and appropriate oral health. The philosophy of SOLO Prophylaxis is based on reducing the number of bacteria that multiply on the non-self-cleaning surfaces of the teeth, using appropriate techniques and special tools for the given task. In deciduous teeth, the interdental spaces are open, so these areas are easier to clean. The first closed interdental spaces develop after the eruption of the first permanent molars. After 24 hours, periodontopathogenic and cariogenic bacteria appear and can induce inflammation in the given area. On the one hand, caries starts on proximal tooth surfaces of contact points. On the other hand, inflammation starts in the direction of the periodontium, with gingivitis and subsequent bone loss. During theoretical education, patients will learn about these processes, after which they will be able to answer the question: what can we do to remove these bacteria? Patients will learn which oral hygiene tools are recommended for their individual needs and how to use them. Patients will also learn about the concept of BOB and be able to consciously control their oral condition. In order to maintain this condition, periodic check-ups by dentists and dental hygienists are essential. Teeth have non-shedding surfaces, which leads to bacterial colonisation, mainly in dental niches such as fissures, gingival margins, and col area, where bacteria cause cariogenic destructive processes. The aim of mechanical biofilm removal is to prevent oral microorganisms from colonising. There is a large body of evidence on the effectiveness of toothbrushes on dental surfaces, but only limited evidence on the anti-caries effect of interdental cleaning. A meta-analysis on approximal cleaning showed that the use of interdental brushes in addition to toothbrushing reduces gingivitis, with the greatest anti-inflammatory effect being seen when using floss, toothpicks or oral irrigators [28, 39].

There are numerous dental care tools available to patients, but their effectiveness in cleaning teeth depends on their personalised use, assessed by professionals. Reliance on toothbrushes alone prevents patients from adequately removing plaque from areas such as interdental spaces. Flossing and interdental brushing are recommended to effectively clean these areas, even if the gingival papillae are intact. For effective plaque removal, the interdental brush should completely occupy interdental spaces, ensuring that bristles are in contact with tooth surfaces and in line with the centre of the space [39, 40].

A toothbrush manufacturer, in collaboration with SOLO-MED GmbH, has conducted a practical study to test the “feather effect” of interdental brushes.

The company produced a metal sheet into which circles of different sizes were carved. The diameters of the circles were increased by 0.1 mm. (Figure 7)

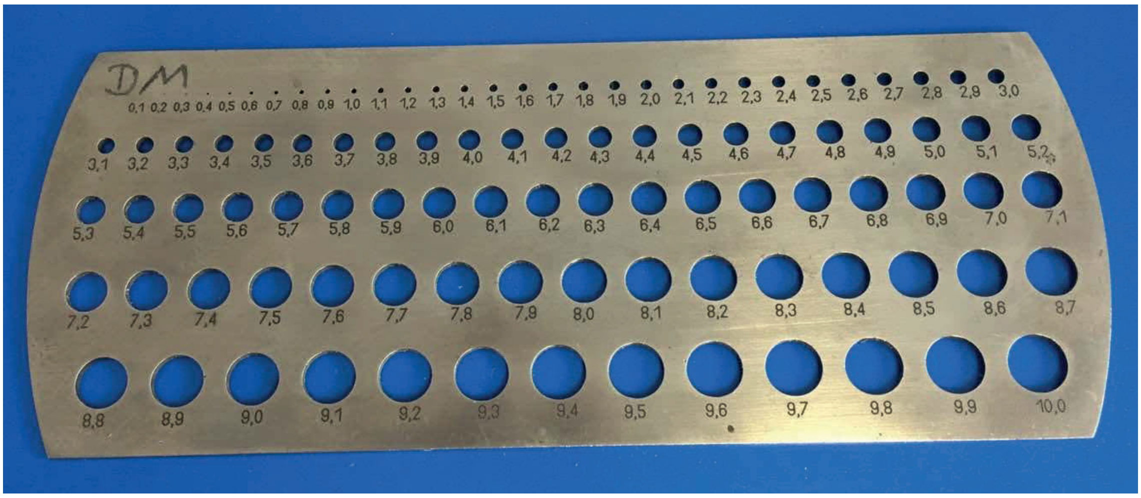

Figure 7: Metal sheet tester for “feather effect. Photograph by Ralf Petersen

This allowed them to simulate all possible interdental sizes. On this metal sheet, they could test all types of interdental brushes (commercially available brushes and their own SOLO-STIX interdental brushes), which could be used to achieve the “feather effect” in every circle.

The company summarised the results in Figure 8. Only their interdental brushes could fill all carved circles, providing the right size of interdental brushes for every possible interdental space.

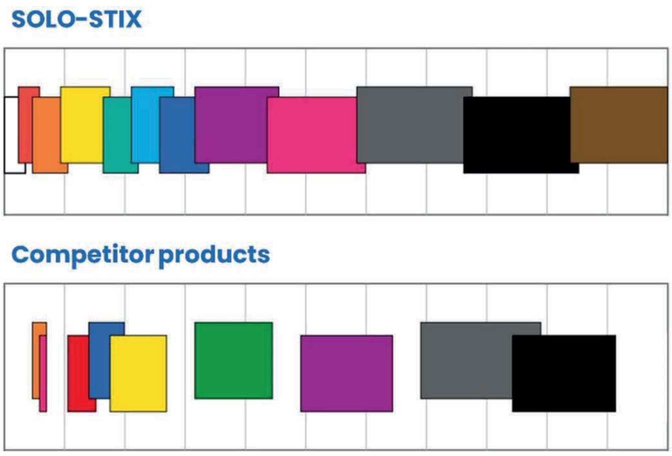

Figure 8: Comparison chart of SOLO-STIX and other interdental brushes available on the market (competitor products). SOLO STIX could fill all carved circles. Illustration by Ralf Petersen

With the use of properly sized interdental brushes, bristles can effectively reach all surfaces in the interdental spaces. The jiggling motion of the interdental brush allows the bristles to move back and forth, sweeping away dental biofilm and bacteria from these spaces. In this way,e the daily physical removal of bacteria prevents bacterial colonisation and the development of inflammation.

BOB can detect whether the interdental spaces are inflamed, so patients use interdental brushes regardless of whether they are properly sized ones or not [28].

The morphology of the col area (Figures 9 and 10) indicates that the "feather effect" can only be achieved with interdental brushes, making flossing potentially less effective in cleaning the interdental spaces.

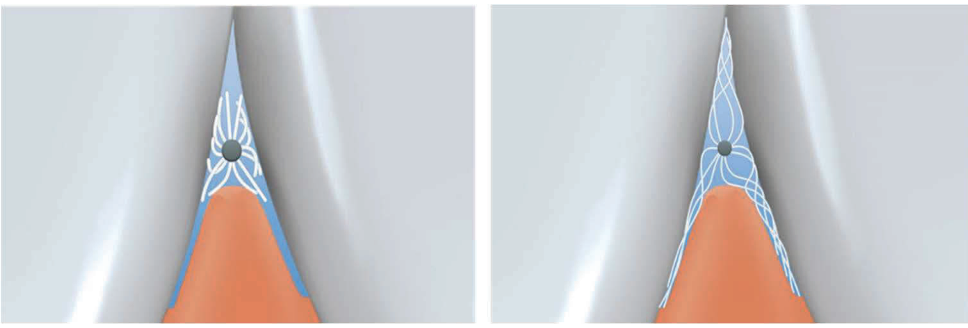

Figure 9: Importance of the "feather effect in interdental spaces due to the morphology of the col area. Pictures by Ralf Petersen

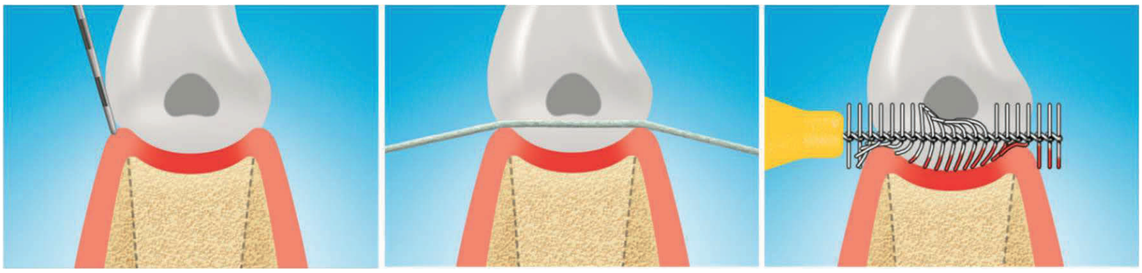

Figure 10: Effectiveness of different interdental tools. (Probe, floss and interdental brush. Pictures by Ralf Petersen

Flossing can cause more damage, such as flossing clefts, and is generally more difficult to use correctly compared to interdental brushes. However, both types of interdental devices can reduce gingivitis if accompanied by professional training that includes motivation and education. Evidence supports the effectiveness of interdental brushes in preventing gingivitis and even in treating periodontitis, although fewer studies have shown their beneficial effects due to inadequate short follow-up periods [41].

1.4. Teledentistry opportunities

Health care systems are challenged to adapt to a rapidly evolving socioeconomic, ecological, technological, demographic, and epidemiological environment. The rise of information and communication technologies (ICT) offers the potential to enhance the effectiveness, efficiency, and equity of modern health systems. However, these technologies also present significant external challenges that health systems need to address. Consequently, the adoption of digital health solutions is not merely an opportunity for improvement; it also serves as a powerful catalyst for change that disrupts traditional organisational and operational structures in healthcare delivery. In the administration of healthcare services, ICT has a significant potential to boost efficiency through various functions such as appointment management, patient notifications, patient information management, service documentation, and prescriptions. However, emerging technologies extend beyond merely replacing paper documentation with electronic formats. Teledentistry, a specialised branch of telemedicine that focuses on dental care, encompasses not only clinical practice but also research, education, and management within the field. Teledentistry has significant potential to enhance access to oral health specialists by streamlining traditional in-person dental care and utilising ICT to develop innovative models of care. For instance, patient education and preventive measures can be facilitated through video streaming platforms that provide information on various dental conditions under medical supervision [42].

2. Objectives

The first aim of our study was to assess the effectiveness and role of individualised oral hygiene education in oral cavity prevention and periodontal inflammation in patients who attended our Department (Department of Public Dental Health, Semmelweis University) with various dental problems between 1 September 2020 and 30 April 2023. On the other hand, we investigated the effectiveness of teledentistry opportunities in order to integrate it into dental, periodontal and preventive dental care. Different oral hygiene tools and programmes were compared and tested for effectiveness.

One of the questions to be answered was how to keep patients motivated and how to maintain a high level of oral hygiene in the long term. Data were recorded using digital documentation and preventive care software.

Studies were conducted to test new clinical diagnostic techniques in order to diagnose the two main diseases (caries and periodontitis) at earlier phases.

3. Methods

Dentists and dental hygienists specialising in prevention and periodontology participated in the study, which was conducted at the Department of Public Dental Health, Semmelweis University, Hungary, from 1 September 2020 to 30 April 2023. The study was approved by the Regional and Institutional Committee of Science and Research Ethics and the Hungarian Office of Health Authorization and Administrative Procedures and was conducted in accordance with the Declaration of Helsinki. (Nr: ETT-TUKEB IV/9854-1/2021/EKU). All patients provided written informed consent prior to participation. During data collection between 1 September 2020 and 30 April 2023, all authors had access to information that could be used to identify individual participants.

3.1. Patient selection

Subjects were selected from patients treated at the Periodontology and Prevention Department of the Department of Public Dental Health. Participation in the study was voluntary, with a total of 102 subjects included. (Table 1)

Table 1: Inclusion and exclusion criteria for the study

Inclusion criteria	***Exclusion criteria***
Over 18 years of age	Smoking
Minimum six interdental spaces in the mouth	Under 18 years of age
	Patient undergoing orthodontic treatment
	Pregnancy
	Patients with less than six interdental spaces
	Medicines containing bisphosphonates
	Diabetes
	Patients with pacemaker devices
	Infectious diseases (HIV, Hepatitis C)
	Cancer patients (radiotherapy, chemotherapy)
	Mentally or physically disabled patients
	Stage IV, Grade C periodontitis

Participants received a patient information sheet and a consent form to sign if they agreed to the terms. Subjects were then divided into two groups (A or B) based on their periodontal status as determined through clinical and radiological assessments. Patients diagnosed with gingivitis were assigned to group A, while those showing signs of periodontal destruction were assigned to group B. These groups were further subdivided into four subgroups (1, 2, 3, and 4) based on their oral hygiene practices and the cleaning tools they used (A1, A2, A3, A4, B1, B2, B3, and B4). Random assignment to treatment groups was not feasible as most participants adhered to their existing oral hygiene routines. Even when informed about potentially better cleaning methods during the study, many were unable to change their habits. Additionally, it would have been unethical to assign participants to a group that used a less effective cleaning method than the one they had already been employing. Nevertheless, participants were keen to assess their current cleaning methods to determine whether they could achieve adequate oral hygiene based on the study criteria. At the start of the study, some patients in each group expressed a willingness to switch to the preferred cleaning method (A1 and B1). By the end of the study, all participants received education on the preferred oral hygiene practices, ensuring that no discrimination occurred. The Prophylaxis Concept (A1 and B1) included a specific protocol detailing tooth morphology, bacterial colonisation sites, and practical training on the use of interdental brushes and single-tufted toothbrushes manufactured by SOLO-MED GmbH. Clinical and radiographic examinations indicated that patients in group A exhibited no periodontal damage or bone loss, only clinical signs of gingivitis. In group A, alongside the four subgroups (A1, A2, A3, and A4), there was a category of "Patients with subclinical symptoms," for which the periodontal probing depth (PPD) was 4 mm or less and FMPS and FMBS values were below 20%. These patients showed no clinical signs of gingivitis; therefore, BOB and MMP-8 values could be assessed to diagnose any pre-existing inflammatory processes. In subjects of group B, radiological and clinical examinations revealed bone loss along with PPD values of 5 mm or more. Participants in subgroups A1 and B1 attended a lecture on the Prophylaxis Concept, which covered the Solo Prophylaxis philosophy and instruction on how to use individualised oral hygiene tools of the system. Meanwhile, patients in subgroups A2 and B2 used other commercially available interdental brushes, as well as tufted toothbrushes and manual toothbrushes. Patients in subgroups A3 and B3 used electric or sonic toothbrushes along with any other commercially available interdental brushes or dental floss. Lastly, patients in subgroups A4 and B4 relied exclusively on manual toothbrushes for their oral hygiene. (Figures 11 and 12)

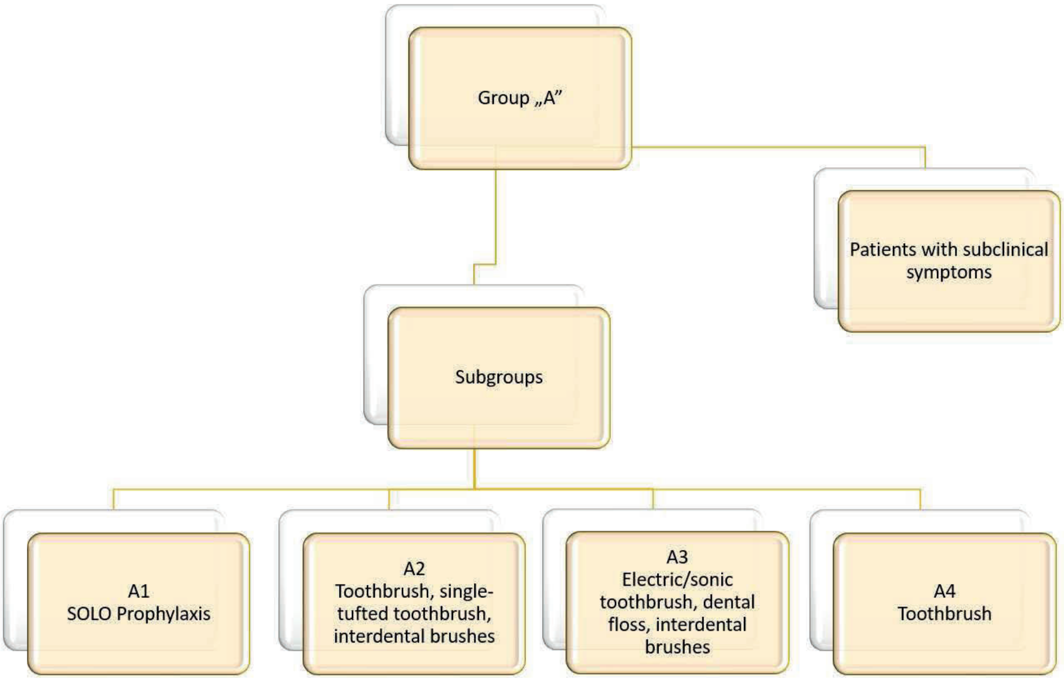

Figure 11: Group A (patients with gingivitis) and subgroups

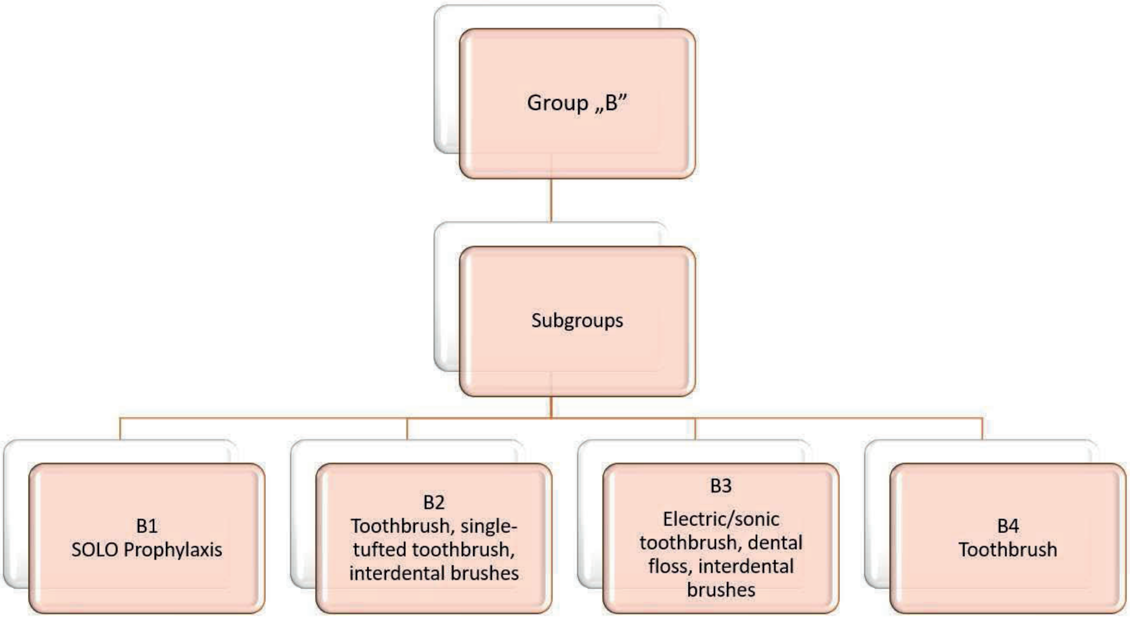

Figure 12: Group B (patients with periodontitis) and subgroups

3.2 Procedure

3.2.1 Measurements

After an initial stomato-oncological, clinical, and radiographic assessment was performed, four primary parameters were documented at predetermined intervals, which are described in detail below. Orthopantomogram radiographs were used to evaluate teeth and bone levels, as well as to assess periodontal status for group inclusion. The periodontal status of patients was categorised based on the Staging and Grading outlined in the Classification of Periodontal and Peri-Implant Diseases and Conditions (2017).
Prior to group assignment, all oral hygiene toolkits were introduced to all subgroups during the initial examination. Patients selected the toolkits they would use throughout the study and were instructed on their proper use. During this first visit, study team members informed patients about the significance of cleaning interdental spaces and optimising their devices based on their oral hygiene practices, while introducing them to the Prophylaxis Concept. Patients were instructed on how to use toothbrushes according to the modified Bass technique. They were shown how to properly use interdental brushes and which sizes were suitable for each interdental space. Educational videos were employed to illustrate tooth morphology and surface cleaning techniques, with an emphasis on the importance of maintaining non-self-cleaning tooth surfaces. Additionally, patients attended lectures on the prevention of bacterial infections in the oral cavity and underlying causes of periodontal tissue issues.

3.2.1.1. MMP-8

The first measurement focused on MMP-8 levels, a neutrophil collagenase involved in breaking down types I, II, and III collagen. Elevated MMP-8 levels serve as an early marker of periodontal tissue destruction and indicate inflammation even before it becomes clinically visible at the gingival margin. MMP-8 is not limited to interproximal spaces; it is also present in saliva, which contains gingival crevicular fluid. The presence of MMP-8 may indicate inflammatory processes in the gingiva due to bacterial invasion. As interproximal areas consist of non-self-cleaning tooth surfaces where inflammation often initiates, MMP-8 levels may rise rapidly and be released into the saliva through gingival crevicular fluid. The PerioSafe PRO DRS Test System was used to measure MMP-8 levels via a chairside test based on the enzyme-linked immunosorbent assay (ELISA). The test identified activated MMP-8 fragments ranging in sizes between 20 and 35 kDa. [43] Subjects were required to avoid eating, drinking, toothbrushing and using mouthwash at least 60 minutes prior to the test. Patients rinsed their mouths with saline, aspirated a sample with a syringe, and placed it on a test tray, which was then analysed by a machine to quantify MMP-8 levels in saliva, expressed in ng/ml. This system measures MMP-8 levels between 10 and 400 ng/ml. According to the recommendation of the manufacturer of the PerioSafe System, MMP-8 levels were measured in different ranges. The healthy range is a concentration under 10 ng/ml, as active periodontal degeneration is between 10 and 20 ng/ml and the inflammatory tissue destruction exceeds 20 ng/ml [44, 45]. An interval table classified collagenolysis as minimal, elevated, or advanced/severe based on these results. The concentration of MMP-8 in sulcus inflammatory exudate was the only objectively measurable marker indicating inflammation severity [46, 47].

3.2.1.2. BOB

The second of the four measurements was BOB, a novel method to assess the number of bleeding interdental spaces in response to stimulation. Bleeding is used as a clinical indicator of inflammation. The measurement tool was a specially designed interdental brush, DiagnoSTIX, manufactured by SOLO-MED GmbH (Figure 13) as part of the Solo Prophylaxis concept. DiagnoSTIX was applied individually to each interdental space, with bleeding recorded as the number of affected sites out of the total examined (e.g., 13 out of 20 spaces exhibited bleeding) [28].

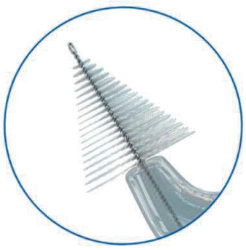

Figure 13: DiagnoSTIX [28]

3.2.1.3. FMPS

The third and fourth measurements used a periodontal chart referenced by the School of Dental Medicine, University of Bern (periodontalchart-online.com), with assessments conducted during the examination of each patient at the appointments. FMPS was recorded at six points per tooth during full periodontal assessments. This score was the percentage of plaque sites compared to all evaluated sites. The PCP-UNC 15 periodontal probe (manufactured by Falcon Medical Polska Sp. Z o. o., Lodz, Poland) was also employed for this measurement [47].

3.2.1.4. FMBS

BoP values were recorded at six points per tooth during comprehensive periodontal examinations. FMBS was calculated by determining the number of bleeding sites from all probed sites and converting this figure into a percentage. The PCP-UNC 15 periodontal probe was used for these measurements [47].

All data from patients participating in the follow-up study were documented by using an application developed in collaboration with the University of Óbuda for streamlined record keeping.

3.2.2 Conservative Therapy

All patients in each group participated in examinations during their initial appointment and subsequently at weeks 2, 4, and 12. Professional oral hygiene treatment was provided at every visit following the measurements (Figure 14).

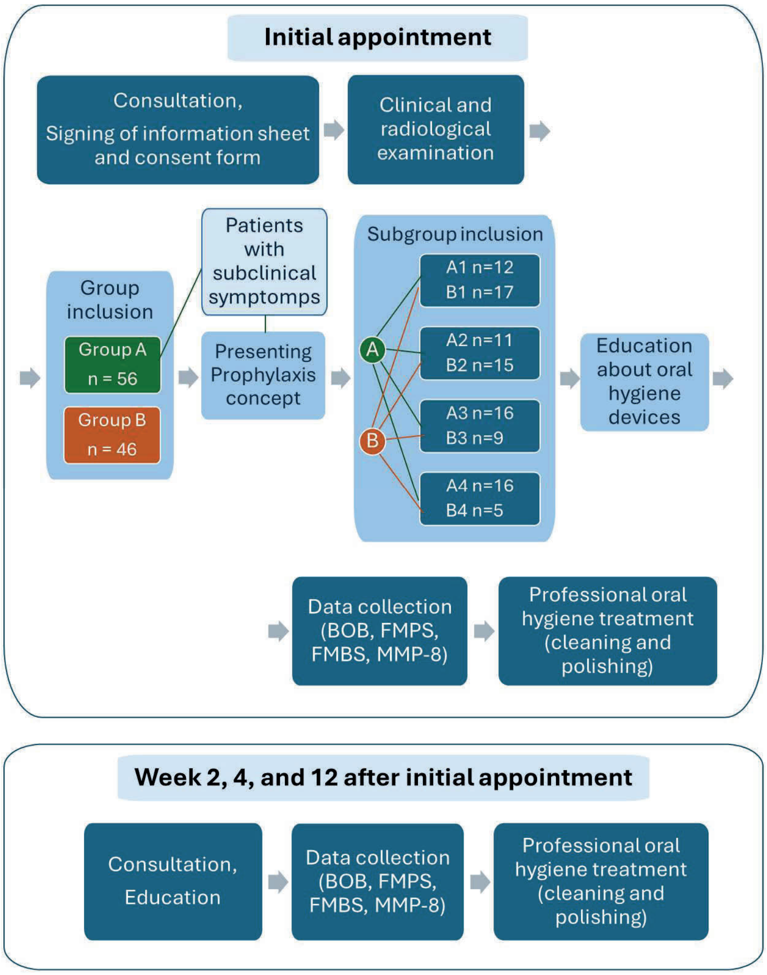

Figure 14. Flow chart of the study process [48]

3.2.3 Patients as subgroup changers

As mentioned above, for ethical reasons, the patients started the study in the same subgroup as the brushing method they had been using. Patients whose scores had deteriorated after the first 12 weeks were switched to our preferred subgroups A1 or B1. They were then re-recorded for three months at the same time and in the same way as in the initial methodology. In this case, the measured data of the 12-week results became the initial measurements for the subgroup change. (A1 and B1)

Ten patients changed oral cleaning instruments after three months (A3: two patients, A4: two patients, B2: three patients, B3: one patient, and B4: two patients).

The remaining patients with good results were allowed to stay in their subgroups and continue the therapy and long-term follow-up.
(Figure 15)

3.2.4 Long-term follow-up

After the initial three-month phase, patients in group A were allowed to continue the study and enter the long-term follow-up phase. In this case, patients were examined at months 6 months, 9, years 1, 1.5 and 2.
After the conservative therapy in the first three-month phase, patients in group B underwent the necessary periodontal surgical interventions. All patients in group B except one were recommended to undergo resective and regenerative periodontal surgery. After surgical therapy, in the maintenance phase, patients underwent measurements at months 3, 6, 9, years 1, 1.5 and 2.
(Figure 15)

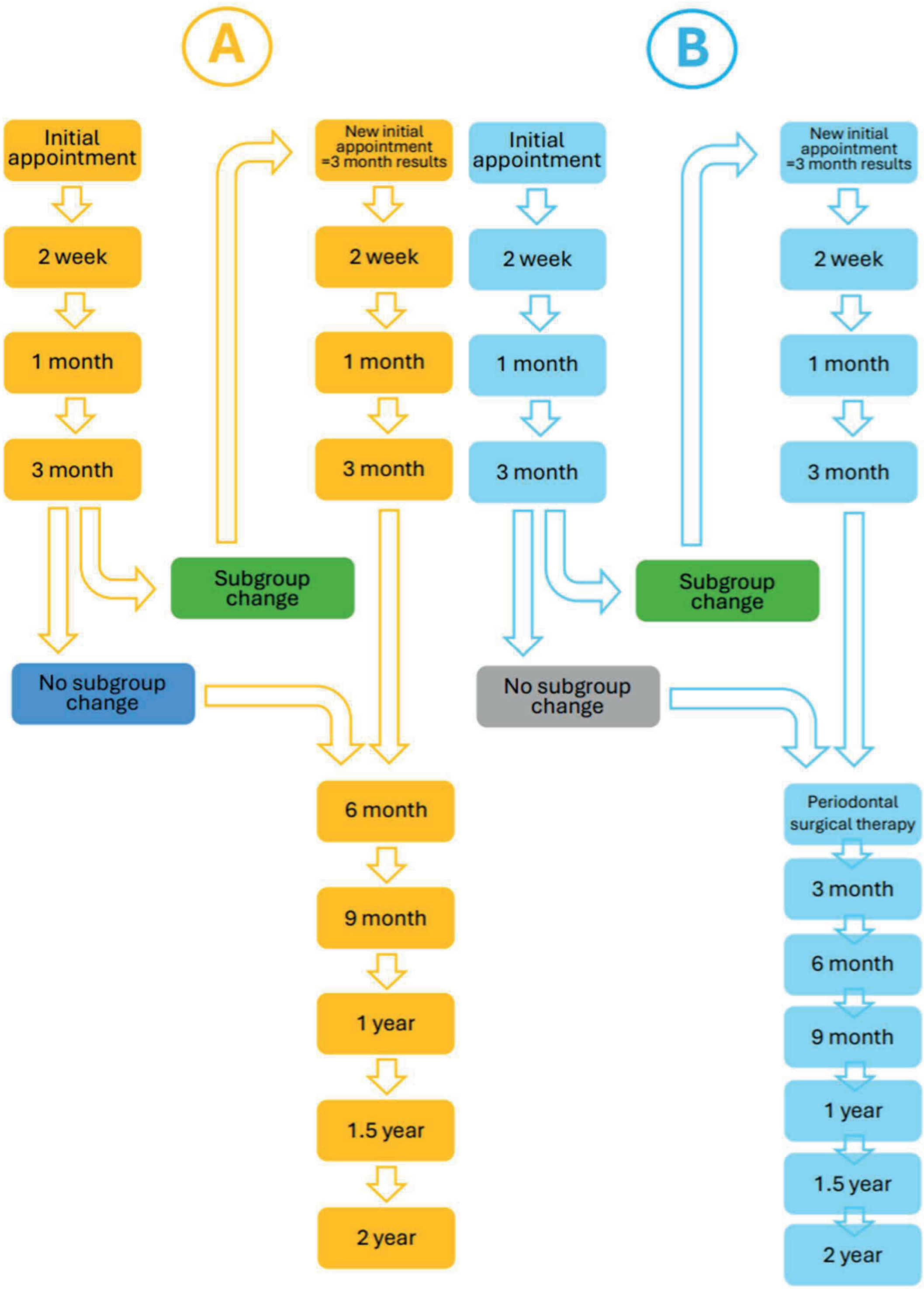

Figure 15: Flow chart of the entire study process of Groups A and B

3.3 Data collection

Table 2: Participants of the study

Subgroups	Gender	Patient number
A1	male	4
	female	8
A2	male	3
	female	8
A3	male	5
	female	12
A4	male	9
	female	7
B1	male	5
	female	12
B2	male	7
	female	8
B3	male	4
	female	5
B4	male	1
	female	4

The study involved 102 participants, 38 male and 64 female individuals. (Table 2) In group A, 21 participants were over the age of 40 years, while 35 were younger. Of the 46 patients in group B, 42 were older than 40 years. During the initial assessment, the study team and dental professionals instructed patients on how to optimise device use based on their oral hygiene practices and introduced them to the Prophylaxis Concept. Patients returned for follow-up visits at weeks 2, 4, and 12 after their first appointment for reassessment and professional oral hygiene treatment. Measurements of MMP-8, BOB, FMPS, and FMBS were taken at each visit. Notably, there were no dropouts among the 102 participants.

All participant data were documented in two applications. The first one was a personalised program used on tablets chairside during the examinations. This program was created and designed in collaboration with the University of Óbuda. This application allowed us to digitally document the complete periodontal status and the calculation results of FMPS and FMBS. It also recorded BOB and MMP-8 values. This program had the potential to fully eliminate the need for paper-based dental medical history and collect all the essential data needed for dental care in a single digital space.

In the study, we used a second application, supported by SOLO-MED GmbH (https://solo-app.com/web; Trier, Germany), which allowed us to record the size of the interdental brushes used to clean the interdental spaces of the patient. The application serves not only as a documentation tool for healthcare professionals, but it is also available to patients. It allows patients to record at home the size of the toothbrush they needed to use for each appliance, how much BOB they had and when their next appointment was. (Figure 16)

Additionally, both programs can be scaled up and integrated with other programs, allowing them to be used in any teledentistry setting.

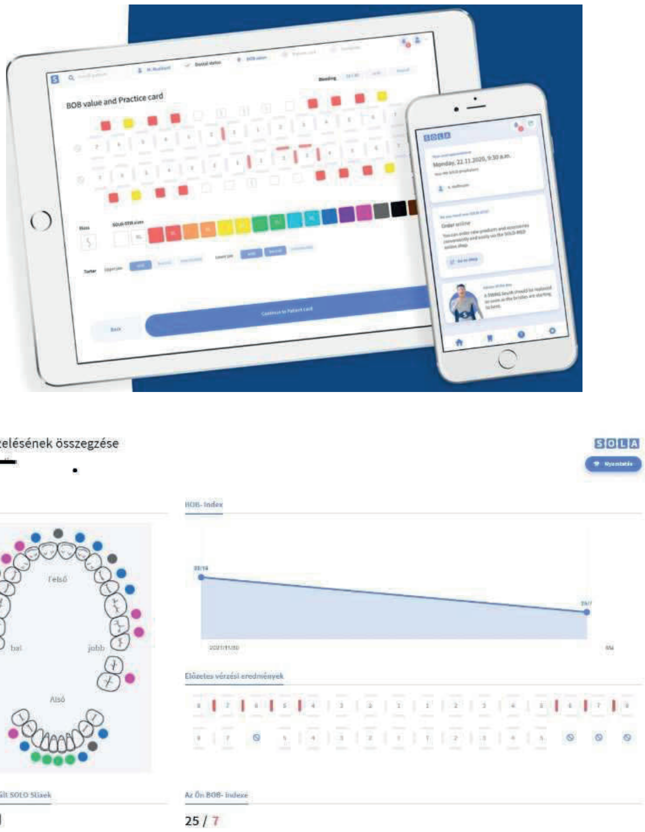

Figure 16 a, b: Pictures of SOLA application from https://solo-app.com/web

3.4 Statistical analysis

The study team of six investigators underwent joint training to ensure consistent interpretation of results, using test photographs and guidelines from the WHO Oral Health Surveys: Basic Methods—5th edition. Their measurements were standardised and validated by using the Fleiss kappa test, which yielded a high reliability score of 0.9, indicating excellent agreement between the evaluators in diagnostic and examination procedures [11].

3.4.1 Conservative therapy

To evaluate the impact of various oral hygiene techniques on MMP-8, BOB, FMPS, and FMBS values, we used generalised linear mixed-effects models (GLMMs) through R version 4.3.3 with the glmmTMB package [49, 50, 51].

Patients in groups A and B were analysed separately, alongside a cohort with subclinical symptoms. MMP-8 levels, BOB, FMPS, and FMBS values served as dependent variables in distinct models across different time points (initial appointment, weeks 2, 4, and 12 later) and subgroups (1, 2, 3, 4), with their interactions incorporated into all models. To capture individual variations, we included the patient ID as a random factor in each model. For MMP-8 analysis, we employed models with a Gamma distribution and log-link function. Six patients (four from B2 and two from B1) had values above 400 ng/mL, whereas three patients (one each from A2, A4, and B2) had values below 10 ng/mL at certain times; these were excluded from the MMP-8 analysis. In our approach, we modelled the percentages of BOB, FMPS, and FMBS values by using a binomial framework (indicating bleeding or plaque presence versus absence). To mitigate overdispersion issues, we adopted the betabinomial model family. Our model selection was guided by the Akaike Information Criterion (AIC) for all models [52].

We systematically eliminated explanatory variables to identify the candidate model with the lowest AIC value, considering a model superior if its AIC was lower by at least 2. Main effects were retained until their interactions were evaluated. In cases where AICs of two or more models differed by 2 or less, we opted for the simpler model. This process continued until an optimal model fit was achieved. We used Wald χ^2 statistics to generate ANOVA-style tables. All executed models are available in the Supplementary Materials, including detailed outcomes of final models and post-hoc tests. Residual analysis and model validation were conducted by using the Dharma package, [53] following the methodology by Smith and Warren (2023). [54] Post-hoc contrasts were computed by using the emmeans package, [55] applying Sidak correction for multiple comparisons. Data collected at various intervals were analysed by using R version 4.2.3 (R Core Team 2022) [49].

3.4.2 Patients as subgroup changers

We used general linear mixed models (GLMMs) to investigate the temporal patterns of MMP-8, BOB, FMBS and FMPS. We ran separate models for each dependent variable. Time was a predictor (initial value, value after months 3 and 6 after initial treatment, which was 3 months after changing subgroups). We used gamma-family for MMP-8, beta-binomial for BOB and FMBS, and a binomial model for FMPS. Patient ID was included in the models as a random factor. All analyses were conducted in R version 4.3.3 (R CoreTeam, 2024), [49] with the glmmTMB v 1.1.9 package. [50] Post-hoc pairwise comparisons were calculated by applying the Tukey-method in the emmeans v 1.10.3 package [54].

3.4.3 Long-term follow-up

We used general linear mixed models (GLMMs) to investigate the temporal patterns of MMP-8, BOB, FMBS and FMPS. We ran separate models for each dependent variable. Groups A and B were analysed in separate models. In group B, only subgroups B1 and B2 were analysed due to the low sample sizes in subgroups B3 and B4. Subgroup and time were used as predictors (months 3, 6, 9, 12, 18 and 24 after the first appointment). We used a gamma-family for MMP-8, a binomial for BOB, and a beta binomial model for FMPS and FMBS. Patient ID was included in the models as a random factor. All analyses were conducted in R version 4.3.3, [49] with the glmmTMB v 1.1.9 package

[50]. Post-hoc pairwise comparisons were calculated by using the Tukey-method in the emmeans v 1.10.3 package [54].

3.5. Teledentistry survey method

The present study is grounded in a comprehensive survey of dental care services provided by the Oral Medicine Unit, the Periodontology Unit, and the Orthodontics Unit within the Department of Public Dental Health, Semmelweis University, Budapest. This investigation focuses on the comparison of the duration of dental examinations and diagnostic procedures conducted through traditional in-person consultations versus those facilitated by teledentistry platforms. The Oral Medicine Unit operates regular clinical hours from 8:30 a.m. to 2:00 p.m. and from 2:30 p.m. to 8:00 p.m. five days per week, offering tooth-preserving treatments, dental prosthetics, and management of oral mucosal diseases. Over a 12-week period, data were collected on the scheduling of 539 conventional patient visits and 592 visits conducted as part of a pilot teledentistry programme. The objective was to quantify potential time savings that could be achieved by the implementation of teledentistry technologies across all eligible patient encounters. Each episode of care is generally divided into two primary phases: the administrative phase and the treatment phase. The administrative phase encompasses patient registration at the coordination desk, documenting the visit within the medical information system of the university, and scheduling follow-up appointments after the procedure is completed. The treatment phase can be broadly divided into two groups: either direct clinical interventions, such as dental restorations or root canal therapy within primary dental care, and tooth extractions within dentoalveolar surgery or consultative services. Consultations may include patient monitoring, preventive guidance, treatment adjustments, and certain diagnostic procedures that do not necessarily involve direct physical contact with the patient. A considerable proportion of patient encounters in specialised dental disciplines, such as orthodontics, periodontology, and oral medicine consist primarily of these consultative activities.

Within the scope of this study, we initially categorised the types of dental visits that can be either supported or entirely substituted by teledentistry. Three primary methodologies were examined. The first approach, commonly referred to as “store-and-forward,” involves the electronic storage of patient data, such as physiological measurements, clinical notes, and various photographic or video records, which can subsequently be accessed by a specialist at a remote location. This technique is well-established and extensively used in the evaluation of diagnostic imaging.

In contrast, the second approach entails real-time consultation, exemplified by video-conferencing sessions that enable synchronous information exchange between participants in different geographical locations. This modality proves particularly beneficial for consultations related to periodontal therapy or dysgnathic surgical procedures.

The third approach, "remote patient monitoring," is a hybrid model that combines elements of the previous two methods. In this scenario, biometric data are either pre-recorded and made available during the consultation or recorded live during the session using specialised equipment [56, 57, 58, 59]. These teledentistry techniques have the potential to enhance efficiency by either reducing the duration of clinical encounters or replacing conventional face-to-face visits with virtual consultations. For example, recall examinations may be effectively conducted through the use of intraoral camera images or smartphone photographs [60,61]. Furthermore, telemedicine platforms facilitate consultations and the exchange of second opinions, thereby broadening access to specialist dental care.

By delineating the types of visits suitable for teledentistry, we established three distinct categories: preventive care, remote patient monitoring, and other consultations. For the purposes of this study, we identified cases suitable for remote patient monitoring across three dental specialties: orthodontics, periodontology, and oral medicine. During the data collection phase, a total of 155 in-person orthodontic visits, 187 periodontologic visits, and 197 oral medicine visits were recorded in two shifts over a 12-week period. The average duration per patient was subsequently calculated for each specialty. A similar data collection was performed for a pilot telemedicine program, encompassing 184 orthodontic, 200 periodontologic, and 208 oral medicine visits, all conducted virtually via a locally developed application. A comparative analysis was then undertaken between in-person and telemedicine settings to evaluate differences in time efficiency and resource utilisation.

4 Results

4.1. Conservative therapy

4.1.1. Patients with subclinical symptoms

A total of 29 patients presented with subclinical symptoms, including 19 females and 10 males, distributed across subgroups as follows: 7 in subgroup A1, 6 in A2, and 10 in A3. One patient in B3 was excluded from further analysis. BOB values showed a significant reduction at the week 2 of follow-up ($p > 0.0001$, Figure 17a). Two patients had MMP-8 levels below 10 ng/mL and were thus excluded from the analyses. MMP-8 chairside test measured between 10 and 400 mg/mL, so the exact values above and below were not visible, and therefore could not be analysed. There was no significant impact of time or group on MMP-8 levels (all $p > 0.5$). Between appointments, FMPS values decreased significantly ($p = 0.036$; Figure 17b), while FMBS values showed only a slight decrease ($p = 0.055$, Figure 17c) throughout the study period.

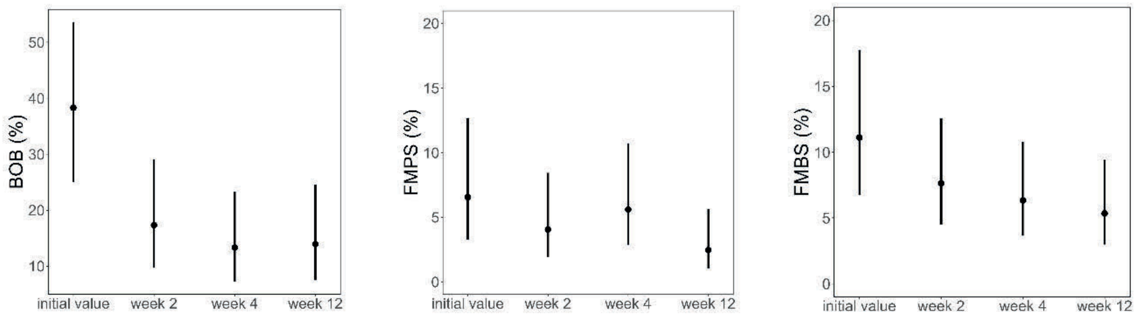

Figure 17. (a) BOB, (**b**) FMPS, and (**c**) FMBS values as percentages of patients with subclinical symptoms before and at weeks 2, 4, and 12 after treatment. Dots and lines represent estimated means ± standard deviations [48]

4.1.2 Patients with gingivitis (group A) and patients with periodontitis (group B)

4.1.2.1 MMP-8

In group A, the evaluation of MMP-8 levels indicated significant effects related to time ($p = 0.004$), subgroup ($p < 0.0001$), and the interaction between subgroup and time ($p = 0.008$; see Figure 18a). While MMP-8 levels showed a reduction only in subgroup A4, there were initial differences in MMP-8 levels across the subgroups. Specifically, subgroups A1 and A2 exhibited lower MMP-8 levels compared to subgroups A3 and A4. In group B, a marginal difference was observed between subgroups ($p = 0.083$, see Figure 18b), suggesting that a larger sample size might highlight this difference more clearly.

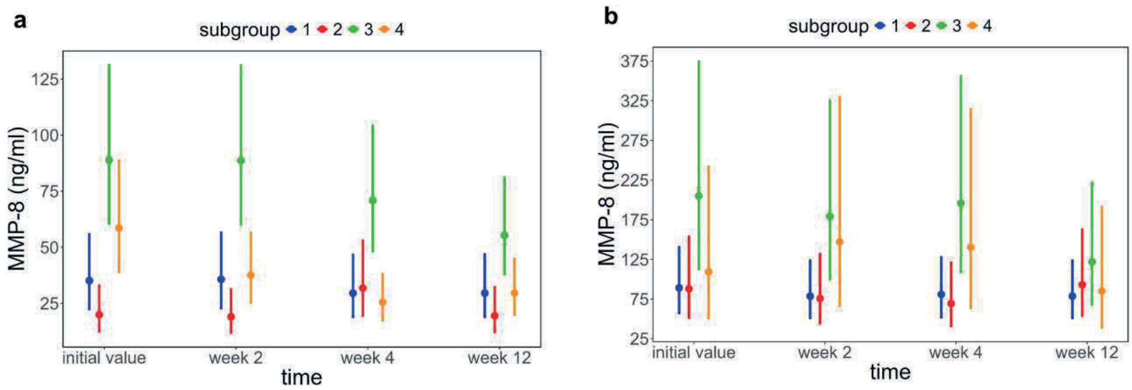

Figure 18. MMP-8 values of group A (a) before and at weeks 2, 4, and 12 after treatment and group B (b) before and at weeks 2, 4, and 12 after treatment. Dots and lines represent estimated means ± standard deviations [48]

4.1.2.2 BOB

BOB values showed a significant reduction in both groups ($p < 0.0001$ for both), and the interaction between time and subgroup also significantly influenced Bo

B values ($p < 0.009$ for both; see Figure 19a). This interaction was manifested as a pronounced decline in subgroups A1 and A2 after week 2, whereas subgroups A3 and A4 experienced a smaller decrease, with higher BOB values in subgroups A3 and A4 compared to subgroups A1 and A2 at week 4. Group B exhibited results similar to those of group A (Figure 19b), with the notable exception that BOB values in subgroup B4 remained unchanged throughout the study.

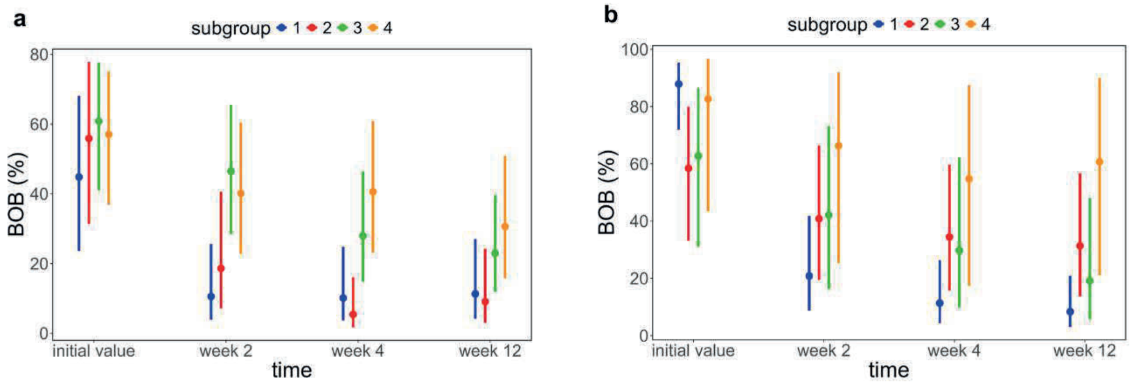

Figure 19. BOB values as percentages of groups (a) A and (b) B before and at weeks 2, 4, and 12 after treatment. Dots and lines represent estimated means ± standard deviations [48]

4.1.2.3 FMPS

In group A, a notable reduction in FMPS values was observed between appointments ($p < 0.0001$; Figure 20a). By the appointment at week 2, FMPS values had dropped significantly and remained low throughout the study. In group B, both the time effect ($p < 0.0001$) and the time–subgroup interaction were significant ($p = 0.001$; Figure 20b). This interaction was evident as FMPS values in subgroup B1 decreased after week 2, whereas those in B2 stayed constant. Although the study concluded that FMPS values in both subgroups B3 and B4 were lower, they still did not exceed those in subgroup B1.

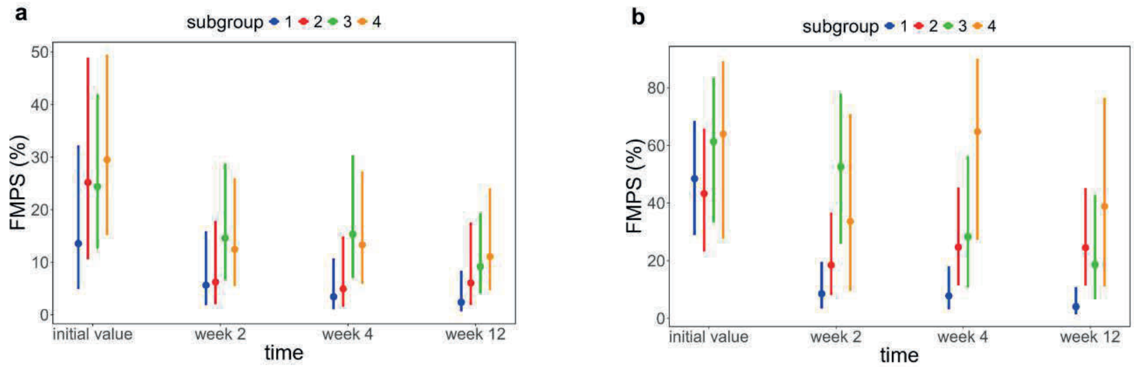

Figure 20. FMPS values as percentages of groups (**a**) A and (**b**) B before and at weeks 2, 4, and 12 after treatment. Dots and lines represent estimated means ± standard deviations [48]

4.1.2.4 FMBS

In group A, time had a significant effect on FMBS values (p < 0.0001, Figure 21a), causing them to drop at the visit at week 2 and remained stable thereafter. Additionally, there was a statistically significant interaction between subgroups and time in group B (p = 0.005, Figure 21b). Subgroup B1 experienced a substantial decline in FMBS values by week 2, which remained at lower levels thereafter. Conversely, in subgroup B2, no change was observed in its already relatively low FMBS values throughout the follow-up period. Meanwhile, subgroups B3 and B4 exhibited a modest decrease in their FMBS values, especially at week 12. Essentially, B2 started with low FMBS levels and maintained these levels, whereas subgroup B1 dropped to these levels, and B3 and B4 showed minimal improvements.

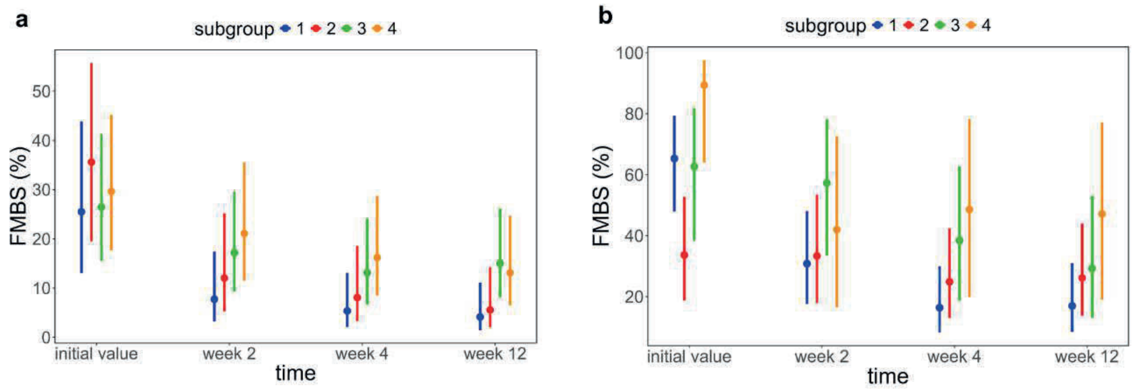

Figure 21. FMBS values as percentages of groups (**a**) A and (**b**) B before and at weeks 2, 4, and 12 after treatment. Dots and lines represent estimated means ± standard deviations [48]

4.2 Patients as subgroup changers

There were no significant differences in MMP-8 values throughout the study ($\chi2$ =4.3, p=0.118). (Figure 22)

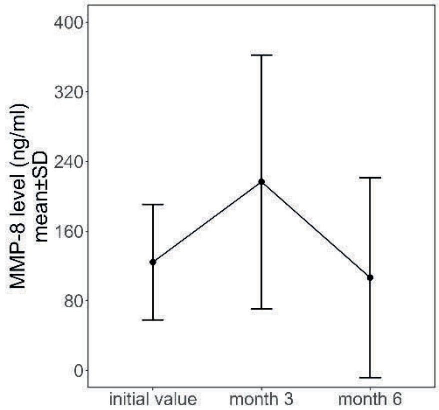

Figure 22: MMP-8 values in patients as subgroup changers

Time had a significant effect on BOB ($\chi2$ =13.7, p=0.001). Post-hoc tests revealed that BOB decreased marginally after the group changes, and significantly after month 6. (Figure 23)

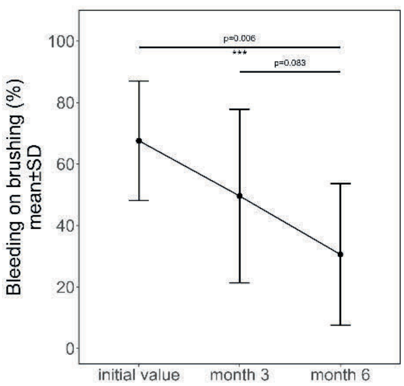

Figure 23: BOB in patients as subgroup changers

Time also had a significant effect on FMPS ($\chi 2$ =524.1, $p<0.001$). Pairwise comparisons showed that FMPS was significantly reduced at each time point. (Figure 24)

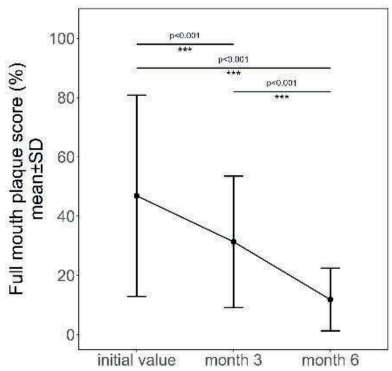

Figure 24: FMPS in patients as subgroup changers

Time also had an effect on FMBS ($\chi 2$ =20.5, $p<0.001$). Pairwise comparisons showed that FMBS did not decrease in the first three months, only after group change. (Figure 25)

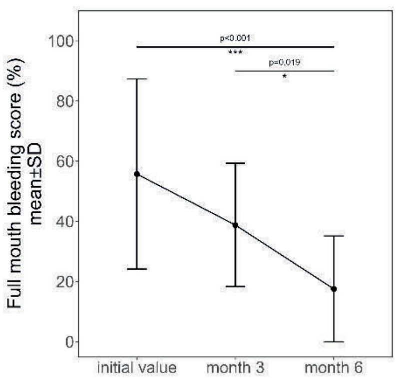

Figure 25: FMBS in patients as subgroup changers

4.3 Long-term follow-up

4.3.1. Patients with subclinical symptoms

By the end of the initial three-month study, all patients in this group had achieved low levels, which were analysed in more detail in the conservative therapy results. Thereafter, there was no difference in the scores of patients in group A during the long-term follow-up. All patients continued to have low scores. Apparently, due to the low sample size, no statistically significant result was detected.

4.3.2. Patients with gingivitis (group A) and patients with periodontitis (group B)

4.3.2.1. MMP-8

There was a significant effect of time ($\chi 2 = 32.6$, $p<0.0001$) and subgroup ($\chi 2 = 13.8$, $p=0.0032$) in the final model for group A. MMP-8 significantly decreased over two years. Patients in subgroup A3 had higher MMP-8 values than those in groups A1, A2 and A4. (Figure 26: a, b)

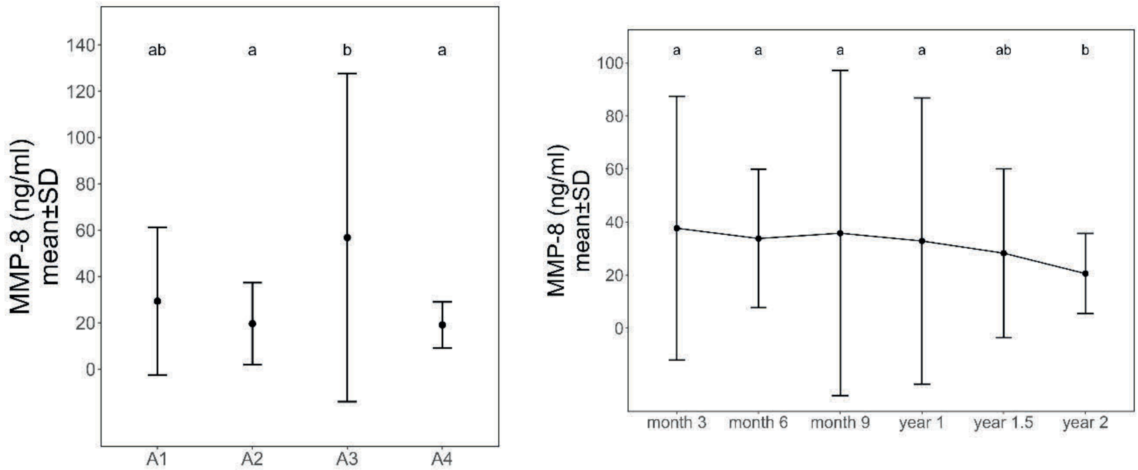

Figure 26 a, b: MMP-8 values in group A during long-term follow-up.
a: subgroup; b: time

In group B, there was a significant effect of time ($\chi 2 = 113.5$, $p<0.0001$) in the final model. Time significantly decreased. (Figure 27)

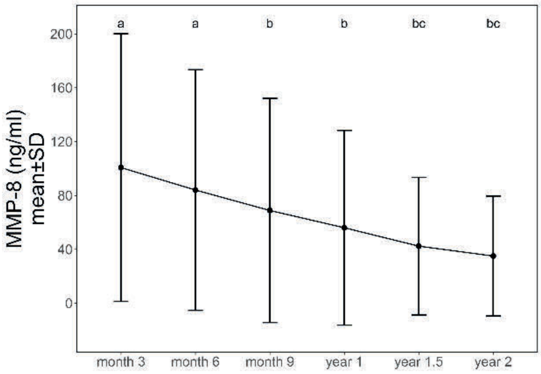

Figure 27: MMP-8 values in group B during long-term follow-up

4.3.2.2. BOB

There was a significant interaction between time and subgroup ($\chi2$ =65.4, p=0.00022) and a significant time effect ($\chi2$ =138.7, p<0.0001) in the model for group A. Tukey's pairwise comparisons showed no difference between subgroups at any time, but different subgroups changed differently over time. In subgroup A1, values decreased between months 3 and 6, then remained consistently low, while the other subgroups showed a gradual decline. (Figure 28)

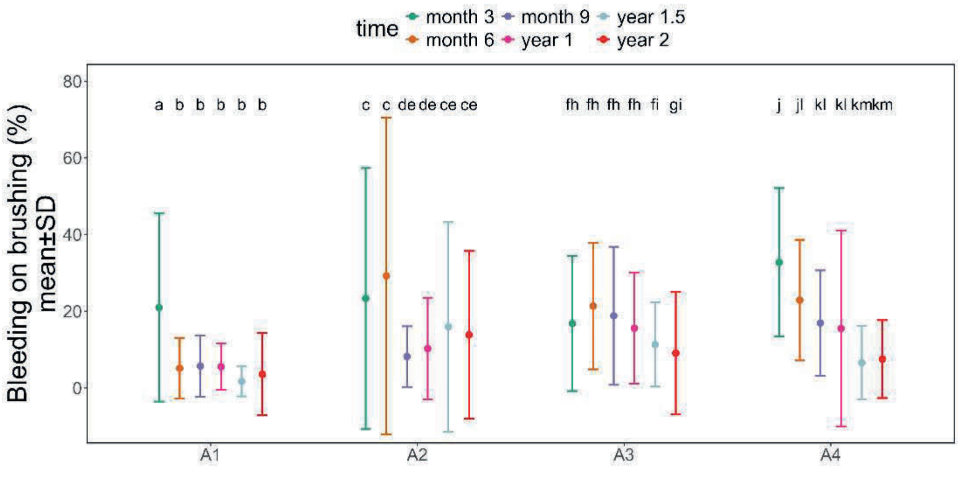

Figure 28: BOB values in group A during long-term follow-up

In group B, there was a significant interaction between time and subgroup ($\chi2$ =15.4, p<0.0086) and a significant time effect ($\chi2$ =92.0, p>0.0001). Tukey's pairwise comparisons showed no difference between subgroups at any time, but different subgroups changed differently over time. (Figure 29)

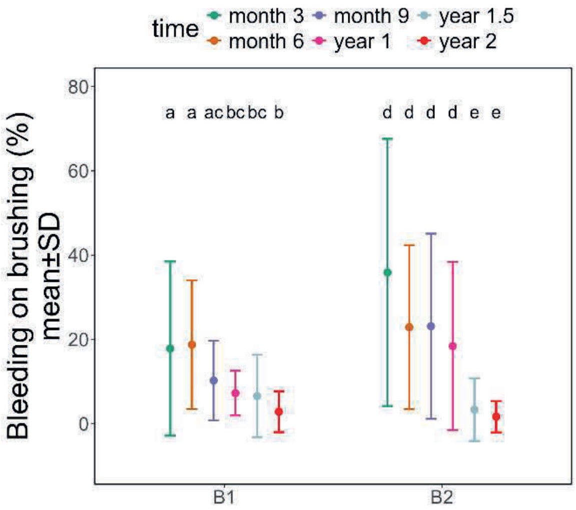

Figure 29: BOB values in group B during the long-term follow-up

4.3.2.3. FMPS

In group A, there was only a time effect on FMPS ($\chi2$ =39.4, p>0.0001), FMPS decreased over time. There was no significant difference between the values of month 3 and year 2, probably due to a larger standard deviation. Thus, the last two measurement points were not statistically different from the first two, but the middle ones were, probably because of the larger standard deviation. (Figure 30)

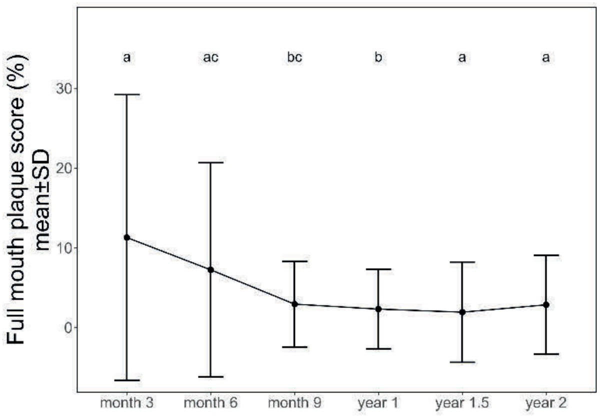

Figure 30: FMPS values in group A during the long-term follow-up

There was only a time effect on FMPS ($\chi 2$ =18.2, p>0.0027). In group B, FMPS initially decreased, and then stabilised. (Figure 31)

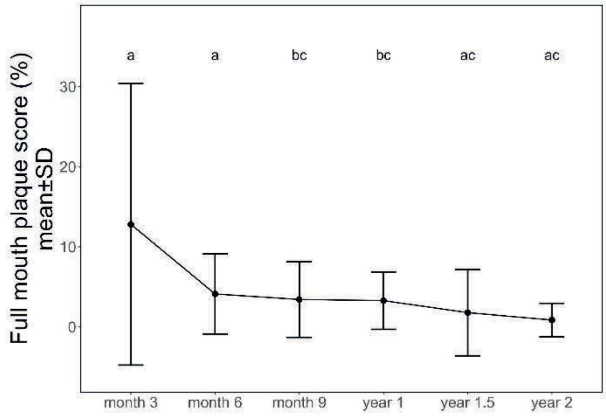

Figure 31: FMPS values in group B during the long-term follow-up

4.3.2.4. FMBS

In group A, there was only a time effect on FMBS ($\chi 2$ =31.1, p>0.0001), FMPS initially decreased in time, then stabilised. (Figure 32)

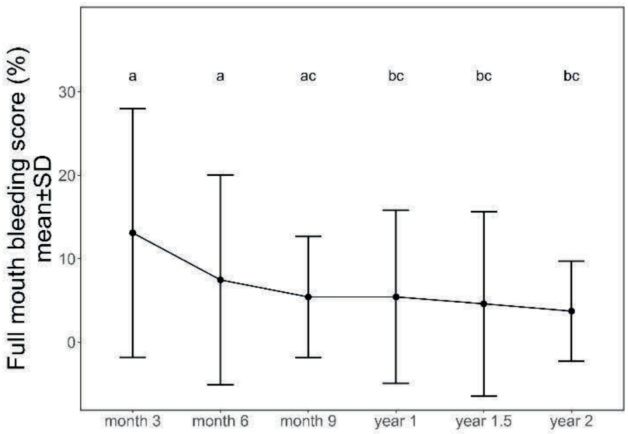

Figure 32: FMBS values in group A during the long-term follow-up

A similar time effect was observed in group B ($\chi 2$ =53.6, p>0.0001), but in this case, a decrease in FMBS was observed even at the end. (Figure 33)

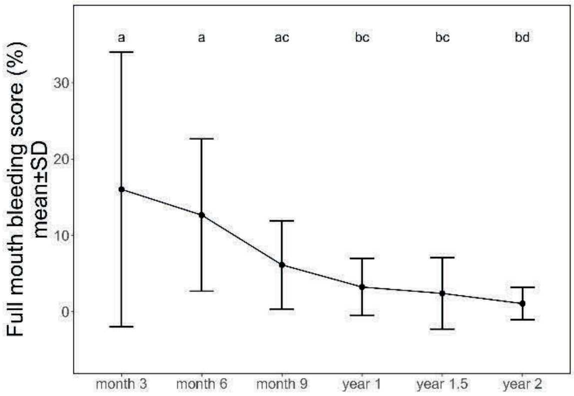

Figure 33: FMBS values in group B during the long-term follow-up

4.4. Results of teledentistry survey

In conventional clinical settings, all patients spend several minutes registering at the desk of the coordinator. However, this procedure does not apply to patients managed through teledentistry. The average duration of actual consultation time for remote patient monitoring varies depending on the dental specialty. Transitioning from traditional face-to-face consultations to a teledentistry model can save approximately 5 to 10 minutes per patient. Of the specialties studied, orthodontics demonstrated the smallest time reduction, with an average of 5.4 minutes, whereas periodontology exhibited the largest, with an average time saving of 10.0 minutes per consultation.

Overall, these seemingly modest improvements in efficiency can substantially enhance clinical capacity and reduce waiting times for patients. Assuming a standard work schedule of five days per week over 46 weeks per year, the cumulative time saved per clinician ranges from 58 to 116 hours, corresponding to nearly 10 to 20 full working days, depending on specialty (Table 3). Furthermore, if the teledentistry approach of this pilot study were implemented across all 13 clinical chairs in a single shift, the total annual time savings could amount to approximately 186 working days. Extending this to two shifts would potentially double the savings to 372 working days per year.

It is important to recognise that these estimates are based on the assumption that all remote patient monitoring visits across the three specialties studied can be transitioned from in-person to teledentistry consultations. In practice, however, not all patients possess the capability or resources to participate effectively in videoconferencing sessions, which may reduce the achievable time savings to some extent.

Table 3. Advantages of implementing teledentistry solutions in terms of working hours and workdays spared [42].

Estimated work time	per day (shift) in hours	per week (5 days) in hours	per year (46 weeks) in hours	in work days	% of the total
Regular surgery hours per dentist	6.00	30.00	1380.00		
Surgery with teledentistry solutions					
Orthodontics	5.73	28.67	1318.72		
Periodontology	5.50	27.48	1264.12		
Oral medicine	5.75	28.75	1322.56		
Difference					
Orthodontics	0.27	1.33	61.28	10.21	4.4
Periodontology	0.50	2.52	115.88	19.31	8.4
Oral medicine	0.25	1.25	57.44	9.57	4.2
Rolled out to all dentists/ dental chairs					
Orthodontics (5)	1.33	6.66	306.42	51.07	4.4
Periodontology (6)	3.02	15.12	695.29	115.88	8.4
Oral medicine (2)	0.50	2.50	114.88	19.15	4.2
Total	*4.85*	*24.27*	*1116.59*	186.15	6.2
Rolled out to non-active staff					
Orthodontics (5)	5.05	25.26	1161.81	193.63	16.8
Periodontology (6)	6.36	31.82	1463.60	243.93	17.7
Oral medicine (2)	1.56	7.78	357.83	59.64	13.0
Total	*12.97*	*64.85*	*2983.24*	497.64	16.6

If all potential remote patient monitoring cases within teledentistry were managed by dentists who are otherwise unable to deliver direct medical care, or by dental hygienists with expanded professional responsibilities, then approximately 3,000 working hours (equivalent to nearly 500 working days) could be reallocated from regular staff in a single shift (Table 3). This number would effectively double in two shifts, enabling the provision of care to an estimated 12,000 additional patients per year. Furthermore, these time savings and improvements in capacity utilisation could be augmented by the inclusion of preventive and consultation visits, which also fit well with teledentistry modalities.

5. Discussion

5.1 Study procedure

Throughout this study, all participants reliably attended their appointments, and all groups used oral hygiene devices effectively as exptected. The findings demonstrated a significant enhancement in the oral hygiene of patients within the Prophylaxis Concept groups (A1, B1), resulting in a sustained oral health free from inflammation. This improvement was validated by a reduction in levels of BOB, MMP-8, FMBS, and FMPS. The application of these metrics not only shortened the duration of conservative treatments, but also supported both short- and long-term follow-ups while maintaining patient motivation. This study indicates that, in addition to FMPS and FMBS assessments, BOB testing can also function as a valuable early diagnostic tool in the evaluation of oral hygiene and periodontal health. In more detail, the MMP-8 chairside test measures a narrower spectrum - between 10 and 400 ng/ml - compared to laboratory-based MMP-8 measurements. However, this spectrum is adequate for the early diagnosis of gingivitis, possibly without clinical symptoms, and is also suitable for the diagnosis of periodontitis. In our study, 102 patients were enrolled and the results of MMP-8 measurements show only trends. Statistically significant results could be obtained with a higher sample size.
The sensitivity of the test is reflected in the baseline values observed in group A, which highlight differences in the interdental cleaning efficacy of various tooth cleaning methods.
The same sampling protocol was used to measure MMP-8 in all patients in the study. In a few cases, the measured results deviated from the expected measurement results, for which no reason was found. It would be worthwhile to examine MMP-8 values with a larger number of samples and compare them with laboratory MMP-8 measurements.
Because of the chairside applicability of BOB and MMP-8, these measurements can be seamlessly integrated into clinical practice, offering patients new diagnostic alternatives and potentially alleviating the impact of periodontitis. The objective diagnostic potential of BOB testing, ranging from subclinical indicators to advanced periodontitis, may offer a novel approach for early identification of periodontitis.
Research conducted in Scandinavia during the 1970s indicated that oral hygiene initiatives led to significant improvements initially, but failed to produce the anticipated

long-term effects. Over the last 10 years, the emphasis has shifted primarily to interproximal areas, as studies have demonstrated that even the best manual and electric toothbrushes do not adequately clean these spaces. To older patients or individuals with open interdental gaps, regular use of dental floss and specially designed proximal toothbrushes are recommended [62, 63].

Preliminary research indicates that dental health education significantly enhances oral health knowledge [54].

A study by Petersen et al. in 2004 demonstrated a positive effect of oral health education on the maintenance of good oral hygiene in school children, which is consistent with our findings [65].

In our study, the impact of patient education was evident through changes in three indicators (BOB, FMPS, and FMBS). For MMP-8, clear results were not always observed. After week 12, all indicators showed lower values compared to their initial measurements. During the long-term follow-up, the decline in values was still visible.

Research indicates that educating individuals about oral hygiene can significantly enhance their knowledge, attitudes, and skills related to oral health. Education programmes have been proposed to address notable deficiencies in oral health awareness, which persist even among healthcare professionals. In various studies, the average plaque index scores showed reductions of 22.8% and 28.5% in the experimental groups, whereas control groups experienced a decrease of 9.1% after participating in an oral health education programme [64].

In our study, the effectiveness of patient education was demonstrated by the FMPS value in group B3, which exhibited a steady decline. Professional oral hygiene treatments were administered during each examination, allowing for the measurement of plaque accumulation at each follow-up. During the first two weeks of the study, subgroup B3 recorded a high FMPS value; however, between weeks 4 and 12, this value decreased significantly. This indicates that regular consultations and educational efforts may have enhanced the effectiveness of device usage, as reflected by consistently lower FMPS values over an extended period.

A study by Kumar et al. in 2016 revealed that a health education programme led to a 34% reduction in plaque scores among school children. In rural regions of India, where oral diseases are prevalent and access to toothbrushes is limited, the experimental groups showed improvements of 21.9% and 37.2% in oral hygiene practices, whereas the control group, which did not receive dental education, experienced only a 5.9% change compared to baseline [66].

The Prophylaxis Concept emphasises the importance of cleaning the col area and cervical zone. To facilitate this, it equips patients with specialized tools and provides a theoretical framework to support personalized and effective oral health practices. The philosophy behind the Prophylaxis Concept focuses on minimising bacterial growth on non-self-cleaning surfaces of teeth, utilising techniques and tools tailored to this objective. Patients who recognise the critical significance of maintaining oral hygiene and have received appropriate education and training from qualified dentists and dental hygienists can maintain good oral health not only during the study period but also in the long term, resulting in lower FMBS and FMPS indices as well as improved MMP-8 and BOB values [28]. Research on oral hygiene education has indicated that effective patient education and thorough follow-up are crucial for enhancing and sustaining oral hygiene [65, 66].

In our study, we observed similar trends in improvements in oral hygiene, utilising a newer indicator (BOB) for monitoring. Although professional oral hygiene treatments were conducted at every appointment throughout the study, only slight improvements in MMP-8 values were noted in subgroups that did not engage in regular interdental cleaning or lacked consistent use of dental bonding devices (A3 and A4). Group B did not show any such improvement, as the management of plaque-induced inflammation is limited in patients with periodontal issues and pockets exceeding 4 mm, which requires further comprehensive periodontal treatment involving surgical or non-surgical therapy.

In this study, patients in group A with subclinical symptoms were analysed separately, as they showed no clinical signs of gingivitis despite utilising various tooth-cleaning methods. Conventional indices (FMPS and FMBS) revealed no significant differences across different appointments; however, BOB testing was effective in identifying early contrasts, which showed a notable reduction by week 2. This indicates that BOB testing can clinically detect the inflammatory process at an early stage, even in the absence of clinical symptoms of gingivitis, thus providing a new avenue for early diagnosis in preventive dentistry. Although MMP-8 testing could yield similar outcomes, the study had an insufficient number of participants to demonstrate significant differences. The results of the four measurements in groups A and B indicated that a different approach to dental prevention is needed. BOB levels in groups A, A1, and A2 significantly decreased after week 2 and remained low until week 12. Subgroup A3 showed a steady decline, but no differences were observed between weeks 4 and 12. In contrast, values of subgroup A4 decreased following the first appointment but then plateaued. These findings suggest that the oral hygiene practices in subgroups A1 and A2 resulted in more effective outcomes compared to subgroups that did not incorporate daily interdental cleaning. Subgroups A3 and A4 exhibited minimal improvement with standard professional oral hygiene treatments; however, their BOB values did not decrease as significantly as those in other subgroups due to the absence of daily interdental cleaning. Group B demonstrated different temporal and group effects. Subgroup B1 showed considerable improvements, with values falling steeply from baseline to week 2 and then gradually declining towards weeks 4 and 12. This suggests that effective daily interdental cleaning quickly led to a non-inflammatory oral status by week 2. In subgroup B2, significant improvements were only observed at weeks 4 and 12; values at week 2 decreased but not as markedly as in subgroup B1. This implies that achieving a non-inflammatory oral status does not depend solely on the use of interdental brushes but also on the correct size of brushes as recommended by dental care professionals. In subgroup B4, scores decreased from baseline to week 4, but increased again by week 12, indicating that without interdental cleaning, only regular professional oral hygiene treatment can maintain adequate inflammation-free oral hygiene.

A comparison of BOB and MMP-8 values with FMPS and FMBS in group A indicated that the FMPS and FMBS did not show significant differences among the various oral hygiene habit groups over the 12-week period. In contrast, BOB and MMP-8 levels decreased in the subgroups using interdental brushes, with reductions observed as early as the first two weeks. All subgroups demonstrated improvement after week 2. This suggests that patient involvement in dental education and regular follow-ups contributed to a reduction in dental plaque and bleeding.

Summarising the results of conservative therapy, in both groups (A, B), the results of subgroups 1 and 2 were better and showed improvement compared to those of subgroups 3 and 4. A similar conclusion can be considered when examining long-term follow-up. The only difference is that in the long term, subgroup 1 achieved better results compared to subgroups 2, 3 and 4, due to the use of properly sized individual interdental brushes and regular patient education. It can be concluded that regular daily cleaning of interdental areas and continuous dental education and control are the basis of dental health.

Individual motivation, professional chairside oral hygiene treatment, and consistent supportive care are essential to mitigate the progression of periodontal damage in high-risk populations. This comprehensive strategy, which may involve one to four sessions annually based on skill levels and risk factors of patients can effectively slow the progression of periodontal damage. Consistent with findings from longitudinal studies, the implementation of this protocol can lead to notable improvements in oral health outcomes and decrease the risk of systemic diseases associated with periodontitis [63, 64].

Consequently, we can enhance dental compliance for these patients and support them in achieving inflammation-free oral health.

Inflammatory processes can be diagnosed at an early stage with a simple and painless test (BOB measurement), which can be used in pediatric dentistry. An early detection of the inflammatory process would result in fewer dental and periodontal lesions, which would be painful and possibly traumatic for the child to treat. By avoiding these, motivation and willingness of the patient to see the dentist and dental hygienist may be improved. Even after the correction of damage that has already developed, proper cleaning and diagnosis of inflammatory processes would be crucial. This would help to improve the dental status of the Hungarian population, improve the DMF-T index, and delay the time to tooth loss and the onset of complete edentulism. Through regular oral hygiene check-ups, dental nodules could be diagnosed more frequently and earlier, which would have a positive impact on overall health. Oral health education would become an integral part of health education, with emphasis on the morphology, bacteriology and health-promoting consequences of cleaning the interdental areas. The message that daily cleaning of interdental areas is essential for long-term dental health would reach an increasing number of people. Regular check-ups and individual oral hygiene education would relieve patients of the financial burden of reparative treatments and oral rehabilitation.

5.2 Digital dental documentation and its role in dental health

A preliminary pilot study conducted by Department of Public Dental Health, Semmelweis University, Hungary, compared the time required to attend to 539 patients in a conventional clinical setting versus 592 patients within a teledentistry framework. The findings suggest that teledentistry may be a viable strategy to address capacity constraints in public dental care and enhance access to services for patients residing in rural areas. Although the time savings per visit - ranging from 5 to 10 minutes - may appear modest, they could cumulatively translate into approximately 186 additional working days per year in three dental specialties during a single shift. This figure could potentially increase to nearly 500 working days if dental hygienists and inactive practitioners who are currently unable to provide face-to-face care are integrated into the teledentistry model.
These results have significant implications, particularly given the widespread shortages of oral health services in rural, remote, and peri-urban regions worldwide. Such inequalities are largely due to the shortage of primary dental care and the centralisation of specialist services within urban centres. Consequently, patients residing at considerable distances from dental facilities face substantial travel-related expenses and time burdens, including travel and waiting periods, despite the availability of publicly funded dental services.
Hungary exemplifies a broader trend observed in numerous countries, characterised by significant temporary and permanent vacancies in primary dental care practices, particularly in socially disadvantaged regions. Despite the presence of a substantial private dental sector catering for affluent populations, the availability of publicly funded dental services remains markedly below the standards recommended by the World Health Organization. Specialist community dental centres, such as the facility at Semmelweis University in Budapest, face considerable challenges due to high patient turnover. Comparable issues have been reported internationally; for instance, Dudko et al. (Australia) suggest that the integration of private dental providers into the public dental care system may offer a viable solution [67]. However, we argue that these challenges might also be effectively addressed within the public sector by leveraging the efficiency gains made possible by contemporary technological advancements.

Our pilot study demonstrated that the introduction of teledentistry solutions for remote patient monitoring can increase the number of patients treated per clinician per shift by approximately 1 to 2. Distributed annually, this improvement could allow the treatment of an additional 4,500 patients in orthodontics, periodontology and oral medicine. Furthermore, teleconsultation is a promising approach to enhance time efficiency in other dental disciplines. Emergency dentistry, for example, could benefit from pre-triage systems and teledental consultations, while pediatric dental screenings might be effectively managed through teledentistry platforms [68, 69].

6. Conclusions

All patients reliably attended the appointments and used the oral hygiene devices as anticipated. The Prophylaxis Concept groups demonstrated notable enhancements in oral hygiene, resulting in lasting inflammation-free oral health. BOB, FMPS, and FMBS examinations can be effective early diagnostic tools for assessing oral hygiene and periodontal health. MMP-8 needs further testing to obtain conclusive results, but it may be a promising diagnostic tool in periodontal diagnostics in the future. These assessments can be readily implemented in a clinical environment, offering new diagnostic possibilities and potentially alleviating the impact of periodontitis.

A new finding is that BOB measurement can diagnose tooth and periodontal destruction before clinically and radiologically detectable signs. The treatment of periodontal inflammation with clinical and radiological signs can be monitored and followed up by BOB measurement, the success of which was confirmed in our study by conventional indices (FMPS, FMBS). The Solo concept is more effective than oral hygiene methods at all levels of dental prevention. Established gingival inflammation can be eliminated and periodontal inflammation reduced, in as little as two weeks. The individually manufactured oral hygiene devices from the Solo concept are more effective than other devices included in the comparison.

The Solo concept significantly shortens the time needed for conservative therapy. Short- and long-term follow-up is controlled and patient motivation is maintained. With the help of telemedicine, patients can be more motivated to take care of their oral health. Teledentistry holds significant promise for improving access to dental care. It can improve the efficiency of traditional dental practices and offer an alternative to face-to-face consultations.

It can be concluded that dental hygiene check-ups every three months, individual prophylaxis treatment and instructions on instrument use lead to significant improvements and long-term maintenance of an adequate level of oral hygiene.

We propose to continue our study, in which statistically more detailed differences between subgroups can be observed with a larger sample size, both at three-month and long-term follow-ups.

Our eHealth case study demonstrates that teledentistry has significant potential to improve access to dental care by optimising the efficiency of conventional dental services and offering a viable alternative to traditional in-person consultations. However, socially disadvantaged populations are unlikely to benefit from these advancements without a comprehensive, systematic program aimed at the digital transformation of dental care delivery.

7. Summary

Currently, Hungary lacks a widely implemented unified dental prevention model. Despite effective dental prevention strategies in Western Europe, these models have not been adopted in Hungary, where the literature indicates a significant need for improvement in oral health outcomes [28, 70]. The absence of standardised dental prevention guidelines has resulted in a lack of comprehensive data on oral hygiene practices in the Hungarian population. This deficiency is reflected in unfavorable epidemiological indicators, such as high DMF-T indices and an increasing incidence of malignant lesions in the head and neck region, which can be associated with inadequate oral care and poor dental attendance habits [71, 72].

The aim of our studies was to assess the effectiveness of individualised oral hygiene education and its role in oral prevention in patients with various dental problems presenting at our Institute (Department of Public Dental Health, Semmelweis University); furthermore, to compare different oral hygiene devices and their effectiveness; finally, to figure out what motivational techniques our patients need to further maintain their commitment to good oral hygiene. During the study period, both BOB and plaque indices were significantly reduced after instruction and motivation in patients who received SOLO training compared to baseline values and control groups. Subgroups A2 and B2 also showed similar reductions, indicating that the use of other commercially available interdental brushes leads to a significant improvement in oral hygiene. However, regular patient education and the use of individualised devices are essential to achieve long-term results.

The BOB and plaque index of patients in the individual education group using interdental brushes significantly improved between dental treatments, and were significantly different, compared to the control group, which neither received education nor used interdental brushes.

The introduction of this oral hygiene model improves the oral hygiene of patients. This is supported by the BOB and plaque indices. The model significantly reduces the time required for conservative therapy and the follow-up time is also controlled. In addition, teledentistry holds significant promise for improving access to dental healthcare by augmenting the efficiency of traditional dental service delivery.

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9. List of publications by the candidate

Thesis-related publications:

- Simon, F., Szabó, G., Orsós, M., Mijiritsky, E., & Németh, O. (2024). The Effectiveness of Individualized Oral Hygiene Education in Preventing Dental Diseases: A Clinical Study. JOURNAL OF CLINICAL MEDICINE, 13(18). http://doi.org/10.3390/jcm13185481
- Németh, O., Simon, F., Benhamida, A., Kivovics, M., & Gaál, P. (2022). eHealth, teledentistry and health workforce challenges: results of a pilot project. BMC ORAL HEALTH, 22(1). http://doi.org/10.1186/s12903-022-02603-6

Other publications:

- Domokos, Z., Simon, F., Uhrin, E., Szabó, B., Váncsa, S., Varga, G., … Németh, O. (2024). Evaluating salivary MMP-8 as a biomarker for periodontal diseases: A systematic review and meta-analysis. HELIYON, 10(22). http://doi.org/10.1016/j.heliyon.2024.e40402
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The Effectiveness of Individualized Oral Hygiene Education in Preventing Dental Diseases: A Clinical Study

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Abstract: Background: Without mechanical cleaning, gingivitis can develop within three weeks. The first clinical sign is bleeding on positive probing. The accumulation of dental biofilm triggers an inflammatory gingival response. In the past decade, attention has focused mainly on interproximal areas and the use of customized interproximal toothbrushes. The aim of this study was to evaluate the effectiveness of individualized oral hygiene education and its role in dental disease prevention among patients with dental problems. **Methods**: Altogether, 102 patients, 38 males and 64 females, were included in the study. All patients were aged over 18 years. Before treatment, patients were clinically and radiologically examined, their full mouth plaque score (FMPS), full mouth bleeding score (FMBS), and bleeding on brushing (BOB) were recorded, and matrix-metalloproteinase-8 (MMP-8) was measured by using a chair-side MMP-8 measuring system. Patients in group A had gingivitis but no periodontal damage, and group B had periodontal damage. Patients in both groups were divided into four subgroups based on their toothbrushing habits and the oral health education they received. Three months after the initial examination, each patient was examined three more times (2, 4, and 12 weeks later). **Results**: It was concluded that subjects in groups A1 and B1 showed a significant reduction in BOB, MMP-8, FMBS, and FMPS levels after two weeks. Solo Prophylaxis (A1 and B1) remained a well-constructed protocol and caused the complete resolution of interdental inflammation after two weeks. Other subgroups achieved significant reductions only after 12 weeks. **Conclusions**: BOB and MMP-8 tests are valuable complements in preventive dentistry, and are able to detect potential pathological processes. The clinical relevance of BOB testing, in addition to FMBS, FMPS and gingival inflammation testing, can be demonstrated to patients, which may increase compliance.

Keywords: oral hygiene; periodontal diagnostic; mmp-8; BOB; dental prevention

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1. Introduction

A lack of regular toothbrushing leads to the accumulation of dental biofilm, and gingivitis develops within three weeks. The first clinical sign is bleeding on positive probing (BoP), demonstrated by Löe [1]. Thus, before the onset of clinical signs, an inflammatory gingival response has already been initiated as a reaction to bacterial invasion. Chronic inflammation causes not only inflammation in the gingiva but also the destruction of the alveolar bone, leading to periodontitis [2,3]. It can be said that dental plaque is a necessary and sufficient causative factor for the development of gingivitis; however, mature biofilm itself is not a sufficient causative factor in the pathogenesis of destructive periodontal disease. There are many tooth-cleaning devices and preventive methods on the market, but the usage of many tools without the supervision of dental professionals does not lead to a high level of maintainable oral hygiene [4–6]. Altogether, the oral hygiene behavior of patients is of paramount significance in the development of periodontal destruction.

Periodontal chart scores such as the full mouth plaque score and the full mouth bleeding score (FMPS and FMBS) are available for the diagnosis of plaque-induced inflammation. New diagnostic devices are also available to diagnose inflammatory processes in interdental spaces such as bleeding on brushing (BOB) tests [7,8]. There are plaque-induced and non-plaque-induced gingivitis, and in our study, we examined the plaque-induced type.

Human saliva, as a biological fluid, can also be a non-invasive diagnostic approach in oral and systematic diseases [9]. It is rich in disease-related biomarkers, such as matrix metalloproteinases, which can be used to detect early-stage periodontal disease. Several immune cells react to bacterial attacks, for example, polymorphonuclear leukocytes, which produce metalloproteinases such as metalloproteinase-8 (MMP-8). Secondarily, this protective MMP-8 causes collagenolysis, leading to periodontal damage. Different stages can be detected during this procedure. In the early stage when immune cells are functioning but clinical signs cannot be detected yet, gingivitis occurs, but with subclinical symptoms such as elevated levels of MMP-8. At the next stage, clinical symptoms such as bleeding on probing, a change in color of the gingiva, redness, and edema occur. In the case of prolonged destructive progression, periodontal damage and bone loss can be detected, indicating the presence of periodontal disease [10,11]. Matrix metalloproteinases obviously play a decisive role in pathological inflammatory processes and malignant tissue destruction [12–15]. It has been shown that matrix metalloproteinase-8 (MMP-8), as a collagenase in gingival connective tissue, is an early biomarker of periodontitis that can be measured not only with laboratory methods but also with chair-side tests. These techniques use the same monoclonal antibodies [16–18]. Lysosomal enzymes released during phagocytosis, such as MMP-8, are discharged into the oral cavity with the sulcus fluid and no tissue damage occurs.

A key to the successful management of oral hygiene is the cleaning of interproximal spaces. Most bacteria settle down in the col area and removing bacteria from these areas is essential to maintaining good oral hygiene. Conventional measurements, such as periodontal probes, can only detect inflammation in advanced stages of periodontitis; they cannot detect inflammation and bleeding in the middle of the col area. A bleeding on brushing (BOB) probe can be used to examine the middle of interdental spaces. MMP-8 can be detected in saliva, which can indicate an increasing level of inflammation at an early stage, before inflammation can be detected with conventional methods. By making patients aware of the importance of interdental cleaning, patient education can be considered effective, and proper oral hygiene can be maintained [19,20].

It is generally accepted that oral hygiene education has a positive outcome, and the oral hygiene of patients improves as a result. Information is mixed on what this improvement might mean during short- or long-term follow-ups. Education provides general dental and oral hygiene advice and information. Previous studies have generally used questionnaires and educational videos to show patients how to use toothbrushes and how often or how long they should clean their teeth [21–23]. The conclusion is always that individualized oral hygiene education is the key to dental disease prevention [4–6]. In our study, a dental hygiene concept achieves a higher level of individual oral hygiene compared to products. Its success is based on its tools, more conscious patient development, and long-term, even lifelong, follow-ups. The long-term effectiveness of this concept is the novelty of this study. Another novelty of this study is that in addition to the traditional indices (FMPS and FMBS), two other indices (BOB and MMP-8) were used in this study. It is of particular importance to teach patients what kind of tooth surfaces they have and what biological processes take place on these surfaces. In our opinion, teaching the morphology of interdental spaces and knowing the biological processes caused by the bacteria living there are of paramount importance. If patients learn that their periodontal condition can be diagnosed from between the teeth and learn how to keep these areas free of inflammation, they will have information that will help them maintain adequate oral hygiene not only in the short term but also in the long term. This learning process is called dental IQ growth.

The aim of our study was to compare four oral hygiene devices (Solo Prophylaxis, toothbrushes, and commercially available interdental brushes as well as electric and manual toothbrushes). Furthermore, we evaluated the effectiveness of oral hygiene education on the correct use of cleaning devices and the importance of inter-dental cleaning in patients visiting our Institute (Department of Community Dentistry, Semmelweis University) with various dental problems. Our hypothesis was that a well-constructed dental hygiene concept, through education and life-long follow-ups, can reduce and stop oral inflammatory processes, thus preventing gingival and periodontal diseases at an early stage.

2. Materials and Methods

This study was conducted at the Department of Community Dentistry, Semmelweis University, Hungary between 1 September 2020 and 30 April 2023. The examination was conducted by a team of dentists and dental hygienists from the Prevention and Periodontology Department of the Department of Community Dentistry, Semmelweis University. The six-member investigation team was trained together, in order to ensure uniform interpretation, using test photographs and recommendations of the WHO Oral Health Surveys: Basic Methods—5th edition. Their measurements were standardized, and their values were checked by the Fleiss kappa test. The team result was 0.9 [24].

Subjects were selected from patients presenting to the Periodontology and Prevention Department of the Department of Community Dentistry. Participation in the study was voluntary, with a total of 102 subjects included. The study was approved by the Regional and Institutional Committee of Science and Research Ethics and the Hungarian Office of Health Authorization and Administrative Procedures and was conducted in accordance with the Declaration of Helsinki. (Nr: ETT-TUKEB IV/9854-1/2021/EKU). All patients provided written informed consent prior to participation. During data collection between 1 September 2020 and 30 April 2023, all authors had access to information that could be used to identify individual participants

After an initial stomato-oncological, clinical, and radiological examination, four main parameters were recorded during appointments at fixed times. In the study, orthopantomogram radiographs were used to examine the teeth and bone level and determine the periodontal status for group inclusion. The first of the four measurements was the bleeding on brushing index (BOB), a new measurement method to determine how many interdental spaces in the mouth bleed due to stimulation. Bleeding is a clinical sign of the presence of an inflammatory process. The measuring and stimulating tool was a custom-designed interdental brush called DiagnoSTIX, manufactured by SOLO-MED GmbH, which created the concept of Solo Prophylaxis, referred to as the Prophylaxis Concept. DiagnoSTIX was applied one by one to each interdental space, and how many interdental spaces were bleeding compared to the total number of interdental spaces was observed (e.g., 13/20, where 13 out of 20 interdental spaces were bleeding) [25].

The second of the four measurements was levels of MMP-8, a neutrophil collagenase involved in types I, II, and III of collagen breakdown. It is an early marker of periodontal tissue destruction, and its elevated levels indicate inflammation before the inflamed gingival margin is clinically detectable. MMP-8 cannot be measured only in interproximal spaces, it is measured in saliva, which also contains gingival crevicular fluid. MMP-8 values can be used to detect inflammatory processes in the gingiva due to bacterial invasion. Interproximal spaces consist of the non-self-cleaning surfaces of the teeth and the col area where inflammation starts early, so MMP-8 levels in this area increase rapidly, and these MMPs are released into the saliva via the gingival crevicular fluid. MMP-8 levels measured in saliva can indirectly affect potential pathological processes in the mouth and interproximal spaces. The measuring device was the PerioSafe PRO DRS Test System, a chair-side test based on the enzyme-linked immunosorbent assay (ELISA). Patients rinsed their mouths with physiological saline in a cup, then aspirated a dose with a syringe and poured it onto a test tray. The tray was placed in a machine that measured the quantitative level of MMP-8 in the saliva and displayed it as a numerical value in ng/mL [15,26].

On the basis of these data, an interval table for the system determined whether collagenolysis was minimal, elevated, or advanced and severe. The only objectively monitorable marker of the extent of inflammation was the concentration of MMP-8 in the sulcus inflammatory exudate, measured in ng/mL [27,28].

The third and fourth measurements were based on the periodontal chart used as a reference by the School of Dental Medicine of the University of Bern (periodontal-chart-online.com) (accessed on 8 March 2024); measurements were also taken during the appointments of each patient. Bleeding on probing (BoP) values were recorded at six points on each tooth when the full periodontal status was taken. The full mouth bleeding score (FMBS) was recorded by the number of bleeding sites out of all probed sites and converted to a percentage. The measuring device was the PCPUNC 15 periodontal probe [29,30].

The full mouth plaque score (FMPS) was calculated from the plaque index (PI) recorded at six points on each tooth when the full periodontal status was taken. This was the percentage of the number of sites with plaque to all evaluated sites. The measuring device was also the PCPUNC 15 periodontal probe [29,30]. The data of all patients participating in the follow-up study were recorded in an application designed in collaboration with the University of Óbuda for easier documentation.

Before the assignment of groups, all oral hygiene toolkits were presented during the first examination. Patients selected the toolkits they would use during the study and were instructed on their correct use. During the first examination, study team members educated patients on the importance of cleaning interdental spaces and how to optimize the use of their devices according to their oral hygiene habits and introduced them to the Prophylaxis Concept.

To use the toothbrushes, patients were taught the modified Bass technique. We showed them how to use interdental brushes, and which sizes were appropriate for each interdental space. We used educational videos to teach tooth morphology and how to clean surfaces to help patients understand the importance of keeping non-self-cleaning tooth surfaces clean. Patients were given lectures on how to protect against bacterial attacks in the mouth and on the causes of periodontal tissues.

Participants were given a patient information sheet and patient consent form, and if they accepted the conditions, they signed them. After signing, subjects were assigned to two groups (A or B) by periodontal status according to clinical and radiological examination. Patients with gingivitis were assigned to group A and patients with detected periodontal destruction were assigned to group B. Each group was divided into four subgroups (1, 2, 3, and 4) based on their oral hygiene habits and the tools used for tooth cleaning (A1, A2, A3, A4, B1, B2, B3, and B4). Patients could not be randomly assigned to treatment groups because most of the patients stuck to their previous oral care routine. Despite being informed of their preferred cleaning method in the study, in many cases they were not able to change it, even if it seemed better than what the patients were using. In addition, it would have been unethical to assign them to a group where they were using a less effective cleaning method than their current one. However, they were keen to test their own cleaning method, which they had been using until then, to see if it was possible to achieve adequate oral hygiene according to the indicators used in the study. In each group, there were patients at the start of the study who were willing to switch to our preferred cleaning method (A1 and B1).

At the end of the study, all patients in the groups received our preferred oral hygiene education, thus avoiding discrimination. This Prophylaxis Concept (A1 and B1) has its own protocol, which describes the morphology of the teeth, sites of bacterial colonization, and hands-on training on the usage of interdental brushes and single-knotted toothbrushes manufactured by SOLO-MED GmbH.

Their radiological and clinical examination showed that patients in group A had neither periodontal damage nor bone loss, only clinical symptoms of gingivitis. Within group A and beside the four subgroups (A1, A2, A3, and A4), there was a group called "Patients with subclinical symptoms" who had a PPD (periodontal probing depth) anywhere less than or equal to 4 mm, and FMPS and FMBS values below 35%. There were no clinical signs of gingivitis, so BOB and MMP-8 values could be detected and a pre-existing inflammatory process could be diagnosed. In the subjects of group B, bone loss could be determined by radiological and clinical examination, and PPD values of 5 mm or more. Patients in subgroups A1 and B1 attended a lecture on the Prophylaxis Concept, during which they were introduced to the Solo Prophylaxis philosophy and the use of individualized oral hygiene tools. These patients used the oral hygiene devices included in the system. Patients in subgroups A2 and B2 used any other commercially available interdental brushes, possibly tufted toothbrushes and manual toothbrushes. Patients in subgroups A3 and B3 used electric or sonic toothbrushes, any other commercially available interdental brushes, and/or dental floss. Patients in subgroups A4 and B4 used only manual toothbrushes. (Figure 1). All patients in each group attended the examinations at the first appointment, and then at weeks 2, 4, and 12 after the first appointment. Subjects received professional oral hygiene treatment at all visits after the measurements (Figure 1).

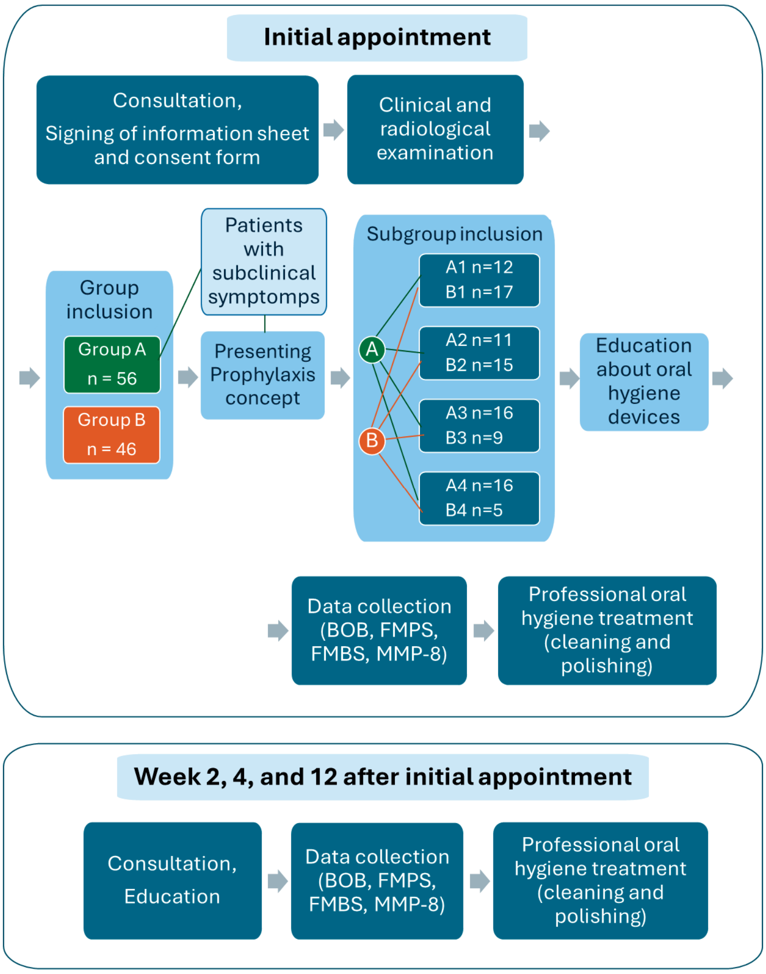

Figure 1. Flow chart of the study process.

Exclusion factors included smoking, mental and physical disability, patients under 18 years of age, patients undergoing orthodontic treatment, pregnancy, patients with less than six interdental spaces, oncological diseases, hematological diseases, genetic disorders, diabetes, bisphosphonate consumption, pacemakers, and infectious diseases.

2.1. Data Collection

The study was conducted on 102 patients, 38/64 male/female (m/f). The number of patients in the subgroups was in the following order: A1: 12 (4/8 m/f); A2: 11 (3/8 m/f); A3: 17 (5/12 m/f); A4: 16 (9/7 m/f); B1: 17 (5/12 m/f); B2: 15 (7/8 m/f), B3: 9 (4/5 m/f); and B4: 5 (1/4 m/f). Twenty-one patients in group A were older than 40 years, and 35 were younger. Of the 46 patients in group B, 42 patients were older than 40 years. A detailed table of ages is provided in the Supplementary Materials. During the first examination, study team members and dentists, educated patients on how to optimize the use of devices according to their oral hygiene habits, and introduced them to the Prophylaxis Concept. Patients returned 2, 4, and 12 weeks after the first visit for reassessment, and professional oral hygiene treatment. MMP-8, BOB, FMPS, and FMBS values were recorded at each visit. There were no dropouts among the 102 patients.

2.2. Statistical Analysis

To assess the effects of different oral hygiene methods on MMP-8, BOB, FMPS, and FMBS values, we applied generalized linear mixed-effects models (GLMMs) [31] using R 4.3.3 [32] with the glmmTMB package [33]. Patients in groups A and B were analyzed separately, as well as a group of patients with subclinical symptoms. MMP-8 levels, BOB, FMPS, and FMBS values were analyzed as dependent variables in separate models and time points (first appointment, 2, 4, and 12 weeks later) and subgroups (1, 2, 3, and 4), and their interactions were included in all models. To view individual changes, we included patient ID as a random factor in all models. When analyzing MMP-8, we used models with Gamma distribution and log-link function. Six patients (four from B2 and two from B1) had values above 400 ng/mL and three patients (one each from A2, A4, and B2) had values under 10 ng/mL at some point and were excluded from the analysis of MMP-8. For the analysis, we modeled the percentages of BOB, FMPS, and FMPS values binomially (bleeding or presence of plaque and sites assessed in the absence of bleeding or plaque). To avoid overdispersion, we used the betabinomial model family. Our model selection approach was based on the Akaike Information Criterion (AIC) for all models [34]. We removed explanatory variables one by one and chose the candidate model with the lowest AIC value. We considered a model to be a better fit if the AIC value was lower by 2. We did not remove the main effects before their interactions. If the AIC value of two or more models differed by 2 or less, we chose the simpler model. We repeated this until we achieved an optimal model fit. We used Wald $\chi 2$ statistics to obtain ANOVA-style tables. All models that were run can be viewed in the Supplementary Materials, with detailed results of the final models and post-hoc tests. Residual analysis and model validation were performed using the Dharma package [35], as described by Smith and Warren (2023) [36]. Post-hoc contrasts were calculated with the emmeans package [37], using Sidak correction to adjust for multiple comparisons.

3. Results

3.1. Patients with Subclinical Symptoms

Altogether, 29 patients had subclinical symptoms (19 females, 10 males; 7 in subgroup A1, 6 in A2, 10 in A3; the only patient in B3 was removed from further analyses). BOB values significantly decreased ($p > 0.0001$, Figure 2a) at the two-week appointment. Two patients had MMP-8 values under 10 ng/mL and were removed from the analyses. Neither time nor group had a significant effect on MMP-8 levels (all $p > 0.5$). Between appointments, FMPS values significantly decreased ($p = 0.036$; Figure 2b), whereas FMBS values only marginally decreased ($p = 0.055$, Figure 2c) over the duration of the study.

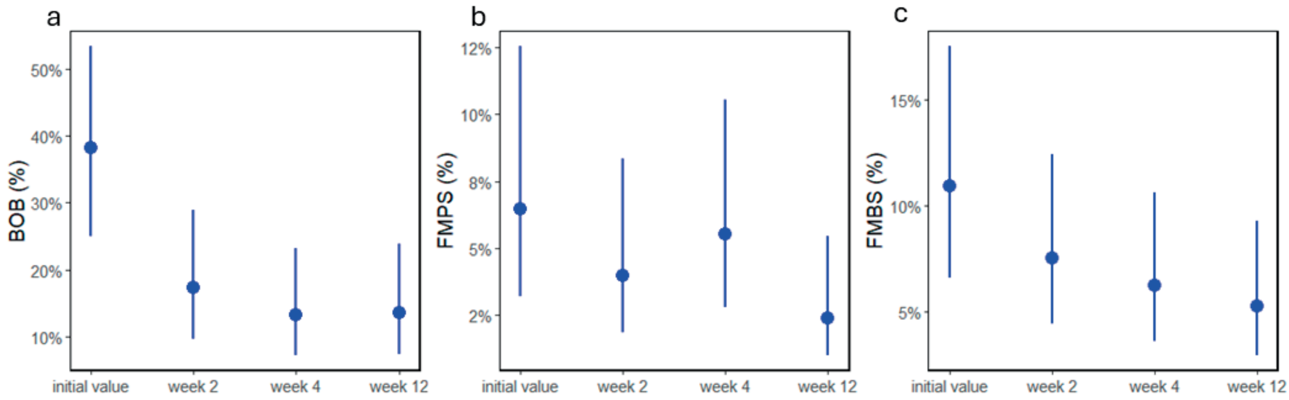

Figure 2. (**a**) BOB, (**b**) FMPS, and (**c**) FMBS values as percentages of patients with subclinical symptoms before and 2, 4, and 12 weeks after treatment. Dots and lines represent estimated means ± standard deviations.

3.2. BOB

BOB values significantly decreased in both groups in our study (both $p < 0.0001$), and the time and subgroup interaction also had a significant effect on BOB values (both $p < 0.009$; Figure 3a). This interaction was reflected in a large decrease in subgroups A1 and A2 after two weeks, whereas in subgroups A3 and A4, the decrease was less substantial, and BOB values were higher at week 4 in A3 and A4 than in A1 and A2. Results similar to those of group A (Figure 3b) were obtained in group B, the only difference being that BOB values in subgroup B4 did not change at all during our study.

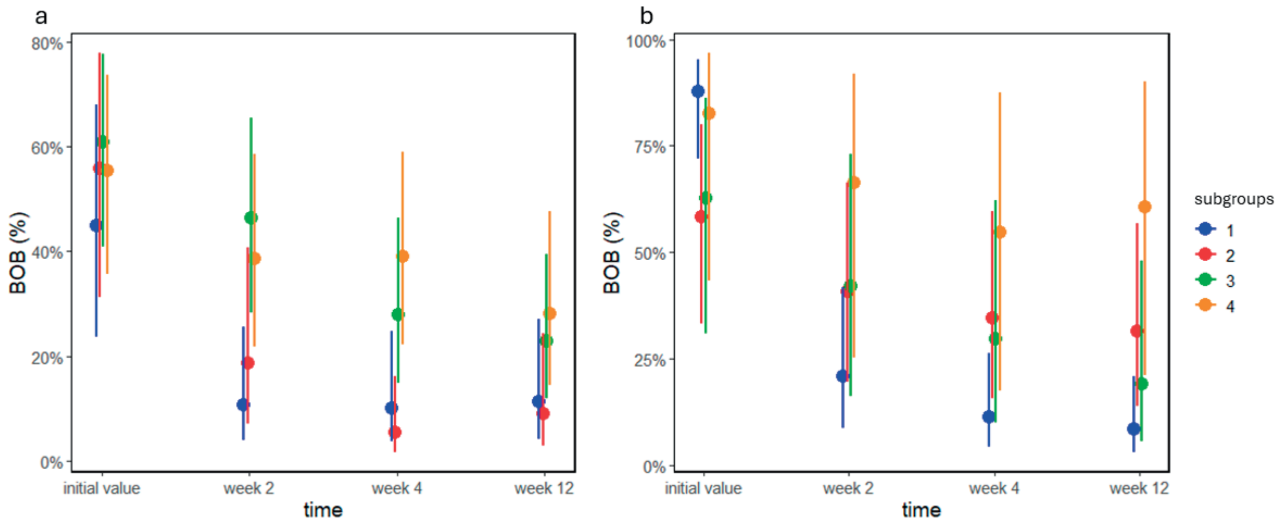

Figure 3. BOB values as percentages of groups (**a**) A and (**b**) B before and 2, 4, and 12 weeks after treatment. Dots and lines represent estimated means ± standard deviations.

3.3. MMP-8

The analysis of MMP-8 values in group A revealed a significant time ($p = 0.004$), subgroup ($p < 0.0001$), and subgroup–time interaction effect ($p = 0.008$; Figure 4a). Although MMP-8 levels only decreased in A4, initial levels of MMP-8 were different in the subgroups. In general, subgroups A1 and A2 had lower levels of MMP-8 than subgroups A3 and A4 (see the Supplementary Materials for exact contrasts). In group B, there was a marginal difference between subgroups (p = 0.083, Figure 4b); we suspect that with a larger sample size, this difference would be more apparent.

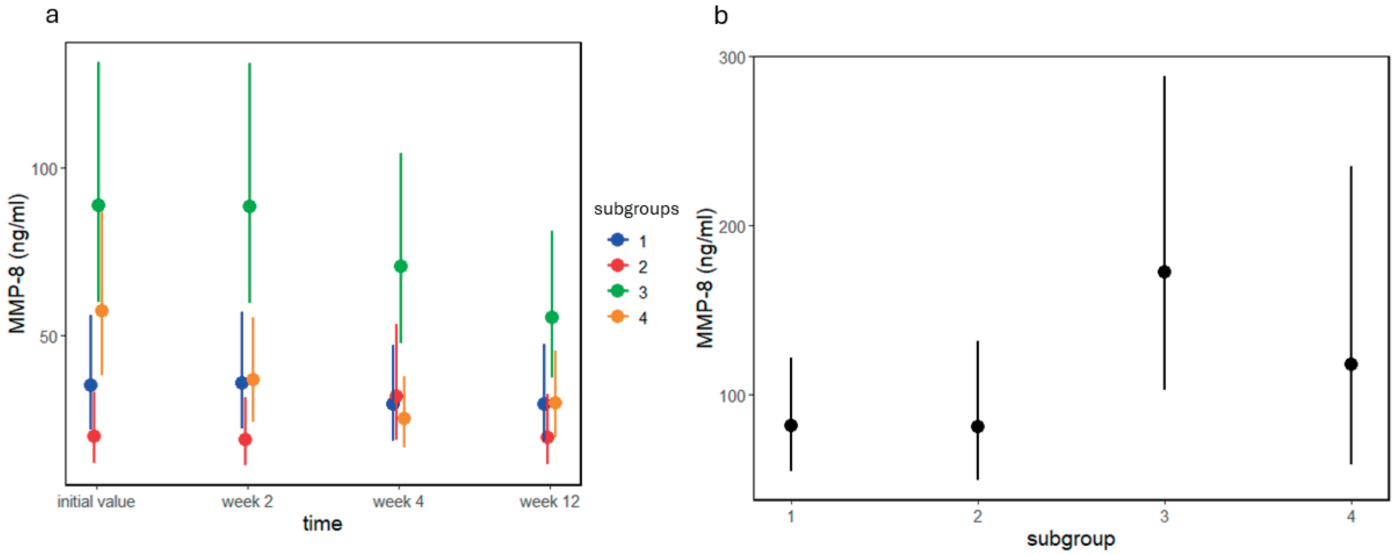

Figure 4. MMP-8 values of group (**a**) A before and 2, 4, and 12 weeks after treatment and (**b**) group B by subgroups 1, 2, 3, and 4. Dots and lines represent estimated means ± standard deviations.

3.4. FMPS

In group A, there was a significant decrease in FMPS values between appointments (p < 0.0001; Figure 5a). At the appointment at week 2, FMPS values were very low, and remained at that level until the end of the study. In group B, the time effect (p < 0.0001) and the time–subgroup interaction were significant (p = 0.001; Figure 5b). The interaction manifested as FMPS values in B1 decreasing after two weeks, whereas in B2 they remained the same. Although FMPS values were lower in both B3 and B4 by the end of the study, they were still higher than in B1.

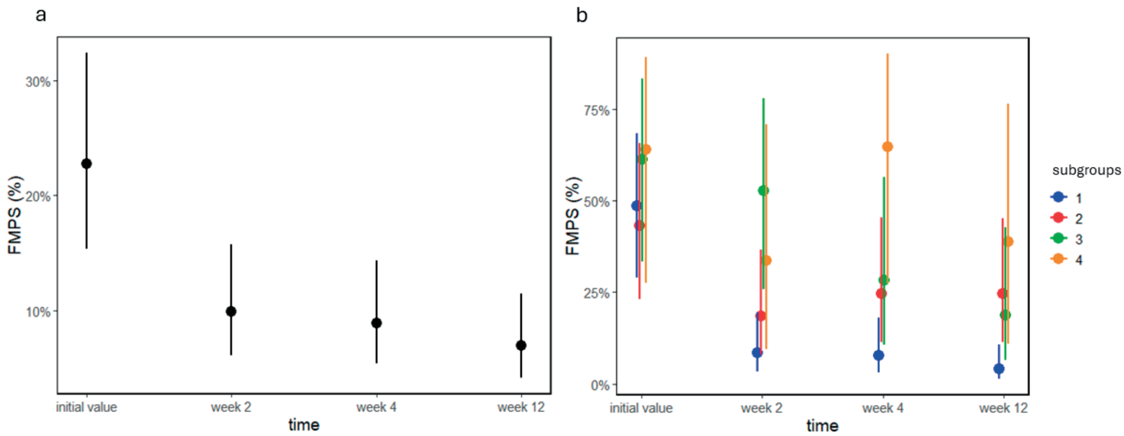

Figure 5. FMPS values as percentages of groups (**a**) A and (**b**) B before and 2, 4, and 12 weeks after treatment. Dots and lines represent estimated means ± standard deviations.

3.5. FMBS

In group A, time had a significant effect on FMBS values (p < 0.0001, Figure 6a), as it decreased at the two-week appointment and remained at that level. There was a significant interaction between subgroups and time in group B (p = 0.005, Figure 6b). In subgroup B1, FMBS values significantly decreased at week 2 and remained at a low level. In B2, FMBS values did not change; however, both B3 and B4 showed a moderate decrease in FMBS values at week 12. This means that B2 started from a low level of FMBS, and remained there, and FMBS values in B1 decreased to this level, whereas in B3 and B4 they barely improved.

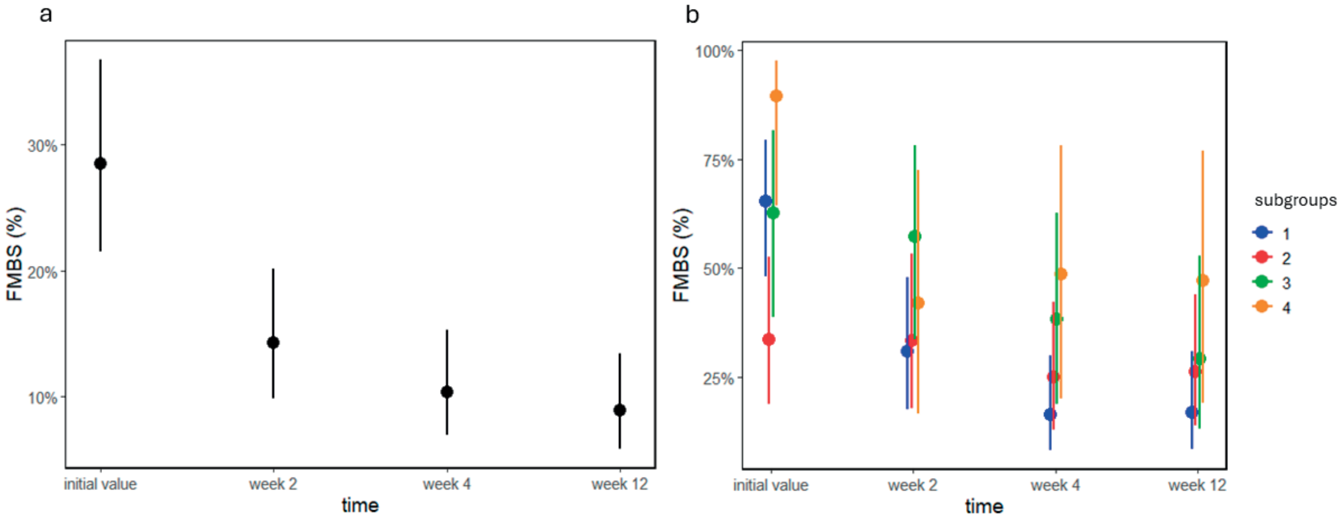

Figure 6. FMBS values as percentages of groups (**a**) A and (**b**) B before and 2, 4, and 12 weeks after treatment. Dots and lines represent estimated means ± standard deviations.

4. Discussion

Throughout this study, all patients consistently attended the examinations and all groups diligently used oral hygiene devices as expected. The results indicated a significant improvement in the oral hygiene of patients in the Prophylaxis Concept groups, leading to sustainable oral health without inflammation. This improvement was confirmed by the elevated values of BOB, MMP-8, FMBS, and FMPS. The use of these values not only reduced the time for conservative therapy, but also facilitated short- and long-term follow-ups while maintaining patient motivation. This study suggests that in addition to FMPS and FMBS testing, MMP-8 and BOB testing can also serve as effective early diagnostic tools to assess oral hygiene and periodontal status. Due to their chair-side nature, these measurements can be easily applied in a clinical setting, providing patients with new diagnostic options and potentially reducing the burden of periodontitis. The objective, diagnostic value of BOB and MMP-8 testing from subclinical symptoms to severe periodontitis may offer a new perspective in the early detection of periodontitis.

Scandinavian studies in the 1970s showed that oral hygiene programs brought significant improvements in the first period but did not have the expected long-term follow-up effect. In the past decade, attention has focused mainly on interproximal areas, as it has been proven that the most effective manual toothbrushes, even electric toothbrushes, do not provide sufficient interproximal cleaning. Regular use of dental floss and custom-sized proximal toothbrushes is recommended for older people or for those with open interdental spaces [38,39].

Preliminary studies have shown that dental health education has a significant effect on improving oral health knowledge [40]. A study by Petersen et al. in 2004 showed a positive impact of oral health education on maintaining good oral hygiene among school children, which is similar to our present study [22]. In our study, the effect of patient education was reflected in changes in four indicators (BOB, MMP-8, FMPS, and FMBS). The 12-week value was lower than the initial values of all indicators.

Various studies suggest that oral hygiene education may be effective in improving oral hygiene knowledge, attitudes, and skills. Educational programs have been proposed to reduce significant gaps in oral health knowledge even among healthcare workers [41].

In other studies, mean plaque index scores decreased by 22.8% and 28.5% in experimental groups and by 9.1% in control groups following an oral health education program [41]. In our study, the success of patient education is shown by the FMPS value in group B3, which had a gradual decrease. Professional oral hygiene treatment was performed at each examination and therefore the amount of plaque formed during this time was measured at each subsequent examination. Between weeks 1 and 2 of the study, a high FMPS value developed in subgroup B3, but a low FMPS level developed between weeks 4 and 12. This suggests that frequent consultation and education may have improved the efficacy of device use. This is reflected in lower FMPS values over a longer period of time.

Similarly, a study by Kumar et al. in 2016 showed a 34% reduction in plaque scores in school children after a health education program [23]. Even in rural areas of India, where oral diseases are highly prevalent and the limited availability of toothbrushes makes affordability difficult, there was a change of 21.9% and 37.2% in oral hygiene practices in the experimental groups and a 5.9% change only in the control group without dental education when compared to the baseline.

The Prophylaxis Concept gives high priority to cleaning the col area and the cervical zone. To achieve this, it provides patients with special tools, as well as a theoretical background to help them achieve individualized and appropriate oral health. The Prophylaxis Concept philosophy is based on the reduction in bacterial growth on non-self-cleaning surfaces of the teeth, using techniques and tools adapted to the given task. Patients who have understood the paramount importance of maintaining oral hygiene and have received the necessary education and training from dentists and dental hygienists trained for this purpose can maintain good oral health not only during the study but also in the long term with lower FMBS and FMPS indices and MMP-8 and BOB values [25].

Studies measuring similar dental education have shown that proper patient education and rigorous follow-up are essential to improve and maintain oral hygiene [22,23]. In our study, we found similar improving trends in oral hygiene, but we monitored oral hygiene using two newer indicators (BOB and MMP-8). As professional oral hygiene treatment was performed at all appointments during this study, a minimal improvement in MMP-8 values was observed in subgroups where no regular interdental cleaning was performed or where no dental bonding devices were used on a regular basis (A3 and A4). No such improvement was observed in group B, as the ability to treat plaque-induced inflammation is limited in periodontally affected patients with pockets larger than 4 mm. In this case, further surgical therapy is recommended.

In the case of BOB values, it is also clear that where there is no regular dental cleaning (A3, A4), there is also an improvement, but this is more due to professional oral hygiene cleaning. For subgroups A1 and A2, where regular dental cleaning was reported, there was also an improvement, which was due to patient education.

In this study, patients with subclinical symptoms in group A were examined as a separate group, as the subjects had no clinical symptoms of gingivitis, although they cleaned their teeth with different methods. In this case, conventional indices (FMPS and FMBS) showed no differences at different appointments, but BOB testing was able to diagnose contrast at an early stage, showing a significant reduction at week 2. This means that at an early stage, when no clinical symptoms of gingivitis are visible, BOB testing can clinically detect the inflammatory process. This represents a new opportunity for early diagnosis in preventive dentistry. MMP-8 testing can also show similar results, but there were not enough patients in the study to see significant differences. The results of the four measurements for groups A and B suggested a different approach to dental prevention. BOB levels in groups A, A1, and A2 significantly decreased after week 2 and remained low until week 12. A3 decreased steadily, but there were no differences between weeks 4 and 12. Due to professional oral hygiene treatments, A4 values decreased after the first appointment but then stagnated. All these mean that the oral hygiene concepts of subgroups A1 and A2 led to more effective oral hygiene results than in subgroups where interdental cleaning was not a daily habit. Subgroups A3 and A4 also showed minimal improvement with common professional oral hygiene treatment, but BOB values did not decrease as much as in other subgroups due to the lack of daily interdental cleaning. Group B has different time and group effects. Subgroup B1 shows significant improvement. The values decreased steeply from the initial appointment to week 2 and then slowly towards weeks 4 and 12. This means that proper daily interdental cleaning led rapidly to a non-inflammatory oral status at week 2. In subgroup B2, significant improvement was only observed at weeks 4 and 12. Values at week 2 decreased but not as much as in subgroup B1. This means that it is not only the use of interdental brushes that leads to a non-inflammatory oral status but also the use of the right size of interdental brushes by a dental health care professional. In subgroup B4, scores decrease from the initial appointment to week 4 but increase again at week 12. This means that without interdental cleaning, only regular professional oral hygiene treatment can maintain adequate inflammation-free oral hygiene.

Overall, patients who used electric or ultrasonic toothbrushes, despite their dental education, did not use interdental brushes regularly because they felt their mouths were much cleaner than with normal toothbrushes and lost motivation to spend time with interdental brushing. A comparison of BOB and MMP-8 values with FMPS and FMBS values in group A made it clear that FMPS and FMBS indices cannot show significant differences between the different oral hygiene habit groups during the 12-week period. All subgroups showed improvement after week 2. This implies that the involvement of patients in dental education and regular follow-up led to a reduction in dental plaque and bleeding.

The key to reducing the progression of periodontal damage in high-risk groups lies in individual motivation, professional oral hygiene chair-side treatment, and regular supportive care. This comprehensive approach, which includes one to four sessions per year depending on the skill level and risk factors of the patients, can effectively slow down the progression of periodontal damage. Similar to the results of longitudinal studies, adopting this protocol can significantly improve oral health outcomes and reduce the risk of systemic diseases associated with periodontitis [39,40]. In this way, we can improve the dental IQ of these patients and help them achieve inflammation-free oral health.

5. Conclusions

All patients consistently attended examinations and used oral hygiene devices as expected. The Prophylaxis Concept groups showed significant improvement in oral hygiene, leading to sustainable oral health without inflammation. BOB, MMP-8, FMPS, and FMBS testing can serve as effective early diagnostic tools to assess oral hygiene and periodontal status. These measurements can be easily applied in a clinical setting, providing new diagnostic options and potentially reducing the burden of periodontitis.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jcm13185481/s1.

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Informed Consent Statement: All patients provided written informed consent prior to participation.

Data Availability Statement: The datasets generated and analyzed in this study are not publicly available as it is impossible to obtain data anonymously. Patient anonymity cannot be preserved by the investigator conducting the measurement, but data can be obtained from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

MMP-8	matrix-metalloproteinase-8
BOB	bleeding on brushing
FMPS	full-mouth plaque score
FMBS	full-mouth bleeding score
PMN-leukocytes	polymorphonuclear-leukocytes
ELISA	enzyme-linked immunosorbent assay
PPD	probing pocket depth
DMFT-index	decayed, missing, filled teeth—index

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RESEARCH

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eHealth, teledentistry and health workforce challenges: results of a pilot project

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Abstract

Background: In the twenty-first century, health systems have to cope with the challenges posed by their rapidly changing environment. Among these changes, the emergence of digital health solutions is an opportunity to make health systems better, but also a compelling force to change. Community dentistry is one area of health care, where the rapid technological development has the potential for substantial performance improvement benefitting dental patients in terms of access to care and conveniance.

Methods: This study is based on a survey of the dental care provided by three units (Oral Medicine, Periodontology, Orthodontics) of the Department of Community Dentistry, Semmelweis University, Budapest. During a period of 12 weeks, we have collected time balance data on 1131 patients, 539 in the traditional and 592 in a pilot teledentistry setting, in order to estimate how much time could be spared by monitoring patients through videoconferencing instead of face-to-face visits.

Results: According to our findings, teledentistry has the potential to shorten the visit with an average of 5–10 min per patient, which adds up to 58–116 work hours in a year. If the pilot was rolled out to all the 13 chairs of the surveyed 3 specialties (orthodontics, periodontology and oral medicine) the time saving would sum up to 186 workdays in one shift alone, which would translate to close to 4500 additional patients per year, considering remote patient monitoring cases alone. Further, if inactive doctors and highly qualified dental hygienists were involved in delivering telecare, 2.67 times as many workdays could be spared, which would allow about 12,000 more patients treated per year.

Conclusions: The rapid development of digital health technologies coupled with the evolving task distribution between health professionals have a great potential to improve health system performance in pursuit of population health. Unfortunately, the adaptation to these technological changes is uneven, and without a national strategy, the poor will unlikely benefit from these opportunities in public dental care.

Keyword: Public health, Epidemiology, Health workforce, eHealth, Telecare, Telemedicine, Teledentistry, Dental health education

Background

Health systems of the twenty-first century have to cope with the challenges posed by their rapidly changing socioeconomic, ecological, technological, demographic and epidemiological environment. The revolution of information and communication technologies (ICT) has the potential to make contemporary health systems more effective, efficient and equitable at the same time, but represents an external challenge on their own right, as

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well, which health systems have to adapt to. The use of digital health solutions, therefore, is not just an opportunity to make health systems better, but a compelling force to change, which disrupts the traditional organizational and operational framework of medical care.

Digital health solutions, such as eHealth, mHealth, Big and Long Data, are ICT based medical and management technologies to improve the performance of health systems [1–5]. The ICT based administration of service delivery in health care has, in itself, a great potential to increase efficiency (appointment management, patient notification, patient information, documentation of services, e-prescribing, communication of test results, etc.) [6], but new technologies go beyond simply replacing paper-based with electronic documentation. Telemedicine utilizes advanced communication technologies to enable distance diagnosis, therapy and monitoring, in which the participants of the health procedure are at different geographical locations and connected electronically. Teledentistry is one subgroup of telemedicine defined by the medical specialization, dentistry, and in addition to dental practice, it extends to dental research, education and management, as well [7, 8]. The common to all telemedicine solutions is that they make the data, the information travel instead of the patient, relatives and health workers, with the data being processed real time (e.g. in the case of videoconferencing), or at different time points (store-and-forward systems). Typical teledentistry solutions include tele-consultation, when the patient-doctor encounter is managed through videoconferencing (D2P) and tele-support, when the doctor treating a particular patient receives support from another doctor, who is at a different location (D2D). The technological development has made it possible to perform not just diagnostic, but therapeutic procedures, such as surgical interventions, from a distance, and while the doctor being present with the patient is only for reassurance, the opportunity can also be used for training purposes [7, 9, 10].

According to the available literature, teledentistry solutions have been successfully implemented in Australia, the USA and England [7, 11, 12]. They delivered improved access to services in rural, remote areas and reduced travel for patients and their families. For instance, in Australia, the government has an ongoing struggle to provide access to high quality dental services for the population of remote geographical areas [13]. Although the dental care of school-age children is fully covered, human resources shortages have created large regional disparities manifested in long waiting times [14, 15]. According to a study by the Clinical Department of the University of Melbourne, the introduction of a cloud-based, store-and-forward teledentistry system was able to reduce unnecessary patient visits, waiting times, and could save 275.75 h of work (i.e. 36.7 days) per year, while 95% of the patients was satisfied with the service and found the software user friendly [16]. Further, dentists in rural areas with backward infrastructure and unfavorable working conditions could receive on the job training in the form of telesupport [16].

The experiences suggest that one of the most important advantages of teledentistry is the more efficient use of human resources, which has recently become a critical factor of health systems performance all over the world [17, 18]. The recent COVID-19 pandemic has shown, how even relatively well staffed health systems can easily be overwhelmed with a sudden surge of critical condition patients, and the bottleneck of upscaling meaningful health care capacities is not necessarily the special pieces of equipment needed, but the appropriately trained health care workers to operate them [19]. Digital health solutions have been widely used to support coping with the challenges posed by the COVID-19 pandemic in this respect [20–23]. Hungary also exemplifies the importance of the health workforce, as the country has been experiencing a serious human resources crisis in the health sector, due to the massive emigration of doctors and other health professionals into the higher income countries of the EU, especially Germany, the UK and the Scandinavian countries [24–26]. The shortage is even more worrisome, if we consider that Hungary had a substantial surplus of physicians during the communist era [27].

As far as dentistry is concerned, the situation is not at all better, despite the fact that the number of dental graduates are increasing (Table 1). According to WHO guidelines, no more than 2000 inhabitants should be cared for by 1 dentist. Theoretically Hungary meets this criterion, as on the basis of the number of licensed dentists and the size of the population, there were on average 1708 inhabitants per dentist in 2015. However, if we take into account the number of publicly financed dental practices

Table 1 The state of human resources in dental care in Hungary, 2015. *Source*: (1)

Indicator	Figure for 2015
Number of inhabitants per dentist	1708
Number of inhabitants per publicly financed dentist	3370
WHO recommendation	2000
Number of vacant practices	280
Number of permanent vacancies	42
Average age of dentists (year)	50.5
Share of dentists over the pension age (%)	20

only, this figure was as high as 3370 [28]. The almost two-fold difference is attributable to fact that there is a sizeable private sector in Hungary, which a huge percent of the population cannot afford to utilize.

Further, the averages hide large regional disparities. In terms of dental primary care, there are currently 280 vacant practices, and the number of permanent vacancies (practices, which have been unoccupied for over 10 years) is as high as 42 [28]. The trends are also worsening, despite that universities supply close to 300 new dentists in each year. Fresh graduates are reluctant to work in deprived rural areas and migration also takes its toll. Patients living in these remote locations are forced to travel, sometimes for hours, to central dental providers, which are also responsible for specialist dental care, such as periodontal and orthodontic care, oral medicine or dental surgery, as well as the care for patients with special needs, such as multiple chronic diseases, or disabilities [29]. As a result, central dental providers are jammed, dentists struggle with lack of time, while waiting times are increasing and unacceptably long.

The human resources crisis in dental care is further aggravated by aging. The average age of dentists is 50.5 years, and 20% of dental professionals are over the pension age [28]. Sudden external shocks, such as the COVID-19, further amplify these tensions [30]. In this paper, we have studied how teledentistry could be applied to ease the performance problems created by the shortage of dental health professionals, using the example of a university clinical department (Department of Community Dentistry, Semmelweis University, Budapest), which provides the full spectrum of dental health services from primary to tertiary care.

Methods

The study is based on a survey of the dental care provided by the Oral Medicine Unit, the Peridontology Unit and the Orthodontics Unit of the Department of Community Dentistry, Semmelweis University, Budapest. The present study investigates dental examination and diagnostic hours comparing the personal examination and teledentistry facilities. The Oral Medicine Unit regular surgery hours are from 8.30–14.00 and from 14.30–20.00 daily, 5 days a week, and it provides tooth preserving and dental prosthetics services and treats diseases of the oral mucous membrane. During a period of 12 weeks, we have collected time balance data on a total of 539 regular patient visits compared to 592 patients, who were attended in a pilot teledentistry setting, in order to estimate the worktime, which could be spared with the roll out of teledentistry technologies to all eligible visits.

The Department of Community Dentistry of the Faculty of Dentistry, Semmelweis University, Budapest, is the only dental care provider in the Hungarian health system, which has exclusively public employees and it has a contract with the National Institute of Health Insurance Fund Management (NEAK) to provide the full spectrum of primary and specialist ambulatory dental care and dental surgery. Hungary has a social health insurance system with a single national pool (the Health Insurance Fund), managed by the NEAK, which contracts mainly with public providers for the provision of health services to the population [31, 32]. The benefit package covers almost every dental and oral prevention service, dental treatment, emergency intervention, periodontal therapy and orthodontic procedure, but co-payment is required for prosthodontic treatment of individuals from 18 to 62 years of age [29, 33]. Each patient also pays the technical costs associated with dental treatment. This is unique in Europe. The service delivery system is organized on the basis of the so-called territorial supply obligation, in accordance of which each service provider is assigned a catchment area, whose inhabitants have to be cared for by this provider, but the same provider can have different catchment areas for different services (usually the smallest catchment area is in primary care—these are called primary care districts, and the largest is the whole country for highly specialized tertiary care services) [31]. The Department of Community Dentistry has to provide primary dental care for the inhabitants of district VIII of Budapest and Budapest, Pest County and Nógrád County is the catchment area of specialist and emergency dental care. In practice, as a university clinical department, it accepts patients from the whole territory of Hungary.

One dental shift is comprised of a number of episodes of care, in the frame of which a patient is attended by the staff of the Department of Community Dentistry in one of its 35 chairs. Each episode of care is by and large divided into an administration period and a treatment period. The administration period is comprised of the patient registration at the coordinator desk and the recording of the visit in the medical information system of the university, together with the scheduling for the next appointment after the completed intervention. The treatment period, by and large, can be divided into either an actual intervention, such as tooth filling or root canal treatment in primary dental care, and tooth extraction in dentoalveolar surgery, or consultation, including for instance patient monitoring, prevention advice, treatment modifications and certain diagnostic procedures, which do not necessary require physical contact with the patient. A substantial part of patient visits, for instance, in specialist dental care, such as orthodontics, periodontology, and oral medicine fall into this latter category.

In the frame of this study, we first identified the type of visits, which can be supported or replaced entirely with teledentistry solutions. Three techniques have been considered. The first is the so-called “store-and-forward”, in which the patient data, such as physiological data, medical notes, various photos and videos are stored electronically and made accessible to another specialist at a distant geographical location. This is already a well-known, and widely applied technique in the evaluation of diagnostic imaging. As opposed to the first technique, the second is real time consultation, such as a video-conferencing session that allows the participants at different geographical locations to exchange information at once, without delay. This system is useful, for instance, for consultation about periodontal treatments or dysgnath surgeries. The third technique is the so-called “remote patient monitoring”, which is a mixture of the two previous options, when biometric data are obtained and stored before the session and made accessible during the session, or generated online, during the session with appropriate equipment [34–37]. These can save time either by shortening of a session, or by replacing a regular face-to-face session with a virtual one. For instance, recall examinations can be provided by using photos of an intraoral camera or smartphone [6, 12]. Consultations, requesting or providing second opinion can also be managed in a telemedicine system.

By considering which types of visits are amenable to teledentistry, we have created 3 categories: prevention, remote patient monitoring and other consultations. In the frame of this study we identified appropriate cases of remote patient monitoring in 3 specialist areas: orthodontics, periodontology and oral medicine. During the data collection period, we recorded the time balance data of 155 scheduled regular visits, with the patients being present physically, in orthodontics, 187 in periodontology and 197 in oral medicine, over a 12-week period in two shifts, and calculated the average time per patient for each specialty. We have done the same with 184 orthodontics visits, 200 periodontology visits and 208 oral medicine visits in a pilot telemedicine setting, where the visits have been managed virtually in the frame of a locally developed application, and compared the data of these two settings.

We have expected that attending the same type of patients in the teledentistry setting does not only good for the actual patients, who spare the travel, registration and waiting time, but the patient-doctor encounter also requires less time due to the more efficient administration of the case (integrated patient history, case documentation, appointment scheduling) and the sparing of time required for the preparation of accepting the next patient (e.g. disinfection procedures). First we calculated the average time difference per remote patient monitoring visit in each specialty and then estimated the total time that could be spared and used to attend more patients, on the basis of the total patient turnover of the Department, regarding the relevant cases in the 3 specialties concerned.

Results

Table 2 presents the time data of a patient visit, based on the average of altogether 539 patients in the regular setting and 592 patients in the teledentistry setting. All the patients in the regular setting spends a couple of minutes with registering at the coordinator desk, which, of course does not apply to patients in the teledentistry setting. The average of the actual consultation time of remote patient monitoring varies with the specialty. As Table 2 shows, attending a patient in a teledentistry setting instead of the traditional patient-doctor encounter results in some time saving, which varies between 5 to 10 min, orthodontics yielding the least with 5.4 min and periodontology the most with an average of 10.0 min.

If we add up these seemingly small performance improvements, the capacities can be increased and waiting times can be reduced significantly. Calculating with 5 workdays per week, and 46 weeks per year, this improvement is summing up to 58–116 h, which are equivalent to almost 10–20 workdays per doctor, according to specialty

Table 2 Time utilization in specialist dental care without and with teledentistry (in minutes)

	Avg. consultation time per patient	SD	Ci	Cl min	Cl max	N
Regular						
Orthodontics	20, 40	1.71	0.269	20, 10	20.6	155
Periodontology	21, 10	1.50	0.215	20, 90	21.3	187
Oral medicine	29, 80	3.37	0.471	29, 40	30.3	197
Tele						
Orthodontics	15, 00	3.58	0.517	14, 50	15.5	184
Periodontology	11, 10	2.11	0.292	10, 80	11.4	200
Oral medicine	20, 30	2.40	0.326	19, 90	20.6	208

(Table 3). Further, should the pilot study be rolled out to all chairs within a shift (i.e. 13 chairs), we are talking about as many as 186 workdays per year and twice as many, i.e. 372, in two shifts. It is important to note that this figure assumes that all the remote patient monitoring visits in the studied 3 specialties can be shifted from the regular face-to-face to the teledentistry setting. In practice, not all the patients are capable of handling a videoconferencing session, which reduces somewhat the time saving that can be achieved realistically.

In addition, teledentistry solutions have the potential to mitigate human resource shortages by making it possible to utilize the professional know-how of those chairside doctors, who are temporarily or permanently unable to provide direct medical care. There are many professionals from different levels, who would be able to take part in teledentistry programs. Highly qualified doctors prior to pension or retired dental specialists are such examples. Doctors sustaining sick leave (for example as a result of tumor therapy, trauma, hand issues, or doctors receiving physiotherapy), who are eager to work, but are not able to provide manual interventions, may be involved. Doctors on maternity leave (sometimes with fresh graduation and up-to-date knowledge) could also join the professional side of teledentistry (mostly store-and-forward type as 2–2.5 h can be spent on teledentistry while childcare is provided). In the case of the Department of Community Dentistry we are talking about 6 dentists on maternity leave, which is equivalent to 36–45 work hours weekly, calculating with 3 workdays per dentist per week, i.e. at least 6 full shifts on one "additional chair" weekly.

Further, qualified dental hygienists may enter into a connected practice relationship with a dentist to provide oral health care services for underserved populations without general or direct supervision in public settings [12, 13, 38]. In case all of the potential remote patient monitoring teledentistry cases could be attended by dentists, who are unable to provide direct medical care, or by dental hygienists, whose work roles are enhanced, a total of close to 3000 work hours (and close to 500 workdays) could be freed for the regular staff in one shift alone (Table 3), and twice as many in two shifts, which translate to the care of about 12,000 additional patients in a year. These time savings and more efficient capacity utilization can be increased further with considering prevention and consultation visits, which are also amenable to teledentistry.

Discussion

Summary of main findings

Our small scale pilot study of comparing the time required to attend 539 patients in the regular setting and 592 patients in the teledentistry setting at a community dentistry department of a medical university in Budapest,

Table 3 Advantages of the deployment of teledentistry solutions in terms of working hours and workdays spared

Estimated work time	Per day (shift) In hours	Per week (5 days) In hours	Per year (46 weeks) In hours	In work days	% Of the total
Regular surgery hours per doctor	6.00	30.00	1380.00		
Surgery with teledentistry solutions					
Orthodontics	5.73	28.67	1318.72		
Periodontology	5.50	27.48	1264.12		
Oral medicine	5.75	28.75	1322.56		
Difference					
Orthodontics	0.27	1.33	61.28	10.21	4.4
Periodontology	0.50	2.52	115.88	19.31	8.4
Oral medicine	0.25	1.25	57.44	9.57	4.2
Roll out to all doctors/chairs					
Orthodontics (5)	1.33	6.66	306.42	51.07	4.4
Periodontology (6)	3.02	15.12	695.29	115.88	8.4
Oral medicine (2)	0.50	2.50	114.88	19.15	4.2
Total	4.85	24.27	1116.59	186.15	6.2
Roll out with the involvement of inactive personnel					
Orthodontics (5)	5.05	25.26	1161.81	193.63	16.8
Periodontology (6)	6.36	31.82	1463.60	243.93	17.7
Oral medicine (2)	1.56	7.78	357.83	59.64	13.0
Total	12.97	64.85	2983.24	497.64	16.6

Hungary suggest, that teledentistry could be one of the solutions to the capacity problems of public dental care and to improve access to care for patients in rural areas. The seemingly small time saving of 5–10 min per visit could translate into, as many as, 186 additional workdays per year in the three specialities studied in one shift alone, and almost 500 workdays, if dental hygienists and inactive doctors, who are unable to work in the face-to-face setting, could be involved.

These are important findings, since many rural, remote and outer suburban areas all over the world receive inadequate oral health services, due to workforce shortage in primary care, and the centralization of specialist dental care in urban centers. These patients, that live far from dental centers, have to shoulder the travel costs, as well as the time costs of travel and waiting, even if the services, themselves, are covered publicly.

Hungary is no exception with substantial temporary and permanent vacancies of primary dental care practices in socially disadvantaged regions of the country. Having an extensive private sector for the well-off, the availability of publicly financed dentists is well below the recommendation of WHO, and specialist community dental centers, such as the one at Semmelweis University in Budapest, struggle with a very high patient turnover. Other countries deal with similar issues. In Australia, Dudko et. al. suggest, that the involvement of private dental providers in public dental care could be a reasonable solution [39], but we argue that the problem could also be addressed within the public sector by utilizing the efficiency enhancing potential of the technological development of our age.

Teledentistry with its technologies has an enormous potential to increase the availability of oral health specialists by making the delivery of traditional face-to-face dental care more efficient, and by using information and communication technologies to create new forms of care, which connect care processes among patients, primary care doctors, specialists and other health workers staying in different geographical locations [40]. As an example, patient education and prevention could be introduced throughout video streaming webpages, where medically supervised information could be found about illnesses. Di Stasio et al. found that most of the videos on a specific oral medicine-related problem was uploaded by generalists [41]. Also, photos of oral lesions could be sent to specialists via mobile phone application that can reduce referral decision to special care from 96.9 to 35.1% [42]. It is the dentist, who should consider the type of consultation (tele or face-to-face) that is needed for the patient, in order to achieve the best therapeutical effect [43].

In our pilot project, just by the application of teledentistry solutions in remote patient monitoring, we have shown, that about 1–2 more patients could be treated per doctor per shift, which would add up to 4500 patients more in a year in orthodontics, periodontology and oral medicine. On the other hand, teleconsultation could be another helpful tool, if we would like to raise the time-effectiveness in other areas, as well. Emergency dentistry could benefit from pre-triage systems and teledental consultations [44]. Also, children's dental screening could be managed by teledental solutions [45].

With teledentistry, we could involve those chairside doctors, who are temporarily or permanently out of direct patient care, or dental hygienists with enhanced competencies to further improve the patient throughput, to 12,000 additional visits per year. These methods could also support the substitute/replacement doctors in rural areas, with remote specialists taking over patient diagnostics and providing consultancy.

Nevertheless, unlike in Australia, where government project funding has allowed the centers to investigate different workforce strategies for increasing access to care, such as telehealth, care coordination programs, mobile technology and financing of graduate medical education [16, 46], currently there is no dedicated funding available to support the implementation of such dental care initiatives in Hungary. The COVID-19 pandemic did give a push to the systemic application of digital health solutions in medicine, such as the widespread application of the e-prescription system, the inclusion of telemedicine services in public financing, and the extension of the functions of the Hungarian eHealth Cloud, but public dental care unfortunately still lags behind [47, 48].

Unfortunately, task shifting to dental hygienists is also problematic in Hungary, since the general regulatory framework does not let the full delegation of medical tasks to qualified health professionals. The same issue plagues other areas, such as the deployment of advanced practice nurses in pain management [49].

Strengths and limitations

The strength of this study is that it addresses an important problematic issue of community dentistry and demonstrates the potential of teledental solutions in solving the problem of capacity constraints by improving the efficiency of and increasing the access to public dental care. It was conducted by specialists, who attend dental patients daily in the public sector.

The main limitation of the pilot is that it has been confined to only one center in one country, Hungary, with a relatively small number of participants. A multicenter research would be useful in the future to be able to compare the differences between centers, regions and countries, as well as different settings and levels of care. Further, we investigated the use of teledentistry only from the point of view of time-effectiveness. Other aspects, such as the reduction of face-to-face visits, the costs of implementation and other dimensions of feasibility should also be considered in future studies.

Future directions

In addition to an extended study with a broader scale and scope in community dentistry, the application of digital health solutions in other areas of dental care should also be explored and studied. Primary dental practice, gate-keeping by assisted pre-triage, and graduate and postgraduate education are a few examples, where teledentistry can also prove to be useful, but have not been addressed in Hungary, yet.

Conclusions

Our case study has shown that teledentistry has a great potential to offer better access to dental care, both by improving the time utilization of traditional dental care, and as an alternative to classic face-to-face dentistry, but the socially indigents will unlikely benefit from these opportunities without a systematic development program of the digital renewal of dental care. According to the investigation, the usage of teledentistry is recommended. Hungary desperately needs such a policy change as public dental care struggles with capacity problems, whose solution will unlikely be forced by the wealthier part of the society, since they have already left the public sector, and utilize dental services with the providers of a well-developed private sector.

Abbreviations

ICT: Information and communication technologies; D2P: Doctor to patient; D2D: Doctor to doctor; WHO: World health organization; NEAK: National Institute of Health Insurance Fund of Hungary.

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Author contributions

Conceptualization: ON and PG. Methodology: ON, AB, FS and PG. Validation: ON. Formal analysis: ON, FS, AB, and PG. Investigation: ON and FS. Resources: ON. Writing—original draft preparation: FS. Writing—review and editing: ON and PG. Writing—final draft: PG. Supervision ON, MK. Project administration: ON. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials

The datasets generated and analysed during the current study are not publicly available due to the impossibility of earning the datas anonimly. In proper measuring examiners it is not possible to keep the anonimity of the patients, but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and constent to participate

The study was approved by the Regional and Institutional Committee of Science and Research Ethics and the Hungarian Office of Health Authorization and Administrative Procedures, and was conducted in accordance with the Declaration of Helsinki. (No.: ETT-TUKEB IV/9854-1/2021/EKU). All patients provided written informed consent prior to participation.

Constent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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