Characterization of the antioxidant profile of human saliva in peri-implant health and disease

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Abstract
Objectives: Peri-implant disease is considered to be an inflammatory disease, but many aspects of its pathogenesis remain unknown. At present, peri-implant disease is considered to be initiated and perpetuated by a small group of predominantly Gram-negative, anaerobic, or micro-aerophilic bacteria that colonize the subgingival area. Bacteria cause the observed tissue destruction directly by toxic products and indirectly by activating host defense systems, i.e. inflammation. A variety of molecular species appears in the inflamed tissues, among them are reactive species such as free radicals and reactive oxygen species (ROS). The purpose of this study was to assess levels of various antioxidants in saliva to identify differences between the saliva of patients with healthy peri-implant tissues and patients with peri-implant disease, and to examine whether the whole saliva of those with peri-implant disease conditions might have lower levels of antioxidants than that of healthy individuals.

Materials and Methods: Thirty healthy adult volunteers (14 men and 16 women) with implant-supported overdentures (Ankylos® Biofunctional Implants) were selected from the group of patients from Tallinn Dental Clinic. Biochemical and clinical parameters evaluated were the following ones: the levels of urate, ascorbate, myeloperoxidase in saliva, total antioxidant status of saliva, pocket probing depth (mm), gingival index (0, 1, 2, or 3), and bleeding on probing (0 or 1).

Results and conclusion: Total antioxidant status (TAS) of saliva and concentration of uric acid and ascorbate, which are the main salivary antioxidants, are significantly decreased in patients with peri-implant disease. TAS in healthy subjects was 0.41 ± 0.10 for resting saliva and 0.31 ± 0.09 for stimulated saliva; in diseased subjects TAS was 0.19 ± 0.07 and 0.12 ± 0.03, respectively. In healthy subjects, the concentration of urate was 307.2 ± 78.06 µM/l in resting saliva and 241.5 ± 89.09 µM/l in stimulated saliva. In diseased patients, the concentration of urate was 120 ± 36.13 and 91.60 ± 39.35 µM/l, respectively. The concentration of ascorbate did not differ in resting and stimulated saliva. In healthy subjects, it was 2.79 ± 0.81 mg/l and in diseased subjects, it was 1.54 ± 0.30 mg/l. This may indicate that excessive ROS production in peri-implant disease is leading to the situation of excessive oxidative stress, which may be an important factor contributing the destruction of peri-implant tissues.

The importance of these findings may be the better understanding of the processes involved in the pathogenesis of peri-implant disease and that the treatment of peri-implant disease may involve adjuvant anti-oxidants supplementation together with cumulative interceptive supportive therapy concept introduced by Mombelli & Lang.
Saliva is the first biological medium confronted by external materials that are taken into our body as part of food, drink, or inhaled volatile ingredients. During evolution, various defense mechanisms have developed in the saliva aimed at combating penetrating bacteria, viruses, or fungi and protecting against chemical or mechanical attack. Moreover, even after swallowing, saliva has mucosal protective capacity within the gastrointestinal tract (Marcozzi 1996, Rao et al. 1997). An extensive amount of research has been devoted to the immunological defense mechanism of saliva, primarily based on secretory IgA and the protein-enzymatic defense system, which, in turn, is based on the enzyme lysozyme and other components, such as histatin, lactoferrin, proline-rich protein, mucin, etc. The soft tissue integrity defense system, in which epidermal growth factor plays a pivotal role, has also been evaluated quite thoroughly [Rao et al. 1997].

Recently, the importance of another salivary defence system has become obvious. Similar to other biological systems, the salivary antioxidant system includes various molecules and enzymes, and of these the most important are the uric acid molecule and the peroxidase enzyme, both of which are water soluble. The lipid-soluble antioxidants carried by lipoproteins, whose concentration in saliva is very low, contribute no more than 10% of the total salivary antioxidant capacity [Moore et al. 1994; Hirayama et al. 1997; Meucci et al. 1998]. Uric acid, the most important antioxidant molecule in saliva [Terao et al. 1993; Moore et al. 1994; Kondakova et al. 1999], contributes approximately 70% of the total salivary antioxidant capacity, according to Moore et al. (1994), with the antioxidant role of ascorbic acid molecule being secondary [Terao et al. 1993; Moore et al. 1994]. Correlation between concentrations of uric acid in both saliva and plasma points the latter as the origin of salivary uric acid [Kondakova et al. 1999].

In the enzymatic salivary antioxidant system, peroxidase is by far the most important enzyme. Two peroxidase enzymes are found in saliva: salivary peroxidase, which resembles in structure and antigenic characteristics the lactoperoxidase found in bovine milk [Mansson-Rahemtulla et al. 1988, 1990; Marcozzi 1996], and myelo-peroxidase, produced by leucocytes in inflammatory regions of the oral cavity [Morrison et al. 1965; Kowolik & Grant 1983; Smith & Yang 1984; Pruitt et al. 1990; Revis 1977].

The involvement of reactive oxygen species (ROS) in periodontal pathology has been studied in last decades. Several studies [Asman et al. 1984; Henry et al. 1984; Shapira et al. 1991] have demonstrated that early onset forms of periodontitis are associated with functionally activated PMN exhibiting increased ROS production.

The detection of ROS oxidation products, the elevation of iron and copper ions, which catalyse the production of the most reactive-free radical species, and the identification of an imbalance in the oxidant/antioxidant activity within periodontal pockets, suggests a significant role for ROS in periodontal tissue destruction. In vitro studies have shown that ROS are capable of degrading a number of extracellular matrix components including proteoglycans, resulting in the modification of amino acid functional groups, leading to fragmentation of the core protein, while the constituent glycosaminoglycan chains undergo limited depolymerisation [Waddington et al. 2000].

Although extensive research has been done concerning the role of ROS and protective capacity of salivary antioxidants in periodontal disease, few have studied the role of excessive (high grade) oxidative stress in peri-implant disease. To our knowledge, there are no studies regarding the role of excessive oxidative stress and salivary antioxidant system in the pathogenesis of peri-implant disease at present.

Peri-implant disease is considered to be an inflammatory disease, but many aspects of its pathogenesis remain unknown. At present, peri-implant disease is considered to be initiated and perpetuated by a small group of predominantly Gram-negative, anaerobic, or micro-aerophilic bacteria that colonize the subgingival area. Bacteria cause the observed tissue destruction directly by toxic products and indirectly by activating host defence systems, i.e. inflammation [Page & Kornman 1997]. A variety of molecular species appears in the inflamed tissues, among them free radicals and ROS.

As all the patients participating in the study had no natural teeth (upper full denture and lower implant-supported overdenture wearers), we choose whole saliva as a medium for diagnostics. The overall advantages of using saliva as a diagnostic fluid have been recently reviewed [Streckfus & Bigler 2002]. The advantages of saliva compared with peri-implant sulcus fluid are (a) simple collection procedure and (b) non-invasive method of collection. Both issues were especially important concerning the age of patients (varied between 62 and 70 years). Saliva has been widely used for the quantification of different antioxidants and enzymes in oral cavity [Nagler et al. 2000; Reznick et al. 2003; Brock et al. 2004].

The purpose of this study was to assess levels of various antioxidants in saliva to identify differences between the saliva of patients with healthy peri-implant tissues and patients with peri-implant disease, and to examine whether the whole saliva of those with peri-implant disease conditions might have lower levels of antioxidants than those of healthy individuals.

Material and methods

Patient population

Thirty totally edentulous patients (62–70 years of age; 14 men, 16 women) with implant supported overdentures (Ankylos® dental implants, DentsplyFriadent, Germany), from the group of patients who were receiving maintenance care, were selected to participate in this study. All the patients had two implants in lower jaw.

Before the start of the study the subjects gave their informed consent. Inclusion criteria were: (1) presence of two endosseous dental implants, (2) appropriate overdentures, (3) the same soft tissue biotype among all the patients, (4) healthy oral mucosa (no denture stomatitis, etc.), (5) no history of antibiotic treatment before the study for 3 months, (6) no history of medical conditions that required antibiotic prophylaxis, (7) negative history of chronic corticosteroid use, (8) no history of medication interfering with saliva secretion and (9) no history of taking nutritional supplements for 3 months. As smoking adversely affects antioxidant capacity in biological fluids [Zappacosta et al. 1999; Nagler et al. 2000; Reznick et al. 2003], all patients included in the study were non-smokers.
A complete oral examination was carried out before sialometry and measurement of clinical parameters.

Clinical examination

The clinical evaluations were performed by single examiner [S. L.]. The clinical examinations included assessment of peri-implant pocket probing depth (PPD) [mm], gingival index [GI] [0, 1, 2, or 3] [Löe & Silness 1963] and bleeding on probing [BOP] [0 or 1]. The PPD was measured to the nearest millimeter with a pressure-calibrated periodontal probe with a tip diameter of 0.5 mm and a probing force of 0.25 N [ClickProbe®, Hawe-Necos Dental, Bioggio, Switzerland] (Karayannis et al. 1994).

Criteria for health and disease

Studied patients were categorized on the basis of PPD, GI and BOP into two different groups: patients with peri-implant disease (peri-implantitis and peri-implant mucositis) and healthy patients. The criteria have been referred to in previous reports [Pontoriero et al. 1994; Mombelli & Lang 1998]. Briefly, peri-implantitis is defined as inflammation process around implants with loss of supporting bone and peri-implant mucositis is defined as reversible inflammation of the soft tissues with no loss of supporting bone.

The selection criteria were as follows: [1] in the healthy group both implants had no signs of peri-implant disease and in the peri-implant disease group both implants were affected with peri-implant disease, [2] patients in healthy and diseased groups had to conform to the clinical parameters shown in Table 1.

Sialometry

Unstimulated (resting) saliva specimens were obtained in the morning, and no oral stimulus was permitted for 90 min before collection. Saliva was collected before clinical evaluations were made. Whole saliva was collected by open suction method. Briefly, saliva was aspirated from the floor of the mouth into a test tube by a saliva ejector connected to the aspiration system. The ejector was gently swept around the subject’s mouth in a circular motion with one pass in the buccal vestibules and around and under the tongue at approximately 158 intervals for 5 min. Subsequently, a 2% citric acid solution was applied to the tongue dorsum bilaterally at 30 s intervals. After 2 min, glands were again stimulated while whole saliva was collected by the same method. Salivary gland flow rates are expressed as volume of saliva [ml] secreted per minute. The mean volume of saliva secreted [ml/min] under resting conditions was 0.43 ± 0.17 ml/min. Under stimulated conditions this value was 1 ± 0.16 ml/min.

All samples were assayed for blood contamination using an enzyme immunoassay kit for transferrin (Salimetrics, State College, PA, USA). Transferrin is a large protein prevalent in blood at very high concentrations. Its large size prevents transferrin from being passively or actively transported from the general circulation into saliva. Saliva samples were assayed for transferrin using an enzyme immunoassay as described by Kivlghan et al. 2004. Contaminated samples were not included in the study.

Table 1. Clinical assessment and diagnosis of implants

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>PPD (mm)</th>
<th>GI</th>
<th>BOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients with peri-implant disease</td>
<td>≥ 4</td>
<td>≥ 1</td>
<td>1</td>
</tr>
<tr>
<td>Healthy patients</td>
<td>≤ 3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

BOP, bleeding on probing; GI, gingival index; PPD, pocket probing depth.

Salivary uric acid concentration

Uric acid concentration was measured with a kit supplied by Roche Diagnostics GmbH (Mannheim, Germany). In this assay, uric acid was transformed by uricase into allantoin and hydrogen peroxide, which under the catalytic influence of peroxidase oxidized the cromogen [4-amino- 

Salivary ascorbic acid concentration

Ascorbic acid concentration was measured according to Ihara et al. [2000]. Briefly, ascorbic acid is oxidized by 4-hydroxy-2,2,6,6-tetramethylpiperidinoxy, free radical [TEMPO] to dehydroascorbic acid. The latter condenses with o-phenylenediamine [OPDA] to form a quinoxaline derivative that absorbs light at 340 nm. The change in absorbance at 340 nm is proportional to the concentration of ascorbic acid in specimen.

Salivary total antioxidative status (TAS)

The assay used was based on a commercial kit supplied by Randox Laboratories [Ardmore, UK] in which metmyoglobin in the presence of iron was turned into ferrymyoglobin. Incubation of the latter with the Randox reagent 2,2’-azino-bis-[3-ethylbenzothiazoline sulphonate] [ABTS] resulted in the formation of a blue-green coloured radical that could be detected at 600 nm. Inhibition of the radical formation of ABTS*⁻ by antioxidant was calculated in millimolar quantities of ABTS disappearance.

Statistical analysis

For all variables mean and standard deviation [SD] for patients in different categories are presented. For statistical comparison between groups, Student’s t-test was used. To archive approximate normal distribution, log-transformed values of myeloperoxidase levels were used for testing. All tests were conducted at conventional 5% significance level. For statistical analysis software package R 2.0.0 for Windows [http://www.r-project.org] was used.

Results

Patient data and clinical results

Twelve patients showed signs of peri-implant disease. A second group of 18 patients with healthy peri-implant tissues was used as control.
The study of Sculley & Langley-Evans (2003) indicated that subjects with the worst periodontal health status tended to

Table 2. Patient demographics (n = 30) and clinical data

<table>
<thead>
<tr>
<th></th>
<th>Healthy (n = 18)</th>
<th>Diseased (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>8♂ and 10♀</td>
<td>6♂ and 6♀</td>
</tr>
<tr>
<td>Mean age (range)</td>
<td>66 ± 2.5 (62–70)</td>
<td>65.8 ± 2.2 (63–69)</td>
</tr>
<tr>
<td>PPD (mean ± SD)</td>
<td>2.63 (0.52)</td>
<td>3.85 (0.38)</td>
</tr>
<tr>
<td>% sites with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gingival inflammation (GI ≥ 1)</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Bleeding on probing (BOP = 1)</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>R</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>0.41 ± 0.10</td>
<td>0.31 ± 0.09</td>
</tr>
<tr>
<td>Diseased</td>
<td>0.19 ± 0.07</td>
<td>0.12 ± 0.03</td>
</tr>
<tr>
<td>P</td>
<td>0.0004</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

BOP, bleeding on probing; PPD, probing pocket depth.

Table 3. Total antioxidant status (TAS) of resting (R) and stimulated (S) saliva samples from healthy and diseased subjects

<table>
<thead>
<tr>
<th></th>
<th>Healthy</th>
<th>Diseased</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAS (mM/l) ± SD</td>
<td>R</td>
<td>S</td>
</tr>
<tr>
<td>Healthy</td>
<td>0.41 ± 0.10</td>
<td>0.31 ± 0.09</td>
</tr>
<tr>
<td>Diseased</td>
<td>0.19 ± 0.07</td>
<td>0.12 ± 0.03</td>
</tr>
<tr>
<td>P</td>
<td>0.0004</td>
<td>&lt;0.0001</td>
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</table>

The total salivary antioxidant status is shown in Table 3, revealing a significantly lower activity in patients with peri-implant disease as compared with healthy subjects. Significant differences were observed both in resting and stimulated saliva (P = 0.0004 and P<0.0001, respectively). The results of measurements of individual antioxidants in healthy subjects are shown in Table 4. Calculation of antioxidant production rates [per minute] showed that when salivary flow is taken into account, significantly more urate [P<0.0001], ascorbic acid [P<0.0001] and myeloperoxidase [P<0.0001] is secreted during salivary stimulation. The antioxidant composition of the saliva from patients with peri-implant disease was measured and summarized in Table 5. We also observed that under stimulation, significantly higher activity in patients with peri-implant disease. At the same time, myeloperoxidase [P<0.0001] and uric acid [P<0.0001] are secreted in saliva, if salivary flow rate is taken into account.

Table 4. The myeloperoxidase, uric acid and ascorbate concentrations and production rates in resting (R) and stimulated (S) saliva samples from healthy subjects

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
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<tbody>
<tr>
<td></td>
<td>Uric acid</td>
</tr>
<tr>
<td></td>
<td>μM/l</td>
</tr>
<tr>
<td>R</td>
<td>307.20 ± 78.06</td>
</tr>
<tr>
<td>S</td>
<td>241.50 ± 89.09</td>
</tr>
</tbody>
</table>

Table 5. The myeloperoxidase, uric acid and ascorbate concentrations and production rates in resting (R) and stimulated (S) saliva samples from subjects with peri-implant disease

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uric acid</td>
</tr>
<tr>
<td></td>
<td>μM/l</td>
</tr>
<tr>
<td>R</td>
<td>120 ± 36.15</td>
</tr>
<tr>
<td>S</td>
<td>91.60 ± 39.35</td>
</tr>
</tbody>
</table>

Biochemical analysis of saliva

The total salivary antioxidant status is shown in Table 3, revealing a significantly lower activity in patients with peri-implant disease as compared with healthy subjects. Significant differences were observed both in resting and stimulated saliva (P = 0.0004 and P<0.0001, respectively). The results of measurements of individual antioxidants in healthy subjects are shown in Table 4. Calculation of antioxidant production rates [per minute] showed that when salivary flow is taken into account, significantly more urate [P<0.0001], ascorbic acid [P<0.0001] and myeloperoxidase [P<0.0001] is secreted during salivary stimulation. The antioxidant composition of the saliva from patients with peri-implant disease was measured and summarized in Table 5. We also observed that under stimulation, significantly more urate [P<0.0001], ascorbic acid [P<0.0001] and myeloperoxidase [P<0.0001] are secreted in saliva, if salivary flow rate is taken into account.

Discussion

Several studies indicated that there are increases in nitric oxide synthesis [Matejka et al. 1998], superoxide anion levels and myeloperoxidase activity [Cao & Smith 1989] in the inflamed periodontium. ROS play important roles in physiological and immunoinflammatory reactions [Battino et al. 1990; Waddington et al. 2000]. In the human body, there is an antioxidant mechanism to maintain the balance of oxidation–reduction [Teng 2003]. The breakdown of this balance (i.e. increased ROS) could lead to increased damage directly by ROS. Indeed, several diseases have been correlated to an imbalance of oxidation–reduction or excessive oxidative stress [Halliwell 1993; Liu & Mori 1999; Macnee & Rahman 1999; Zhang et al. 2000]. There are two possible causes for the excessive oxidative stress: increased ROS with no concomitant or less increased levels of antioxidants, or substantially decreased levels of antioxidants with no marked change of ROS. Enhanced superoxide anion production with no change of the antioxidant activity in gingival fluid of patients with chronic adult periodontitis, presumably due to the bacterial stimuli, has been reported [Gurrieri et al. 1991; Shapira et al. 1994]. More recently, Brock et al. (2002a, 2002b) reported that antioxidant defense is reduced, and non-surgical therapy with improvements in clinical parameters can increase the antioxidant defense in chronic periodontitis patients. Similar results were reported in the recent study by Tsai et al. (2005).

The study of Sculley & Langley-Evans (2003) indicated that subjects with the worst periodontal health status tended to...
Table 6. Antioxidant activity of saliva from healthy subjects and subjects with peri-implant disease

<table>
<thead>
<tr>
<th>Antioxidants</th>
<th>Saliva</th>
<th>Resting</th>
<th>Stimulated</th>
<th>Healthy</th>
<th>Diseased</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urate (μM/l)</td>
<td></td>
<td></td>
<td></td>
<td>307.2</td>
<td>120</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Ascorbate (mg/l)</td>
<td>2.79</td>
<td>1.54</td>
<td>0.003</td>
<td>2.79</td>
<td>1.54</td>
<td>0.003</td>
</tr>
<tr>
<td>TAS (mM/l)</td>
<td>0.41</td>
<td>0.19</td>
<td>0.0004</td>
<td>0.31</td>
<td>0.12</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

TAS, total antioxidant status.

Table 7. Myeloperoxidase activity (ng/ml) of saliva from healthy subjects and subjects with peri-implant disease

<table>
<thead>
<tr>
<th>Saliva</th>
<th>MPO activity in saliva</th>
<th>Healthy</th>
<th>Diseased</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting</td>
<td></td>
<td>50.6</td>
<td></td>
<td>0.001</td>
</tr>
<tr>
<td>Stimulated</td>
<td></td>
<td>26.2</td>
<td></td>
<td>0.0008</td>
</tr>
</tbody>
</table>

have greater oxidative injury. This is wholly consistent with the hypothesis that there is enhanced ROS-mediated damage to tissues in the most advanced stages of periodontal disease [Sculley & Langley-Evans 2002]. It is unlikely that oxidative processes play a causal role in the aetiology of periodontitis, but they are likely to contribute to disease progression unless abated through antioxidant action. Recent study [Sculley & Langley-Evans 2003] has demonstrated that subjects with advanced periodontitis and evidence of oxidative injury had the lowest TAS rates. This is believed to be the consequence of antioxidant depletion due to the ongoing free radical activity and destruction of scavenging antioxidant species.

Recent evidence shows that urate is the major antioxidant component in saliva [Lennander-Lumikari et al. 1998; Scully & Langley-Evans 2003]. Urate, ascorbate and albumin contribute most of the antioxidant protection in whole saliva, but there is evidence of a salivary peroxidase enzyme too [Lennander-Lumikari et al. 1998]. It is not clear whether the urate content of whole saliva directly reflects plasma concentrations or concentrations present in gingival crevicular fluid.

In the present study, two groups of patients were identified by clinical observations: a first group comprising patients with healthy dental implants and a second group including fixtures with inflammatory lesions. The current study included a rigorous pre-sampling protocol. As smoking is known as a source of ROS, ‘reducer’ of antioxidants [Pryor & Stone 1993] and risk factor for periodontal disease [Haber et al. 1993], only non-smokers were included in the study. Patients having whether two healthy or two diseased implants were included to the healthy and diseased groups, respectively. Strict clinical criteria were used to identify healthy and diseased groups; patients were identified as diseased only when all clinical parameters were showing signs of disease [PPD ≥ 4 mm, GI ≥ 1 and BOP = 1] and as healthy only when all clinical parameters allowed identifying peri-implant health [PPD ≤ 3 mm, GI = 0 and BOP = 0].

Our study data indicated that MPO activity in saliva is increased in patients with peri-implant disease. These findings are similar to those of a previous study in which peri-implant sulcus fluid around diseased implants had higher MPO activity compared with healthy sites (Liskmann et al. 2004).

Total antioxidant status of saliva and concentration of uric acid and ascorbate, which are the main salivary antioxidants, are significantly decreased in patients with peri-implant disease. This may indicate that excessive ROS production in peri-implant disease is leading to the situation of excessive oxidative stress, which may be an important factor contributing the destruction of peri-implant tissues.

Local decreases in antioxidant capacity in peri-implant sulcus fluid are likely to be of greater significance in the aetiology of peri-implant disease and associated damage to the implant supporting structures than the more systemic changes we have noted in whole saliva. The presence of antioxidants bathing the peri-implant sulcus may be of major importance in dampening down inflammatory processes initiated by bacterial infection. Obtaining and analyzing peri-implant sulcus fluid samples is, however, a complex process requiring a degree of specialization. The results of this study suggest that whole saliva may contain simply measured indicators of oxidative processes and may provide a tool for developing and monitoring of new treatment strategies. The importance of these findings may be also that the treatment of peri-implant disease may involve adjuvant anti-oxidants supplementation together with cumulative interceptive supportive therapy concept introduced by Mombelli & Lang (1998).

The results of this investigation should be interpreted with caution due to the cross-sectional design. This particular study is of explorative value. We suggest that longitudinal monitoring of the antioxidant profile of human saliva may confirm present results.


References


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