The relevance of physico-chemical and diagnostic properties of saliva during orthodontic treatment
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Abstract
Saliva is the principal defensive mechanism in the oral cavity and is critical for preserving and maintaining the health of oral tissues. The physico-chemical properties of saliva are affected by the local factors in the oral cavity and general health of an individual. Orthodontic treatment significantly affects the chemical composition and physical nature of oral fluids. The alteration in the properties of saliva can be utilized to evaluate the advent of orthodontics treatment in an individual. The present article focuses on the relevance of the physico-chemical properties of saliva during the progression of orthodontic treatment and the significance of saliva as a diagnostic analyte during orthodontic treatment.

Keywords: Contamination, orthodontic bonding, physico-chemical, saliva

Introduction
Saliva is the principal defensive mechanism in the oral cavity and is critical for preserving and maintaining the health of oral tissues. The composition and physical properties of saliva are subject to changes by the local and systemic conditions of an individual. Patients who undergo orthodontic therapy present with oral ecologic changes because of the retentive nature of the orthodontic appliances. These appliances create an ecological niche for bacterial activity leading to changes in the oral environment thus altering the salivary profile. The physico-chemical properties of saliva determine the progress of orthodontic treatment and its adverse effects in an orthodontic patient. Thus, continuous monitoring of the salivary composition, pH, flow rate and its chemical profile is desirable in orthodontic patients enabling the clinicians a better control over the orthodontic treatment. The present article summarizes the role of saliva during various stages of orthodontic treatment.

Orthodontic Bonding
The first step of orthodontic treatment in the oral cavity begins with bonding of the fixed orthodontic appliances on the dentition. Orthodontic appliances are bonded to the tooth surface using polymeric materials. Contamination by moisture, saliva or blood during bonding procedures leads to a reduced bond strength of orthodontic brackets.[1] Non-contaminated enamel surfaces have the highest bond strengths but saliva contamination leads to lower shear bond strengths for metallic brackets.[2] Mehmet et al. studied the effect on shear bond strength of four adhesives after salivary contamination and found a reduction in the bond strength values of most of the adhesives.[3] Prasad et al. in their study evaluated the effect of salivary and blood contamination on bond strengths of conventional and self-etching bonding systems. They suggested that the contamination during the bonding procedure reduced the shear bond strength of all groups.[4] Mao et al. demonstrated the effect of salivary contamination at various steps of bonding procedure and concluded that salivary contamination both before and after the application of the primer could significantly reduce the shear bond strength of orthodontic brackets.[5] Paschos et al. used artificial saliva in their study and showed contamination by saliva significantly decreased the bond strength when using the conventional acid-etching method.[6] Detailed investigations of the effect of saliva on the alteration of polymeric material properties has not been broadly covered.
in the dental materials literature but it has been suggested that
the presence of high mucous protein content and enzymes in
saliva would result in increased degradation reactions in the
adhesive. Water sorption by the adhesive matrix leads
to plasticizing of the polymer and a notable reduction of its
mechanical properties and physical characteristics.[17] It can also
cause hydrolytic breakdown of the filler surface through either
elemental leaching from the filler surface or destruction of the
filler-matrix bonding.[6]

Thus, orthodontic bonding procedure requires complete
isolation to prevent the contamination of the tooth surface
leading to adequate bond strength of the orthodontic adhesives.
Further, newer materials like moisture insensitive and hydrophilic
adhesives have been developed to aid in orthodontic bonding
in cases where salivary contamination is difficult to control.[9]
Deprá et al. concluded in their study that saliva contamination
reduced bond strength when a conventional hydrophobic resin
composite was used. However, the hydrophilic resin was not
affected by the contamination.[10]

Few authors have suggested that use of self-etching primers
could lead to improved bonding in cases where moisture
control is difficult.[11-14] In situations in which moisture
contamination is critical there is a distinct advantage in using
hydrophilic primers.[15] Cyanoacrylates have been tested in
various studies and have shown better performance under conditions
where there was a salivary contamination. Although shear bond strength of cyanoacrylate adhesive has been found
to be significantly lower than other adhesives, it is the
only adhesive that is not affected by contamination.[16] Hence,
cyanoacrylate adhesive is indicated under moist conditions
(particularly the saliva), and when a short setting time is
required.[17]

Ciola et al. tested a moisture insensitive primer on wet enamel
and showed that it had higher bond strength outcomes compared
to one-step etching primer.[14] Silverman et al. suggested the use
of a light cured glass ionomer which exhibited sufficient tensile
strength in the presence of salivary contamination.[19] Few
researchers have also suggested the role of protective liquid
polish in preventing the effect of contamination by blood or
saliva.[20]

**Remineralization of White Spot Lesions**

The enamel decalcification is one of the most common and
undesirable complications of the orthodontic therapy.[21]
Lee et al. demonstrated the formation of salivary pellicles on
the surface of various orthodontic materials indicating their
significance in the formation of bacterial adhesions during
orthodontic treatment.[22] Bacterial growth promoted by
the orthodontic appliances leads to decalcification of the
mineralized tooth surfaces.[23] Demineralization of the enamel
around brackets can be an extremely rapid process, which
appears most frequently on the cervical and middle thirds of
the buccal surfaces of the maxillary lateral incisors, mandible
canines and the first premolars.[24] Saliva acts as a reparative
medium against the demineralizing activity during orthodontic
treatment. The reparative properties of saliva toward early
demineralizing erosions have been shown in vitro studies.[24,26]
Saliva acts as a remineralizing medium due to its protective
properties such as salivary clearance, buffering power and its
chemical composition.

**Salivary Flow**

**Continuous salivary flow**

It is the quantity of saliva which is produced at rest, without
any exogenous or pharmacological stimulation. It is the basal
unstimulated secretion which occurs as film that covers,
moisturizes, and lubricates the oral tissues.

**Stimulated saliva**

Stimulated saliva as name suggests is produced by mechanical,
gustatory, olfactory, or pharmacological stimulus and
contributes to 80-90% of daily salivary production. In adults,
normal total stimulated salivary flow ranges from 1 to 3 mL/min
and the normal unstimulated salivary flow ranges from 0.25 to
0.35 mL/min. Enhanced remineralization of white spot lesions
by stimulated salivary flow (e.g., from chewing a sugar-free gum)
illustrates dynamic protective effects of saliva.[16] Salivary flow can
be used as a clinical marker, which can be used to evaluate the
oral health of orthodontic patients.

**Salivary pH**

Salivary pH is a measurement of acidity or alkalinity of the
saliva. Normal pH of saliva is 6.3, but could be modified by an
oral health. Decrease in salivary pH increases the susceptibility
towards enamel demineralization. The pH at which enamel
demineralization begins is the critical pH. Orthodontic
appliances favor retention of food debris, decreasing salivary
pH, thus increasing the microbial action. The oral health of
orthodontic patients can be evaluated by assessing the pH of
saliva using pH strips.

Increase in salivary pH after placement of orthodontic
appliances indicates the anti-demineralization properties of
saliva.[9] Carillo et al. evaluated various clinical markers along
with salivary pH in 34 orthodontic patients and showed
an increase in salivary pH highlighting the increase in host
response on change in oral environmental conditions.[25]
Peros et al. conducted a study to determine the physiologic
changes of salivary flow rate, pH, and buffer capacity and
the levels of *Streptococcus mutans* and *Lactobacillus* spp. in
patients undergoing fixed orthodontic treatment. They found a
significant increase in stimulated salivary flow rate and salivary
pH. They suggested that the 6-12th week of orthodontic therapy
is the period of the most intensive intraoral growth of *S. mutans*
and *Lactobacillus* spp.[26]

Although contradictory results were shown by Bonnetti et al.
who showed that the placement of fixed orthodontic appliances
did not change the salivary pH, buffer capacity and flow rate after 1 year of treatment, most of the studies have shown a favorable change in the properties of saliva promoting remineralisation of decalcification lesions.\(^{[9]}\)

**Cleansing Action and Buffer Capacity**

Saliva helps in mechanical cleansing of the residues like bacteria and debris in the oral cavity. Buffer capacity is the salivary ability to neutralize acids saliva buffers the acidic environment of the oral cavity thus preventing the growth of micro-organisms. Buffer capacity of the saliva can be measured by using reactive strips and thus indicating the host response toward acidic oral environment. An increase in buffer capacity of saliva was seen in orthodontic patients by Chang et al.\(^{[9]}\)

**Salivary Composition**

Salivary fluid is an exocrine secretion which comprises of approximately 99% water, electrolytes (sodium, potassium, calcium, chloride, magnesium, bicarbonate, phosphate), glucose, nitrogenous products and proteins, which include enzymes, immunoglobulins, antimicrobial factors, mucosal glycoproteins, and traces of albumin.\(^{[11]}\) The dissolution and deposition of minerals of the hydroxyapatite in enamel are regulated by various structural components of saliva. These include the inorganic, i.e., calcium and phosphate levels and fluoride content. The organic factors include proline-rich proteins (PRPs), statherins, cystatins and histatins. Many components in saliva are taken up by dental biofilm and protect the enamel surface. The ability of the biofilm to sequester calcium, phosphate and fluoride from the saliva, as well as from sources outside the oral cavity allows enamel to undergo remineralization after demineralization.

**Calcium and Phosphate Ions**

Calcium availability remains the singular limiting factor in enamel remineralisation. While phosphate levels in resting saliva do not vary markedly, large fluctuations in calcium concentrations occur in an individual.\(^{[12]}\)

Differences in calcium concentration have important implications for the critical pH and for the possibility of remineralization, since the latter will not occur when the degree of saturation of saliva with respect to tooth mineral is low. Remineralization may be enhanced by providing low levels of bio-available calcium and phosphate ions.\(^{[13]}\)

**Fluoride Ions**

Fluoride adsorsbs to the surface of the partially demineralized crystals and attracts calcium ions. Fluoride speeds up the growth of the new surface by bringing calcium and phosphate ions together and is also preferentially incorporated into the remineralized surface.\(^{[14]}\) This produces a surface that is more acid resistant. A continuous supply of fluoride ions decreases the caries susceptibility of the enamel which can be made available by various fluoride releasing solutions, varnishes and toothpaste.\(^{[15]-[17]}\)

**Salivary Proteins**

Salivary proteins include PRPs, statherins, cystatins and histatins. The acidic PRPs bind to hydroxypatite, bind calcium ions, and inhibit crystal growth of calcium phosphate in supersaturated solutions.\(^{[18]}\) When adsorbed onto the hydroxypatite, the acidic PRPs are capable of binding numerous oral bacteria, which might reduce the acidic action of bacteria on enamel. Statherins and histatins also bind with high selectivity to hydroxypatite\(^{[19]}\) and inhibit crystal growth of calcium phosphate salts. In vitro studies on human enamel have shown that Histatin-1 enhances the rate of remineralisation when compared to statherin.\(^{[20]}\) Thus, organic components of saliva also play a significant role in enamel remineralisation.

**Role in Sliding Mechanics**

Various in vitro studies have been conducted to evaluate the effect of dry and wet states on friction between orthodontic brackets and arch wires. When human saliva and dry testing were compared, the human saliva sometimes behaved as an adhesive (e.g., steel-on-steel couples) but at other times behaved as a lubricant (e.g., beta titanium archwires on stainless steel brackets). Ho et al. evaluated the frictional values when different archwires were pulled a distance of 2 mm through ceramic and stainless steel brackets. They concluded that lubrication in the form of saliva reduced friction.\(^{[30]}\) Stannard et al. evaluated the effect of dry state and artificial saliva on the frictional properties of different archwires and suggested that artificial saliva did not increase friction for cobalt chromium, stainless steel sliding against stainless steel, or stainless steel wire on Teflon compared to the dry condition.\(^{[31]}\) Leal et al. conducted a study evaluating the effect of dry state, human saliva and artificial saliva medium and concluded that dry states and water leads to increased friction when compared to friction values present in salivary media.\(^{[32]}\) Downing et al. showed an increase in friction between stainless steel and ceramic brackets when used with various archwire materials in the presence of artificial saliva. In most of the literature, it was confirmed that human saliva substantially facilitates sliding of wire-bracket couple beyond the dry state. Thus, the presence of saliva in the oral cavity reduces friction at the wire bracket interface in the orthodontic appliances.\(^{[31]}\)

**Use as a Diagnostic Analyte**

Whole saliva is most often studied because its collection is easy, non-invasive and rapid to obtain without the need for
specialized equipment. Saliva can be used as a diagnostic medium to detect the biomarkers of orthodontic tooth movement. The underlying mechanism for tooth movement is an inflammatory process in the periodontal tissues which is mediated by biochemical molecules. These molecules can be detected in saliva and can be used to assess the progress of orthodontic treatment. Immunological factors like RANKL/OPG ratio, interleukin (IL)-8, granulocyte-macrophage-colony-stimulating factor, IL-1β and tumor necrosis factor-alpha have been detected in the saliva of orthodontic patients. Increase in the levels of molecules like salivary IgA have also been linked to root resorption in orthodontic patients. Chair-side diagnostic kits are being developed to analyze these biomarkers and thus to provide the clinicians an opportunity to monitor and manipulate the progress of orthodontic treatment.

Salivary samples can also be used to assess the metal ions that leach out from orthodontic appliances. In orthodontics, a lot of emphasis has been laid on release of nickel and chromium ions because of the hazardous nature of these elements. Several studies have been conducted to detect nickel ions levels in saliva in patients undergoing orthodontic treatment, although, no significant differences have been found in the salivary levels of metals in orthodontic patients and normal population.

Senkutvan et al. evaluated the release of Ni and Ti from four types of archwires stored in artifical saliva. They found large variation in concentration of Ni released but the amount of Ni ions released in all test solutions diminished with time and was below the critical value necessary to induce allergy and below daily dietary intake level. Milošev et al. used artificial saliva medium to evaluate the effect of fluoride ions on the dissolution of metals from archwires. Briceno et al. determined the effect of different phases of NiTi wires on their corrosion in artificial saliva and concluded that martensitic phase improved the corrosion resistance of these wires. Amini et al. conducted a study to evaluate the effect of stress on salivary metal ions levels from archwires. They suggested that the induction of stress led to increasing in nickel ions concentration and gradual increase in chromium ion concentration. Zhang et al. tested the biocompatibility of composite archwire in artificial saliva solutions simulating oral environment thus suggesting a new biomaterial for application as orthodontic material. Zhang et al. studied the corrosion behavior of composite archwires in the presence of protein in artificial saliva and suggested that low protein content led to increased corrosion of wires. Brandão et al. evaluated the corrosion of metal brackets due to brushing with dentifrices. Artificial salivary medium was used for evaluation, and they concluded that immersion in artificial saliva did not affect alter the surface corrosion of these brackets. Huang et al. showed that diamond like coating of archwires had lesser wear using artificial saliva. Knutson et al. evaluated the corrosion of temporary anchorage devices in artificial saliva and effect of fluoride on their corrosion. They showed that presence of fluoride in saliva increased carrion of temporary anchorage devices.

**Conclusion**

It is important for the clinicians to have knowledge of the role of saliva and the changes in its physico-chemical properties during orthodontic treatment. This would enable the orthodontists in monitoring the progress of orthodontic treatment and control its adverse effects like enamel demineralization from the initial stages. Further research in this field will also help the orthodontists in managing patients suffering from systemic conditions featuring xerostomia. Newer chair-side diagnostic kits and lab-on-chip technologies need to be developed so that real-time monitoring of salivary samples can be done in orthodontic patients.

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