NARRATIVE REVIEW

Methods of assessment of early dentine erosion: a review

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Abstract

Dentine erosion is an increasingly recognised problem, especially in aging population, and various methods have been utilised for its assessment. This narrative review was planned to summarise the methods for the assessment of the early stages of dentine erosion. Relevant original articles published in the English language from 2013 to 2017 were reviewed. Laboratory techniques and methods with in vivo potential were separately studied. It is evident that the assessment of early dentine erosion is complex and requires a combination of methods. For clinical evaluation, chemical analysis and optical methods show great potential but are in need of more validation.

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Introduction

Dental erosion has been defined as a chemical process that involves the dissolution of enamel and dentine by acids not derived from bacteria when the surrounding aqueous phase is under-saturated with respect to tooth mineral.[1] Initial exposure of sound enamel or dentine to acid results in surface-softening where there is partial dissolution of mineral[2] and surface substance loss has not ensued. At this stage, these acid-softened tissues are remineralisable[3] and susceptible to mechanical wear. Progressive acid attack will subsequently lead to irreversible surface loss,[4] which may be a painful experience for the patient and extensive restorative treatment will eventually be needed. Timely detection of the early lesions followed by appropriate preventive therapy is imperative to arrest and reverse these lesions. This would lead to a better aesthetic and functional outcome for the patient.

Dentine is often exposed at the cervical area where the enamel layer is relatively thin[5] or on the root when there is gingival recession and loss of cementum.[6] In the coronal area, exposed dentine is frequently found on worn cusps.[7] Moreover, gingival recession can also result in the loss of cementum which makes the exposed dentine surfaces prone to dentine erosion.[6] Therefore, early detection of not only enamel erosion but also dentine erosion is imperative and dentine too should be considered an important target tissue for anti-erosion strategies.[5] In order to test the efficacies of anti-erosion strategies, assessment of erosion progression over the period of therapy is required. Over the years, various methods have been proposed for the assessment of dental erosion with most of them more suited to enamel.[8] Less importance has been given to the assessment methods suitable for erosion softening stage of dentine. The current literature review was planned to provide a critical overview of some frequently applied methods for the quantification and monitoring of early dentine erosion. The methods discussed were categorised into laboratory and in vivo methods (Table-1).

Table-1: Potential methods for assessing early dentine erosion.

Laboratory methods	Methods with in vivo potential
■ Surface hardness	■ Chemical analysis.
◆ Surface micro-hardness.	■ Optical methods.
◆ Nano-hardness.	◆ Non-contact profilometry.
■ Atomic force microscopy.	◆ Quantitative light induced fluorescence.
■ Microradiography.	◆ Optical coherence tomography.
	◆ Optical specular and diffuse reflection.

Laboratory Methods

Surface Hardness

Surface micro-hardness has been claimed to be the most useful assessment technique for the investigation of softening stage of enamel.[9] Dentine, as opposed to enamel, is a highly elastic tissue. It has been found that the micro-indentations made on demineralised dentine with a load of 500g for 10 seconds were unstable and reversed by about 30% within the first 24 hours.[10] Therefore, it has been recommended that indentations in dentine applied with forces as high as 500g be measured after 24 hours. However, this arrangement would not be feasible for longitudinal study designs where the measurements may have to be repeated within 24 hours depending on the study protocol. For lower forces, no clear-cut instructions have been given.[11] This indicates

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that micro-hardness might have limited applicability in the assessment of early dentine erosion.

Nano-hardness seems to be a more suitable tool than micro-hardness for the assessment of dentine erosion. Dentine has a complex structure composed of a composite micro-structure of dentinal tubules, peri- and inter-tubular dentine. Not only does each component have a distinct hardness and elastic modulus value, the diameter of the tubules and the relative density of these structures are location-dependent. The size of micro-hardness indenter is generally larger than micro-structures of dentine and so it gives only a composite average of hardness and elastic properties of peri-tubular dentine, inter-tubular dentine and tubular orifices. Nano-hardness, because of its smaller size, can allow the measurement of properties of peri-tubular and inter-tubular dentine separately rather than giving only a composite average. This gives a more accurate picture of material properties of dentine as it eliminates the possibility of competing effects of tubular morphology and density.[12]

However, as each micro-structure of dentine has a distinct hardness value, the indent has to be made at the same component at every measurement. This is especially important if several measurements are to be made for instance in a longitudinal study design. Therefore, for visual control, a combination of atomic force microscopy and nano-indentation has been proposed.[13] With nano-hardness, dentine can be measured in hydrated conditions, which is an added advantage.[14] Moreover, nano-hardness has the ability to be used on unpolished, native surfaces and might have the potential of being employed in the in vivo conditions.[11] However, the need to indent specifically at the same dentinal component repeatedly would be time-consuming and non-feasible for longitudinal studies.

Atomic force microscopy

Atomic force microscopy (AFM) had been used to evaluate dentine demineralisation both qualitatively and quantitatively. Quantitatively, the surface roughness of demineralised dentine has been assessed with AFM and it was found that the average roughness (Ra) of dentine after 20 seconds of etching with 32% phosphoric acid was significantly different from that of baseline.[15] Qualitatively, it was found that dentine demineralised by 10 vol% citric acid for 15 seconds followed by immersion in 6.5 vol% sodium hypochlorite for 100-200 seconds could be visualised with AFM at a level at which single collagen fibres could be identified.[16] More recently, topographical and numerical analysis of dentine surface was performed by AFM to evaluate the efficacy of a new formulation toothpaste for the prevention of dentine erosion.[17]

It appears that AFM is highly suitable for the assessment of early dentine erosion because of its ability to qualify and quantify erosion at an atomic level in real time on native surfaces. However, the time needed in scanning and its ability to scan only a small area might limit its usefulness for longitudinal studies.

Micro-Radiography

Transverse micro-radiography (TMR) has been regarded as the gold standard method for measuring erosion. TMR has shown to be sensitive enough to measure very small substance loss and discriminate between different degrees of demineralisation in dentine.[18] However, extensive and destructive specimen preparation required for the analysis makes this technique inappropriate for longitudinal study designs. Longitudinal microradiography (LMR), on the other hand, enables the samples to be non-destructively analysed multiple times, making it suitable for longitudinal studies. However, the increase in thickness of sample compromises the sensitivity of the technique. As a result, this method is not able to measure the minor changes in mineral and might have limited applicability in studies investigating early erosion.[19]

Methods with in Vivo Potential

Chemical Analysis

Quantification of calcium and phosphate ions released from dental hard tissues as a result of dental erosion is a well-established and sensitive technique for assessment of erosion. Being very sensitive to early changes in erosion,[18] these methods might prove useful for the assessment of early dentine erosion. These methods have been employed in the in vitro, in situ and in vivo studies, but the presence of saliva in vivo can cause problems with the analysis.[13] Moreover, these methods have to be combined with the other techniques since they do not provide any structural information.

Optical Methods

Non-contact Surface Profilometry

Surface profilometry is frequently used for quantification of tissue-loss in erosion-related research. After being established for use in the in vitro and in situ erosion studies, it was further adopted for in vivo research[20] indirectly via resin replicas. With profilometry, the advanced stages of erosion can be quantified by measuring loss of dental hard tissue between treated and non-treated areas or early stages of erosion could be assessed by means of surface roughness parameters.[13]

Profilometry has been thoroughly validated for the assessment of enamel erosion.[21] Dentine erosion, however, has a complex histology and assessment of dentine erosion with profilometry requires a few considerations. Erosion in dentine results in centripetal loss of peri-tubular dentine and inter-tubular dentine until a zone of fully demineralised collagen layer appears on surface which is thick and stable when hydrated.[22] This histological feature indicates that there is no bulk tissue-loss and, if mineral loss is the target criterion, it can be difficult to quantify in the presence of this structure on the surface.[23] The other target criterion could be the measurement of level or loss of organic matrix from the surface which is especially of interest when evaluating degradation of organic matrix by enzymes. Dentine when demineralised is prone to shrinkage and non-contact profilometry measurements will reveal a step height difference between demineralised and non-demineralised areas which will be absent in controlled moisture conditions. This step does not represent the true mineral-loss or surface level of organic matrix. Similar problems will be encountered when using a contact profilometry because the mechanical stylus would cave in the organic matrix to an unknown extent. Therefore, it is critical to scan dentine samples in wet or moist states or the drying time be standardised to 10 minutes to allow for the organic matrix to undergo shrinkage.[24]

Profilometry measurements of eroded dentine in the presence of organic matrix are not solely related to mineral loss. To resolve this issue, it was recommended that organic matrix be removed from the dentine samples before performing measurements with profilometry.[23] However, removal of organic matrix will make profilometry a destructive technique and therefore non-suitable for application in longitudinal studies. Surface roughness measurements with profilometry most commonly in the form of roughness average (Ra) seem to be useful for assessing early erosion, and bearing area curve parameters could yield extra information in this regard.[25] However, this is poorly explored for early dentine erosion. If specific surface roughness parameters could be identified and validated for early dentine erosion assessment, then this non-invasive technique can be applied for the assessment of early dentine erosion in the in vitro and in vivo studies. Moreover, this method could have the potential for being used to validate the use of other non-invasive optical techniques.

Quantitative Light Induced Fluorescence

Quantitative light-induced fluorescence (QLF) is an optical method that was developed for longitudinal analysis of early de-mineralisation in enamel caries.[26] Major advantage of QLF for erosion studies would be the non-destructive imaging and its potential for longitudinal assessment of erosion in the in vivo studies. In a study, the fluorescence measured by QLF, issuing from carious dentine was not found to be linked to de-mineralisation which suggests that QLF might not be suitable for the assessment of dentine de-mineralisation.[27] For dentine erosion, however the applicability of QLF remains to be tested.

Optical Coherence Tomography

Optical coherence tomography (OCT) is a non-invasive optical imaging modality which is based on interference between signals received from the object under investigation and a local reference, and is capable of producing cross-sectional real-time imaging.[28] OCT is comparable to ultrasound because both methods provide cross-sectional images of tissues by measuring the echo time delay of back-scattered wavelength. However, OCT uses infrared light waves compared to ultrasound which uses sound waves. The use of light waves as a medium by OCT makes it possible for it to be non-contact for the patient whereas ultrasound needs a transducing medium such as water along its path to conduct the sound waves. Moreover, OCT provides high resolution imaging about 10-100 times higher than conventional ultrasound.[29]

Since OCT is capable of measuring small dimensional changes non-destructively on tooth surfaces, it appears to be an ideal tool for monitoring tooth erosion.[30] When the dental hard tissues are demineralised, they exhibit increased porosity. This alters the optical property of the tissues resulting in increased back-scattering of light at the surface with reduced depth of penetration compared to sound tissues. Therefore, the eroded areas reflect more light intensity at the surface in OCT images. This is the basis on which the sound tissues are distinguished from the demineralised tissues in case of erosion. On the other hand, the remineralised areas can be distinguished as having reduced signal intensity compared to eroded areas in OCT images.[31]

Use of OCT for the assessment of enamel erosion was first tested in a double-blind randomised clinical trial (RCT) and erosive loss in gastro-oesophageal reflux disease (GORD) patients before and after therapy of proton pump inhibitors (PPIs) was measured.[32] The intensity of back-scattered light in the treatment area was significantly reduced compared to reference area as hypothesised. The OCT was further validated for early enamel erosion in an in vitro study.[33] The authors were able to detect demineralisation in enamel after 10 minutes of erosion challenge and the OCT findings were compared with surface micro-hardness. Recently, OCT was employed for diagnosing and monitoring advanced erosion progression in dentine.[34] This study aimed at assessing the progression of erosive lesions after irradiation with Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) laser and topical fluoride application. The authors were able to measure the amount of tooth tissue-loss over the 20 days of erosive cycle, before and after treatments, and monitor dentin demineralisation progression with OCT. However, the applicability of OCT for early dentine erosion assessment remains unevaluated.

Optical Specular and Diffuse Reflection

An optical spectrometer can record specular or diffuse reflection at different wavelengths and therefore characterise the eroded surface. A reflectometer based on this principle was successfully used for the measurement of enamel erosion. It was later developed into a portable optical device and, more recently, a table-top device.[35] These methods were found suitable for the assessment of early enamel erosion and were validated against calcium loss, surface roughness and hardness measurements. However, these methods have been only tested for enamel and little is known about their potential for assessment of dentine.

On the basis of the current literature review, several recommendations for early dentine erosion assessment are in place (Table-2).

Table-2: Some recommendations for early dentine erosion assessment.

Recommendations
◆ Assessment techniques suitable for detection and monitoring of enamel erosion may not be applicable for dentine erosion because of the histological differences between both tissues such as degree of elasticity. Therefore, the applicability of these techniques needs to be re-evaluated for dentine erosion.
◆ Surface micro-hardness although highly suitable for assessment of early enamel erosion is not suitable for early dentine erosion because of lack of reliability of indentations in highly elastic dentine.
◆ Nano-hardness if coupled with AFM is suitable for early dentine erosion although time consuming in case of longitudinal studies.
◆ Atomic Force Microscopy (AFM) is suitable for early dentine erosion assessment but time consuming.
◆ Microradiography has limited applicability for early dentine erosion measurement.
◆ Quantification of calcium and phosphate ions released from dental hard tissues as a result of dental erosion provides a sensitive method to detect early changes in dentine erosion and suitable for clinical settings but lacks structural information.
◆ Surface roughness measurements with non-contact profilometry particularly bearing area curve parameters may have great potential for early dentine erosion assessment and needs to be explored further.
◆ Optical coherence tomography could provide a much needed non-invasive monitoring tool for early dentine erosion in clinical settings but needs validation.

Conclusion

The assessment of dentine erosion is challenging because of its complex histology. Although a number of techniques have been proposed for the quantification of dentine erosion, no single technique by itself is able to satisfy all the requirements needed for the assessment of early dentine erosion. Hence, a combination of techniques is usually employed for the purpose. However, using a combination of methods is non-feasible because of the time-consuming nature of these techniques. It appears that for laboratory assessment, AFM-supported nano-hardness measurement and surface roughness measurements with non-contact profilometry are promising techniques. For clinical studies, chemical analysis and OCT could have the greatest potential for early dentine erosion assessment. However, further validation work is needed.

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