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CLINICAL EVALUATION OF NON-CARIOUS CERVICAL LESIONS-A FIVE
YEAR PROSPECTIVE EVALUATION

by

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A THESIS

CLINICAL EVALUATION OF NON-CARIOUS CERVICAL LESIONS- A FIVE

YEAR PROSPECTIVE EVALUATION

Kanchan Sawlani

MS IN CLINICAL DENTISTRY

Abstract

Non-carious cervical lesions (NCCLs) have a non-bacterial origin and produce a
loss of tooth structure at the cemento-enamel junction. A review of the literature reveals
that these lesions may have a multifactorial etiology (chemical, abrasion, abfraction).
The role of heavy biting forces in the pathogenesis of NCCLs is yet to be firmly estab-
lished. Treatment and preventive measures for NCCLs can be improved if the etiology
can be clearly identified and treated.Objective: This prospective clinical trial measureed
the volume loss (increase in size) of NCCLs and the occlusal biting forces applied to
these teeth; diet and toothbrushing analysis, followed by a comprehensive mounted cast
occlusal analysis to determine which factors were significant in the progression of these
lesions.

Materials and Methods: Patients with non-carious cervical lesions were screened
and consent obtained. Digital images and poly vinyl siloxane impressions (Aquasil Ul-
tra/Dentsply, USA) were made, casts poured (Fujirock Type IV Die & model stone/ GC
America). To measure the NCCL depth and volume, casts were scanned using Proscan
2000 Non Contact Profilometer, and the scans were superimposed over the baseline
scans with the Proform software to measure the change in NCCLs over a five-year peri-
od. T-scan and Fujifilm Pre-scale films (analyzed by Topaq Occlusal Analysis System)
were used to record the relative and absolute biting forces on teeth with NCCL. Lesion

progression from baseline to five years was correlated to absolute occlusal force using regression analysis and KS test for normality. One way ANOVA compared lesion progression with toothbrushing techinique and presence of adverse oral habits like nail biting; while Mann-Whitney test was used to correlate NCCL progression with the diet score.

Results: Rate of progression is related to mean bite force (p=0.01), presence of adverse oral habits (p=0.02) and consumption of a more acidic diet (p=0.04); but not associated significantly with occlusal wear facets, group function or toothbrushing technique.

Conclusions: Within the limitations of this study, it may be concluded that heavy biting forces, erosive diet and adverse oral habits play a significant role in the progression of NCCLs over time.

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INTRODUCTION

Cervical lesions at the gingival of the tooth can be carious or noncarious. NCCLs begin as a notch at the CEJ and slowly progress. (Figure 1)
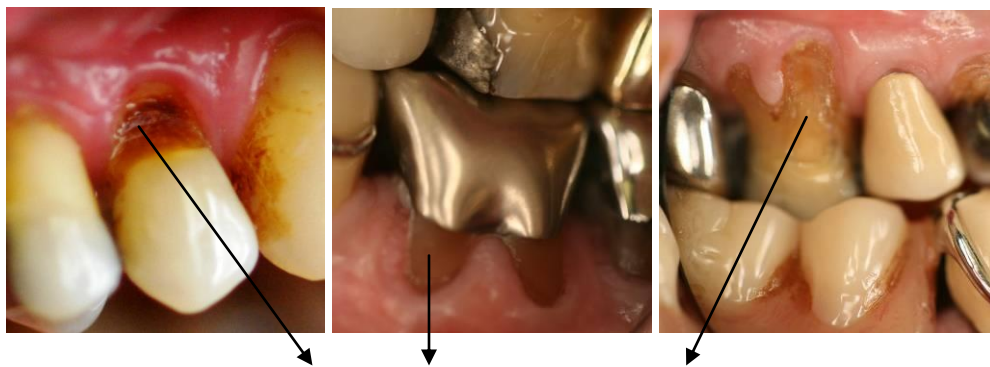
Figure 1. Noncarious cervical lesions with gingival recession

A non-carious cervical lesion (NCCL) is a loss of tooth tissue in the cervical region with a non bacterial etiology [1]. Such lesions are common and have frequently been investigated [2]. However the etiology of the NCCL is complex with erosion, abrasion and tooth flexure from occlusal factors contributing at various times in the initiation and progression of the lesion [3]. An excellent critical review of these lesions has recently been authored by Bartlett and Shah, 2006[4] and Grippo, 2012[1].

Clinical observation has shown that non carious lesions are most prevalent on the facial surface of maxillary incisors, canines and premolars[5].   Hur, 2011[6] scanned 50 extracted teeth by micro computed tomography and related the lesions to the level of the

CEJ which he categorized as wedge shaped, saucer shaped and mixed shaped lesions. These lesions progress slowly involving enamel initially but progress to include dentin [2]. In general the lesion progresses very slowly and may arrest[2]. Treatment ranges from no treatment to placing an adhesive restoration depending upon the size and symptoms of the lesion. The controversy over the etiology of the NCCL has centered on three possible etiologies.

Erosion or Biocorrosion

Erosion is the loss of hard dental tissues by a chemical process without bacterial interaction. Grippo (2012)[1] suggested the term 'biocorrosion' to replace the older term 'erosion' to describe the various forms of chemical, biochemical, and electrochemical degradation of tooth substance. Smooth surfaces of anterior and premolar teeth are particularly vulnerable to acid attack during the consumption of acidic foods and drinks. Posterior teeth are subject to erosion in patients who regurgitate gastric acid. The PKa of the acid is a greater contributor than pH in tooth tissue erosion. A high PKa demonstrates that more of the acid can be ionized producing the hydrogen ion than is indicated by the pH. For example, orange juice causes more chemical degradation than colas although orange juice has a more alkaline pH than cola. Although occupational exposure to airborne acids in the workplace was common, currently industrial exposure to acid is uncommon and is no longer a frequent cause of erosive NCCL. Other activities, however, may produce acid exposure such as frequent swimming in chlorinated swimming pools as well as the corrosion produced on enamel by professional wine tasters. Acid degradation internal sources such as gastric reflux is another possible mechanism for producing

NCCL[7]. Bulimia produces another chemical attack on the teeth and while most lesions produced by bulimia are found on the lingual of maxillary teeth, some individuals regurgitate and hold the acidic gastric contents in the mouth until they are able to expectorate. This may produce buccal lesions on cervical tooth surfaces adjacent to the retained vomit in lower premolar and permanent molar teeth.

Lesions caused primarily by erosion or 'biocorrosion'[1] are classically described as smooth disc-shaped rounded lesions, concave and with no sharp edges, grooves or ridges. (Figure 2) Biocorrosion is defined as the "chemical, biochemical or electrochemical action which causes the molecular degradation of a living tissue". It is a more precise term than erosion. Biocorrosion to teeth can occur by means of chemical exogenous and biochemical endogenous acids, by biochemical proteolytic enzymes, and also piezoelectric effects acting upon the organic matrix of dentin, composed mainly of collagen. The prevalence of such cervical erosion lesions is not well documented, although Zipkin and McClure in 1949[8] reported that 27 percent of the 83 subjects studied had loss of tooth tissue on facial surfaces of teeth attributable to erosion. These investigators reported that the prevalence and severity of erosion lesions increased with age, with more lesions in the maxillary first premolar.

Figure 2. Teeth (#4-#7) with erosion lesions at the cervical area along the facial surface of the teeth.

Abrasion

Toothbrush abrasion, the abnormal wearing away of a substance or structure by a mechanical process [9] (Glossary of periodontal terms, 2001), was described first by Zsigmondy in 1894 as angular defects and later by Miller in 1907 [10] as a wasting of tooth structure. It was demonstrated *in vitro* by Manly in 1944. Abrasion can occur as a result of mastication of coarse foods, inappropriate or overzealous use of dental hygiene instruments and with detrimental oral habits such as fingernail biting, pipe smoking, tobacco chewing, hair pin opening ccupational behaviors: severing thread with teeth, blowing glass and playing wind instruments. Dental appliances such as removable denture clasps and rests can also contribute to excessive cervical wear.[11]
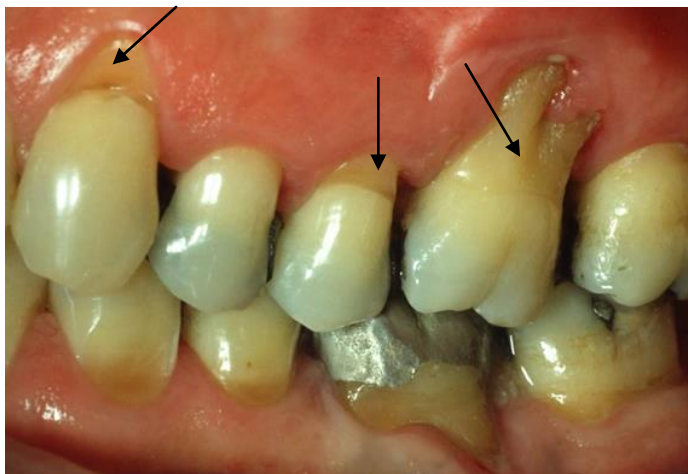
Figure 3. Teeth (#11, #13, #14) with abrasion at the cervical area along the buccal surface

Piotrowski , et al. 2001 [12] noted that many factors influenced the rate of abrasion including tooth brushing technique, brush force, brushing frequency, bristle stiffness and toothpaste abrasiveness. Increased cervical lesions were reported in a large cross-sectional study of subjects who brushed twice daily compared with those who brushed less frequently. Horizontal brushing produced more tooth loss than longitudinal brushing[13]. The literature reports that a greater number of NCCLs are seen on the left side of patients who are right-handed, and areas brushed initially have been shown to have more abrasive lesions, perhaps due to increased brushing force or acidity of toothpaste[14]. Borcic et al[2] noted that abrasion lesions increase in incidence with age.

Abrasive lesions typically have well defined, sharp margins and may be wedge-shaped or grooved with scratched surfaces and sharp line angles. In two cross-sectional studies the incidence of abrasive lesions varied from 31-45 percent and increased with age. [15, 16] Loss of tooth structure is accelerated when acid softening precedes tooth brush-

ing. It has been noted that a one hour delay can increase tooth resistance to abrasion and lessen the defects created by brushing in bovine teeth [17] and in an in situ study [13]. Erosion and abrasion probably act synergistically to differing degrees at different times *in vivo*, and it is difficult to determine the specific etiology of a NCCL at a specific point. While the abrasive effects of tooth brushing have been recognized as a major cause of NCCLs [18], some lesions are difficult to explain by tooth brushing. These etiologies may be combined and one etiology may dominate at any one time. Accurate diagnosis of non carious lesions is probably multifactorial and is difficult to pinpoint at any one point in time.

Tooth flexure or Abfraction

Abfraction is the loss of tooth substance in areas of stress concentration most commonly in the cervical area where flexure leads to fracture of the extremely thin layer of enamel rods, as well as microfracture of cementum and dentin.[11]
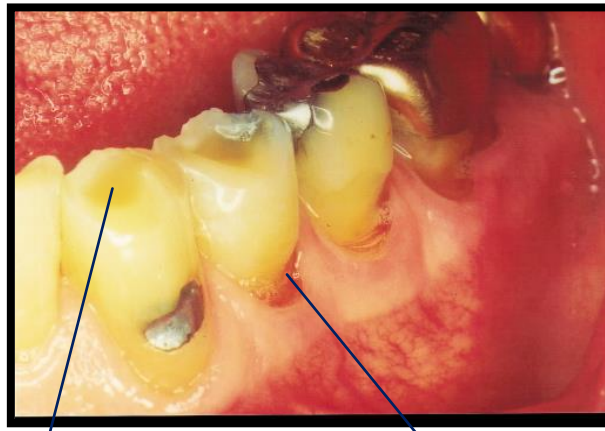
Figure 4. Teeth (#19-#22) with abfraction produced lesions at the cervical area on the buccal surface of the teeth with attrition.

Abfraction is derived from the Latin verb frangere ("to break") and defines a wedge-shaped defect at or near the CEJ of the tooth. 12, 19 Various studies have proposed an association with abfraction and occlusal forces and tooth flexure. But there are very few clinical studies that correlate occlusal forces to rate of progression of the non carious cervical lesion.[19]

The etiological factors for abfraction are:

1. Exogenous factors: parafunction (such as bruxism, clenching); Occlusion: premature contacts, eccentric loading, and deglutition.

2. Endogenous factors: Mastication of hard, resistant foods; Habits: biting foreign objects such as pencils, pipe stems and fingernails; Occupational behaviors: playing wind in-struments, using teeth to hold foreign objects; dental appliances: orthodontic, removable denture clasps and rests.

The loss of tooth substance, is dependent on the magnitude, duration, direction, frequency, and location of the forces applied to the particular tooth.[20]

Wasting and/or erosion were probably the original terms for what is now known as "abfractions". The first articles describing "wasting" were Miller's articles published in the 1907 in Dental Cosmos. [21] Erosion produces a saucer shaped lesion while a wedged shaped lesion is typical of the abfraction lesion.

According to the principles of leverage,[4, 22] the magnitude of tensile stress on the cervical area of a tooth is a function of distance between applied occlusal force and the fulcrum (the CEJ). (Figure 5) The greater the distance between the load and the fulcrum, the higher the intensity of the tensile stress that affects the tooth close to the fulcrum and, consequently, the larger the area of rupture.
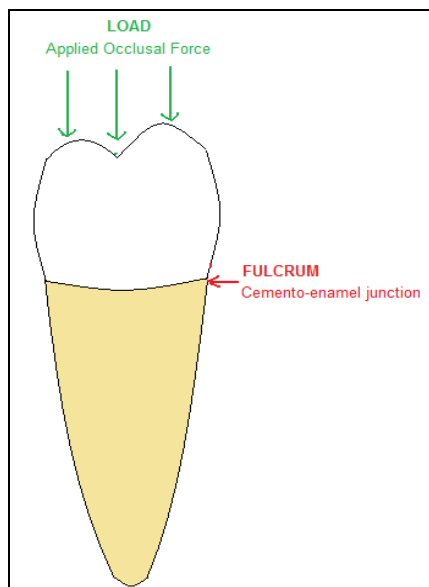
Figure 5. Diagram explaining the principle of leverage acting in the tooth

Studies[23-26] have demonstrated that when teeth are loaded in a horizontal direction the stress becomes concentrated in the cervical region causing flexure, the primary cause of angled notches at the cemento-enamel junction. (Figure 6) McCoy (1982) proposed that bruxism may be associated with abfraction.
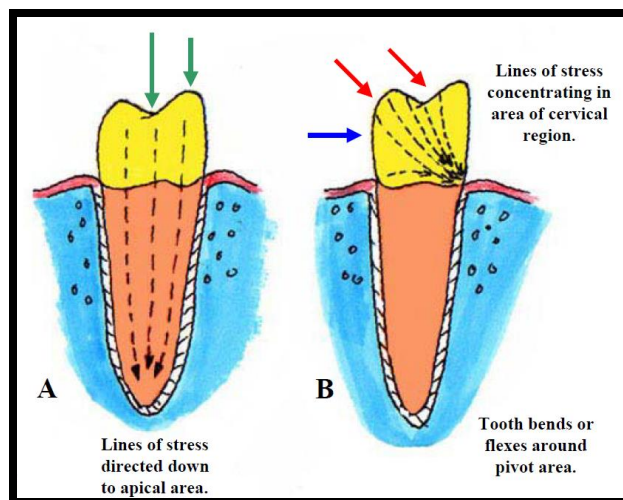
Figure 6. Drawing demonstrating abfraction lesion formation at the cervical area from applied axial and lateral forces.

Factors to consider when deciding to restore non-carious cervical lesions are based on the possibility of strengthening the tooth, decreasing theoretical stress concentration, decreasing flexure, halting lesion progression, decreasing cold sensitivity, preventing pulp involvement, improving oral hygiene and enhancing esthetics. [27] Large wedge-shaped defects that are not indicated for soft tissue coverage can be restored using composite or glass ionomer materials after minimal tooth preparation. [28-30] Other treatment possibilities include metal restorations for posterior teeth, dentin bonding

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agents, copal varnishes, fluoride therapy and desensitizing agents, night guard and oc-

clusal adjustments, dietary modification and cessation of oral habits.[31, 32]

Hanaoka and colleagues[32] stated that cementum and dentin microcracks may act

as the initial contributor for cervical defects. Occlusal and lateral forces may initiate the

lesion and may be the dominant factor continuing its progression. [33] Occlusal loading

forces are transmitted to the periodontal supporting tissues, which may cushion and dis-

sipate the resultant stresses. Kuroe and colleagues[34] showed a positive correlation be-

tween cervical tooth surface lesions with tooth stability and good periodontal support.

Thus mobile teeth are less likely to have abfraction.

Cervical enamel has a weak mechanical bond to the underlying dentin due to a

lack of the normal scalloped pattern of the enamel-dentin junction in this area. Enamel

has high compressive strength but its ability to withstand tensile forces is poor. There-

fore, tensile forces acting on a tooth are more likely to disrupt bonds between hydroxyap-

atite crystals. Lee and Eakle[35] proposed (Figure 7) that a lesion created as a result of ten-

sile forces would be wedge-shaped and located at the fulcrum, the region of maximum

stress. In an ideal occlusion functional loads are directed along the long axis of the tooth,

while in eccentric movements the side towards which the tooth is bending is under com-

pressive stress and the opposite side is in tension. Tensile forces break bonds between the

enamel hydroxyapatite crystals and the ruptured enamel may then fracture away exposing

the underlying dentin.
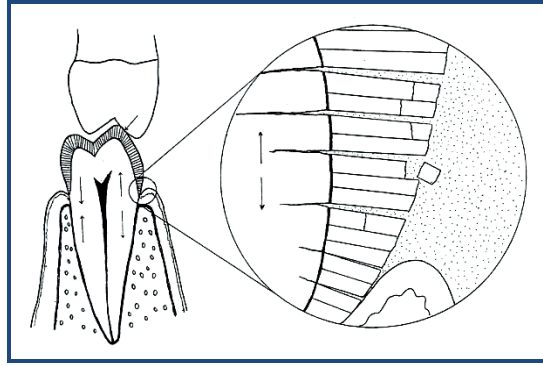
Figure 7. Stress corrosion showing enamel rod fracture and the beginning of the abfraction lesion from Lee and Eakle.

Secondarily toothbrush abrasion and erosion may increase tooth substance loss and enlarge the NCCL. Stress corrosion in teeth is the physicochemical cracking of the cervical area stressed by loading in the presence of a corrosive agent. This can occur and contribute to the etiology of NCCL when food and wine are consumed simultaneously. Tooth brushing after consuming acidic food or drink may have a similar corrosive/abrasive effect. Abfraction lesions as described by Grippo are typically wedge-shaped with sharp margins although secondary erosion or abrasion may alter the appearance of the lesion.

To have strong evidence for the occlusal etiology for NCCL, heavy occlusal forces must be applied to the occlusal surface during excursive movements. The correlation between high occlusal forces and progression of NCCLs is yet to be proven; as some studies state that stress concentration in cervical areas of the tooth contribute to their occurrence, [36, 37] while others reject dental occlusion and articulation as a factor in NCCL development.[38, 39] A recent study[40] examined 1974 teeth from 77 participants:167 teeth

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had a NCCL, while an additional 167 teeth with no cervical lesions were selected from the same population as controls. A thorough occlusal examination was completed and centric occlusion and eccentric movements observed. The direction and magnitude of a slide from centric relation to maximum intercuspation was recorded as were premature contacts in eccentric movements. The relationship between NCCLs and premature contacts was examined using linear regression. The frequency of NCCLs differed significantly, most often occurring in the first premolars followed by canines. The greatest number of premature contacts occurred in first premolars followed by canines. The total number of premature contacts was significantly greater in the NCCL group than in the control group. While this controlled clinical study defined NCCL inclusion criteria, the observation of centric occlusion and eccentric contacts intraorally by the use of occlusal marking paper creates less than compelling evidence of the magnitude of the prematurity. Although this study demonstrated a highly significant positive relationship between the presence of premature contacts and the number of teeth with NCCL, the study methodology results in a low level of evidence. Estafan et al[39] evaluated the relationship between noncarious cervical lesions and occlusal (or incisal) wear. 299 casts were mounted on a Hanau semi-adjustable articulator (Waterpik Technologies, Newport Beach, Calif) without a dental facebow. Mandibular casts were hand articulated and the condylar inclination arbitrarily set at 25 degrees. Data collected included the presence and contour of noncarious cervical lesions (NCCLs) and the presence, location, and severity of any occlusal/incisal wear facets. Also included were Angle's classification, occlusal guidance patterns, midline, reverse articulation (cross bite), open occlusal relationship, and posterior excursive contacts where present. Following calibration, two evaluators made independ-

ent observations on the casts. The first evaluator recorded for each tooth in each subject: presence and severity of NCCLs, presence and extent of occlusal/proximal restorations, and presence of reverse articulation and open occlusal relationship. Following the first evaluation red rope wax was placed at the cervical margins of each tooth for the purpose of blinding the second evaluator from NCCL observations. The second evaluator recorded severity and location of occlusal/incisal wear, presence or absence of posterior excursive contacts, Angle's classification, and occlusal guidance pattern, any midline discrepancy, and presence or absence of tori. 99 of the 299 casts demonstrated at least 1 NCCL, 99% of them on the buccal surface. The study found no correlation between NCCLs and occlusal wear in the well-defined population. Posterior excursive contacts and occlusal guidance schemes also did not correlate with NCCLs. There was no relationship between noncarious cervical lesions and occlusal/incisal wear. While this study presented interesting data, it cannot be considered definitive evidence in the controversial area of the etiology of the NCCL. The homogeneity of the participant population, the arbitrary nature of the mounting process, and the lack of a precise relationship between tooth wear and cervical flexure was not thoroughly established. While occlusal wear was demonstrated on every cast, NCCLs were only evident in 33% of the casts. The conclusions of this study are well founded but the precise level of evidence relating to the true etiology of the NCCL remains less well defined.

Classification of Non Carious Cervical Lesions

Michael et al[3] examined 15,000 teeth macroscopically under illumination at 2X
magnification and found five hundred and forty-two non-carious cervical lesions and
classified them as shallow, concave, wedge shaped, notched, and irregular. (Figure 8)
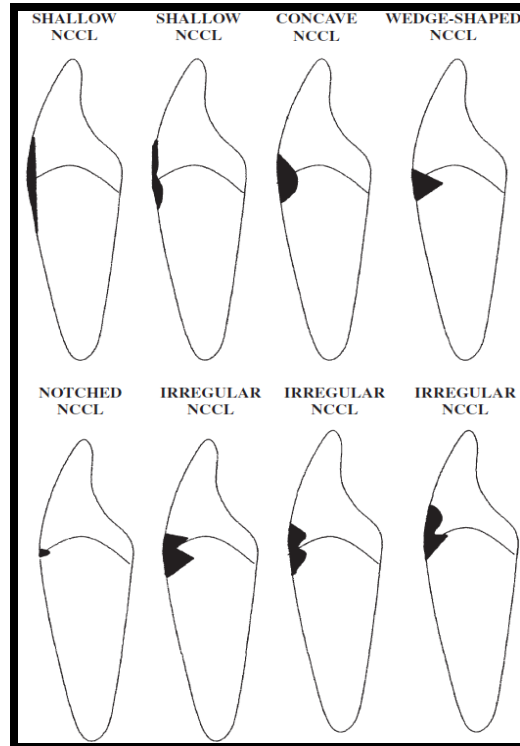
Figure 8. Classification of non carious cervical lesions

Hur[6] examined 50 extracted teeth which were scanned by micro computed to-
mography and classified them according to their morhology.The location of internal line
angle and proximal exits of the lesions were evaluated in relation to the level of the CEJ
and he classified them as wedge shaped, saucer shaped and mixed shaped lesion. (Figure
9)
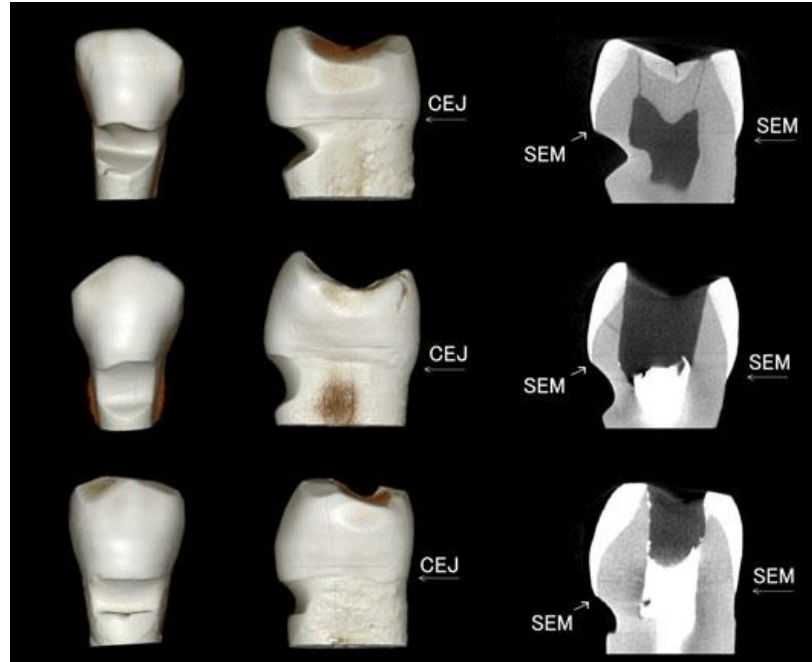
Figure 9. Representative samples of three types of non carious cervical lesions: (a) wedge-shaped lesion, (b) saucer-shaped lesion and (c) mixed shape lesion. Left column shows mid-buccal aspect, mid column shows proximal aspect and the right column shows bucco-lingual longitudinal sectional images. Sectional images show the intact sharp enamel margins (SEM) at coronal margins of the lesions.

Articulated Study Models:

Spranger[41] demonstrated the effects of laterally applied occlusal loads using articulated study models. He took a set of upper and lower study models articulated in a semi-adjustable articulator and placed four piezoelectric transducers in the lower left first molar. Realistic occlusal loads were applied, and he reported that loads applied in centric occlusion produced lateral deformations of 20 µm in the buccal cervical region. When the loads were applied during lateral excursive movements, deformations of 200 to 400 µm were recorded. It may be assumed that this greater deformation can produce more stresses in the region of the CEJ, leading to genesis of NCCLs.

Photo-elasticity Studies:

Photo-elasticity is a technique whereby a model of a structure is made from a bi-refringent plastic and viewed in polarized light once loaded.[42] The areas of high-stress concentration are highlighted by areas with multiple concentric rings. Spranger and colleagues[41] have completed photoelastic studies modeling upper incisors. They reported that the applied loads caused facial bending in the cervical region. Oblique loads applied outside the long axis also caused torsional stresses that were particularly concentrated around cervical region of the tooth, which could be responsible for breakdown of the cervical enamel crystal structure.

Studies of Strain Gauges:

Strain gauges are the most widely used transducer in experimental mechanics to evaluate strain.[43] There are, however, certain limitations to their use in the oral cavity. For instance, they have to be isolated from saliva and blood to prevent short circuits and, in order to measure strain correctly, must be carefully bonded to the surface of the material under examination.

Nohl and colleagues[44] placed strain gauges in the cervical region of extracted premolar teeth on buccal surface and loaded them in the region of the centric stops and at various positions lateral to this along the cuspal inclines. They found that loads applied to the cuspal inclines, which mimicked clinical loads applied in lateral excursion, resulted in high surface tensile strains in the cervical region.

Finite Element Analysis:

It is particularly useful in dentistry because it can readily cope with both the complex geometry of a tooth and its supporting structures, together with the large variation found in the physical properties of the tooth, periodontal ligament and alveolar bone.[45] Goel and colleagues[46-48] developed a three-dimensional finite element model of an upper premolar and found that the contour of the DEJ and the thickness of the enamel in this region markedly affected the magnitude of the tensile and shear stresses present in the cervical region. Concentration of these stresses is potentially responsible for the genesis of non-carious cervical lesions. They also reported that shear stresses on the

buccal side of the tooth were greater than those on the lingual side, which may partly explain why abfraction lesions are not usually found lingually.

Rees et al[49, 50] developed a finite element model of a lower premolar and applied a point load occlusally of 500N. The cervical stresses were sampled on two horizontal planes in the buccal and lingual cervical enamel, just above the CEJ. They reported that a occlusal load applied in the vertical direction to buccal and lingual cusp tips produced cervical stresses of around 50 MPa. However, occlusal loads applied in the oblique direction produced stresses of about 250 MPa, which exceed the known failure stress for enamel. These 500N loads were applied to both the outer and inner aspects of buccal and lingual cusps 1mm below the cusp tip.

Rees and Hammadeh[26] have also developed finite element meshes of an upper incisor, canine, and premolar with sampling planes in the buccal and palatal cervical enamel (Figure 10). The magnitude of the cervical stresses was highest for the premolar, molar followed by the incisor. This mirrors the findings of clinical studies that report a higher prevalence of abfraction lesions in premolars and incisors. This is probably related to the variation in morphology between these teeth and the area of the periodontal ligament available for absorbing the applied load.

The FEA is widely used in dental research. There are a few limitations [51] to 2D modeling, particularly due to the geometric complexity of the biological structures involved. A 2D model cannot accurately represent-clinical reality because of its simplifi-

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cations which do not take into consideration some important biomechanical aspects being studied. In contrast, 3D models present advantages such as images of greater and richer detail, the possibility of rotating in space and visualizing internal areas of the models.
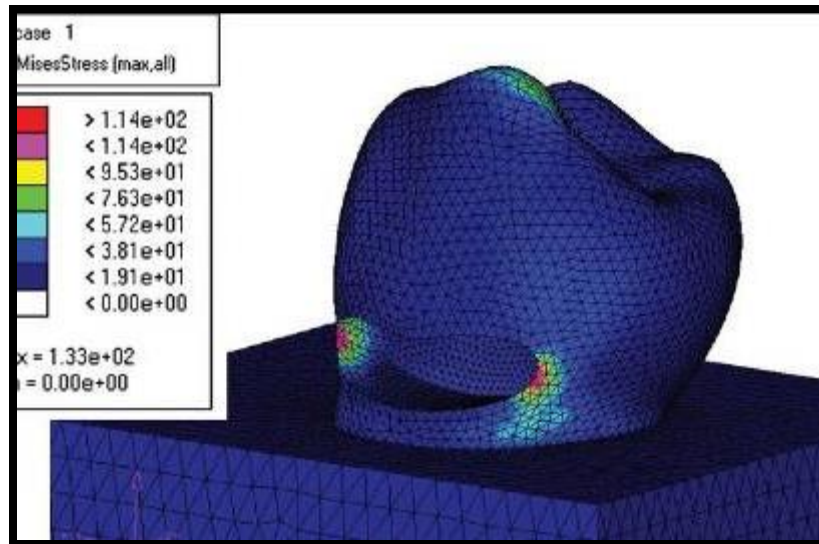
Figure 10. Finite element model demonstrating stress in cervical region

The disadvantages of finite element analysis particularly during analyses of the periodontal ligament and alveolar bone, not modeled in previous studies, have shown that those structures may dissipate occlusal loading forces from the cervical areas.[52] In addition, some models may not fully represent intricate dental anatomy and complex occlusal function. Therefore, the key basis of the abfraction theory may be flawed.

Interaction between Occlusal Loading and Erosion

Erosive agents may exert an influence in many ways. There is variation in susceptibility to erosion between cervical and occlusal enamel, direct effect of occlusal loading, piezoelectric effects, stress corrosion effects. Darling and colleagues[36] demonstrated that small organic molecules can penetrate enamel and replace water molecules, so it is possible that simple organic acids are able to access this internal pore system and than may magnify lesion progression.

Non-axial forces on occlusal and lingual tooth surfaces in an acid environment may increase the damage and erosion at the cervical margin. This effect is called stress corrosion. [53] Maxillary and mandibular first and second premolars are most frequently affected by abfractions. This could be attributed to the tooth morphology and tooth position in the arch which influences the force distribution on the teeth.

The characteristics of non-carious cervical lesions, with their sharp angles, wedged shapes and frequent sub-gingival locations, have not been explained by the proposed theories to date. Yet, occlusal trauma alone cannot fully explain the phenomenon, since evidence indicates that many teeth show signs of traumatic occlusion but do not develop cervical lesions. Despite the need for scientific confirmation, the occlusal trauma concept is well-accepted, since it may explain the morphology and location of the lesions.

Griffith[54] proposed the nucleation and growth of cracks in a material from pre-existing flaws. His theory was based on the assumption that any brittle material contains inherent flaws which concentrate high stress near their tips, and under loading cracks initiate from these flaws and tend to grow, with the process being repeated for initially less critical flaws as the stress is raised.

The rate of progression of the destructive process has not been thoroughly investigated. Early studies by Xhonga et al and Xhonga and Sognnaes estimated the rate to be approximately 1 μm per day.[55] The rates of destruction were reported to be the same in untreated lesions and lesions that were treated with sodium fluoride, which remineralizes tooth structure and renders it less soluble. This finding is consistent with damage caused by tensile stress, which does not depend on the solubility of the tooth structure.

Occlusal loading during mastication can be divided into two phases. The first phase consists of contact of food, during which the food between teeth serves to distribute the forces over the occlusal surface. The spreading of the load helps to minimize the concentration of damaging forces. During the second phase of occlusal loading, teeth that come into contact could result in a virtual point force.[56] This tooth-to-tooth contact is likely to result in a pathologic magnitude of stress, which is evident from the correlation between the contours of wear facets and lesion morphology and by the prevalence of stress-induced lesions in patients with bruxism. The correlation between malocclusion, bruxism and cervical lesion was noted by clinicians decades ago. [35]

The cervical fulcrum area of a tooth might be subject to unique stress, torque, and moments resulting from occlusal function, bruxing and parafunctional activity.[57]Alveolar bone loss changes the position of the fulcrum of bending moment causing more apically placed lesions. Mobile tooth are not affected as mobile teeth dissipates the stress.

The Biomechanics of Abfraction

1)   Theoretical considerations:

The lower anterior teeth usually develop at right angles to the horizontal plane, while the upper anterior teeth develop forwards at around 115–120° to the global horizontal plane. The consequence of this is that, when these anterior teeth make contact, the upper teeth bend outwards, developing tensile strains in the lingual cervical region, which may contribute to the development of abfraction lesions. A cross-section of the premolar shows the presence of cusps of the posterior teeth produce an inclined plane effect on contact with the opposing tooth. This effect tends to cause the cusps to bend outwards during chewing this along with para-functional activities, produce cervical strain which also contribute to the abfraction lesions development.[52]But this concept suggest that abfraction lesions than should develop along lingual cervical region which is not commonly observed.

2)   Cuspal flexure:

The increased cusp flexure seen in heavily restored teeth may suggest that abfraction lesions should be more prevalent in teeth with large amalgam restorations as

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their cusps would deform by up to three times as much as an intact tooth.[58] Unfortunately, this has not been examined clinically.

3)   Structural and physical properties of enamel:

The surface cervical enamel is structurally inferior with reduced mineral content with higher pore and protein content. The amelo-dentinal junction in the cervical region is poorly developed with little scalloping the feature of this structure which may improve the strength of this interface.[59]

Measuring Occlusal Forces (MOF)

a.   Force transducer :

A compressive load transducer is used to MOF in the first molar region. The bite pad containing the load transducer was covered with a hard rubber band, and the set was wrapped with disposable plastic film. The subject was asked to bite the equipment five times with maximal effort for 1 to 2 seconds, with rest intervals between trials. The three highest measures were averaged and considered the subject's MOF (Maximim Occlusal/ biting force) value (in newtons).[60] The maximum biting force values ranged between 300N to 1,300 N (in bruxers).[61]

b.   Hydraulic pressure occlusal force gauge:

Bite force is measured bilaterally in the first molar region using a portable occlusal force gauge that consisted of a hydraulic pressure gauge and a biting element made

of a vinyl material encased in a polyethylene tube. Bite force was displayed digitally in newtons.

In a study using this techinique for bite force measurement, the bite force of 2594 school children (1248 males and 1346 females) living in northern Japan was measured. The findings revealed significant variations in bite force between children of different ages. The average bite force was 186.2 N in males and 203.4 N in females of nursery school children; 374.4 N in males and 330.5 N in females of primary school children; 514.9 N in males and 448.7 N in females of junior high school children; and 545.3 N in males and 395.2 N in females of high school children.
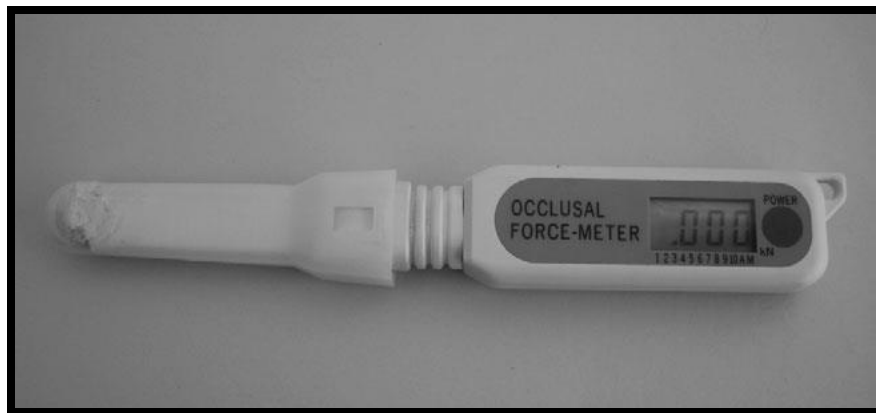
Figure 11. Hydraulic pressure occlusal force guage.

Subjects were instructed to bite as hard as possible on the gauge without moving the head. Bite force were measured alternately on the right and left sides with a 15 second resting time between each bite.[62]

c.   New Pressure-Sensitive Device:

A pressure-sensitive sheet was developed for industrial examination by Fuji

Photo Film Co (Tokyo, Japan).The device consists of the pressure-sensitive sheet (Den-

tal-Prescale) and its analysis apparatus (Occluzer).

Figure 12. Pressure indicating film that is used to measure biting forces

Figure 13. Occluzer used analyzes pressure indicating film, record biting forces

The pressure-sensitive sheet is placed between the upper and lower dental arch, and the subjects instructed to bite as forcefully as possible for about 3 seconds. The sheet was then analyzed with oocluzer.[63]

d.   *Jaw force meter:*

Occlusal forces were measured on the right and left sides by a Jaw Force Meter (MPM-2401, Japan)[43] with a transducer placed between the lingual cusp of the upper first molar and the mesiobuccal cusp of the lower molar. All measurements were made with the subject seated with the head upright, looking forward, and in an unsupported natural head position. The subject was instructed to bite as forcefully as possible. The bite force values were recorded and stored in a computer for analysis.

Figure 14. Jaw force meter

e.   Gnathodynamometer (or occlusometer):

Snodgrass developed the instrument to measure force exerted in closing the mouth. [64]As per the inventor's design study, the instrument works well in measuring maximal bite force and masticatory efficiency of incisor and molar teeth. But this uses an open bite which will record occlusal forces that may not be accurate as it may allow sliding to occur.
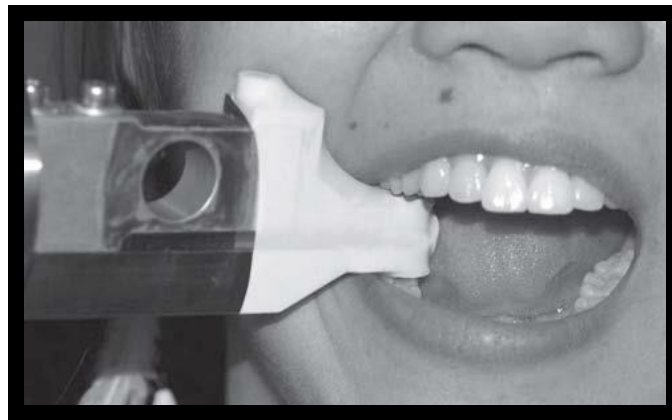
Figure 15. Gnathodynamometer

Table 1: The various clinical studies for the proposed etiology for NCCL

Study	Materials and methods	Results
D. Brandini.[65] Noncarious cervical lesions and their associaton with toothbrushing practices: in vivo evaluation. Operative Dentistry	58 students with mean age=22.9±2.1 years. Clinical examination of NCCLs and questionnaire to assess oral hygiene habits.	53% of the subjects presented with NCCLs. Correlation was found between toothbrush bristle stiffness and toothbrushing force with presence of

2011; 36:581-589		NCCLs.
L Pikdoken. [66]Cervical wear and occlusal wear from a periodontal perspective. Journal of Oral Rehabilitation 2011; 38:95-100	30 patients in the age range of 45-80 years, presenting multiple NCCLs. Clinical examination of clinical and occlusal wear. The levels of cervical wear and occlusal wear were determined according to a tooth wear index.	475 teeth (74.1%) exhibited NCCLs. Occlusal wear was not associated with NCCLs.
H Ahmed. [67]Factors associated with noncarious cervical lesions (NCCLs) in teeth. J Coll Physicians Surg Pak. 2009 ;19:279-282	95 patients presenting NCCLs. Mean age 50.3 years. Clinical examination and questionnaire to determine factors associated with NCCLs.	First premolars were the most affected teeth. No correlation between occlusal wear facets, excursive guidance or Angle's classification.
O. Bernhart. [36]Epidemiological evaluation of the multifactorial aetiology of abfractions, Journal of Oral Rehabili-	2707 subjects aged 20–59 years of age: Medical history, dental, and socio-demographic parameters examined	The abfractions are associated with occlusal factors, like occlusal wear facet, inlay restorations, altered tooth position and tooth

tation 2006 33; 17–25		brushing behaviour.The independent variable of occlusal wear facets of scores 1, 2 and 3 was associated with the occurrence of abfractions, odds ratio (OR) = 1.5, 1.9, 1.9
L.F Pegoraro. [53] Noncarious cervical lesions in adults: Prevalence and occlusal aspects, JADA 2005:136.	70 subjects aged 25 - 45 years to determine the presence and type of NCCL, wear facets, tooth contacts in maximal intercuspal position, and lateral and protrusive movements.	Among the teeth the authors evaluated, 17.23 % had cervical lesions, 80.28 % had occlusal wear.
E Reyes.[38] Abfractions and Attachment Loss in Teeth With Premature Contacts in Centric Relation: Clinical Observa-	46 subjects, the mean attachment loss was determined for teeth with and without PCCR and for teeth with and without	No association was demonstrated between PCCR and the presence of abfractions or increased attachment loss.

tions, J Periodontol • December 2009; 80(12):1955-62	abfractions.	
Study	**Materials and methods**	**Results**
C Tar.[62] Characteristics of Non carious cervical Lesions. J Am Dent As- soc 2002; 133; 725-733.	Total of 57 patients and 171 NCCL teeth, was examined shape, dimen- sion, sensitivity, sclerosis and occlusion	60% had group function or mixed excursive guid- ance, 141(82%) had wear facets.
B Faye.[68] NCCLs among a non-tooth-brushing population with Hansen's disease (leprosy): Initial findings, Quintessence Int 2006; 37:613–619.	Cross-sectional study; N 102; 20-77yrs., clinical examination, diet, para- functional habits & drugs. 47% showed NCCLs. When examined, the sub- jects asserted on their word of honor that they had never used a tooth- brush, nor a Miswak(wooden stick)	Parafunction, oc- clusion and use of medi- cations that cause xero- stomia could be the etiol- ogy for NCCL.

	owing to hand deformities owing to leprosy.	
P Shah.[19] The Prevalence of Cervical Tooth Wear in patients with Bruxism and other causes of Wear, Journal of Prosthodontics 18 (2009) 450–454.	Of 119 subjects, 31 were bruxers with a mean age 48.7 years; 22 had bruxism combined with wear facets, aged 43.5 years; and 66 were controls aged 44.9 years. A tooth wear index (TWI) was used by two trained examiners to record the severity of wear in each group.	There was a statistically significant difference between the controls and both the bruxist and combined tooth wear groups for wear on all surfaces (p < or = 0.001).
ID Wood.[58] Effect of Lateral Excursive movements on the progression of Abfraction Lesions. Oper Dent, 2009, 34-3,273-279.	N=31, one teeth control and other adjusted, area measured under stereomicroscope.	Occlusal adjustments did not reduce the progression of abfraction lesion.
W. A. Smith.[69] The prev-	156 patients with a mean	Bilateral mediotrusive

alence and severity of non-carious cervical lesions in a group of patients attending a university hospital in Trinidad. Journal of Oral Rehabilitation 2008 35; 128–134.	age of 40.6 years were examined of whom 62.2% had one or more NCCLs. Mediotrusive (non-working or balancing contacts; contacts of teeth on side *opposite* of the side towards which mandible moves in articulation) and laterotrusive contacts (working movement contacts; contacts of teeth *on the side* of occlusion toward which mandible has moved) were examined. Data were collected via a questionnaire and clinical examination.	and laterotrusive contacts in incisor-canine-premolar areas were significantly associated with the presence of non-carious cervical lesion.
J Takehara.[37] NCCLs and occlusal factors determined by using pressure-detecting sheet. Journal	159 male self-defense force officials with a mean age of 36.2 years. Occlusal force, occlusal	NCCL occurence– 49.1% (78 subjects); tooth-brushing pressure and occlusal factors in the

Study	Materials and methods	Results
of dentistry 36 (2008) 774 – 779	contact area and average pressure were measured using a pressure-detecting sheet.	study population were associated with an increased occurrence of v-shaped NCCLs.

Table 2: In vitro studies for the proposed etiology of non carious cervical lesion

Study	Materials and methods	Results
E stoica. [70] En face optical coherence tomography investigation of pathological dental wear. TMJ 2010, Vol 60, No. 1	42 extracted frontal teeth, 35 teeth from active eccentric bruxism and 7 control teeth were investigated using eFOCT. eFOCT is a useful imaging method for the microstructural characterization of frontal teeth with pathological wear. It also allows also the monitoring of the wear process.	Most of teeth with bruxism were associated with abfraction. The eFOCT investigation of frontal teeth with a normal morphology revealed a homogeneous structure of the occlusal and cervical enamel. The OCT images obtained from the occlusal overloaded frontal teeth visualized the wedge-shaped loss of cervical enamel and damage

		in the microstructure of the underlying dentin.
A Estafan.[39]In vivo correlation of NCCLs and occlusal wear, New York University College of Dentistry, 2005.	N = 299; casts mounted on a semi-adjustable articulator.	NCCLs are not related to occlusal wear, posterior excursive contacts and occlusal guidance.
A Asundi.[60] A strain gauge and photo elastic analysis of in vivo strain and in vitro stress distribution in human dental supporting structures. Archives of Oral Biology 45 (2000) 543-550	Strain gauge experiment 1. To measure the strain on supporting alveolar bone 2. To measure the strain on the root surface; Photo-elastic experiment - To analyse the stress distribution pattern from the tooth to the surrounding bone	Most of the stresses on the root surface were distributed along the cervical and middle thirds, stress patterns diminished towards the apex.
A. Kishen.[71] Digital moire´ interferometric investigations on the deformation	6 freshly extracted non-carious mand. Central incisor teeth; specimens	The strains in the lateral direction within the enamel and the strains in the axial

gradients of enamel and dentin: An insight into non-carious cervical lesions. Journal of Dentistry (2006) 34, 12–18	mounted on horizontal loading fixture permitted compressive loading along the long axis of the tooth specimen The loading fixture was positioned interferometer - to visualize the resulting load induced deformation	direction within the dentin increased towards the cervical region adjacent to the cementoenamel junction on the facial side.
N Noma. [72]Cementum crack formation byRepeated loading *in vitro*, Journal of periodontology J Periodontol 2007 Apr ; 78(4):764-9.	5 human mandibular premolars, compression load – 5 kgf, 1,000,000 cycles sterioscopic microscope photograph and SEM @100,000cycles, dye – 2%methylene blue to see cracks.	Cementum cracks initiated in the cervix on buccal, mesial, & distal surfaces after repeated compressive loadings and extended toward the root apex
D.Palamara. [73]Strain patterns in cervical enamel of teeth subjected to occlusal loading, Dental Materials, 16 (2000) 412–419.	1 intact mand 2nd premolar, 3D geometry reconstructed, FEMs developed, 100N load axially & obliquely on inclines of buccal cusp;	Strains concentrated near the CEJ at both angles. Strains predicted from FEA model agreed with strain gauge measurement

	Strain gauge: 10 intact mand. PMs, 1 gauge at lingual surface & 2 on the buccal surface, 100N load – 45° & 90°.	
A. Palamara.[74] Tooth morphology and characteristics of non-carious cervical lesions	2 intact human mand.2nd premolar & central incisor – FEA model constructed, 100N load at 45° to long axis of teeth	Strains were concentrated near the cementoenamel junction (CEJ) regardless of load direction, and oblique loading showed higher tensile strains
John J. Dzakovich. [75] In vitro reproduction of non carious cervical lesions, 2008	Three pairs of toothbrush types (generic and name-brand) with soft, medium, or firm bristles were tested with 3 different toothpastes of varying abrasive potentials (low, medium, and high) or with water only, on mounted human teeth with and without simulated gingival tissues. 70,000	NCCLs were created by horizontal brushing with toothpaste, while brushing with water only did not create these cervical lesions. Dentin wear appeared at 10,000 strokes

	strokes, horizontal brush-ing.	

Measuring Volume of Non Carious Cervical Lesions

Recent studies have focused on a characterization of lesions such as height, depth, location, patient age and gender information.[76] Findings have demonstrated strong correlations with age, dietary acids and toothbrushing[77], and the presence of lesions in association with occlusal attrition and erosion[55].

In a review of techniques for the measurement of tooth wear and erosion, Azzopardi et al.[76] concluded that the current methods of quantifying tooth substance loss involving impressions, pouring of models, mechanical or laser digitization and analysis were slow and cumbersome and confined to laboratory investigations. There seems to be wide variation in techniques used to measure tooth wear and erosion. In vitro techniques may have little direct clinical relevance but can lead to new and more accurate clinical methods. In vivo studies have problems with reference points and accurate validation of the techniques.

Modern digital photogrammetry maps tooth surfaces and monitors the progression of NCCLs if a suitable optical texture is present on the imaged tooth surface.[78] The application of optical texture onto or into a dental casting material has not been reported and may offer an alternative path to development of a more clinically relevant technique. It has been proposed that the shape of lesions may be related to the NCCL etiology.[79] However this has not been confirmed experimentally or clinically.[23]
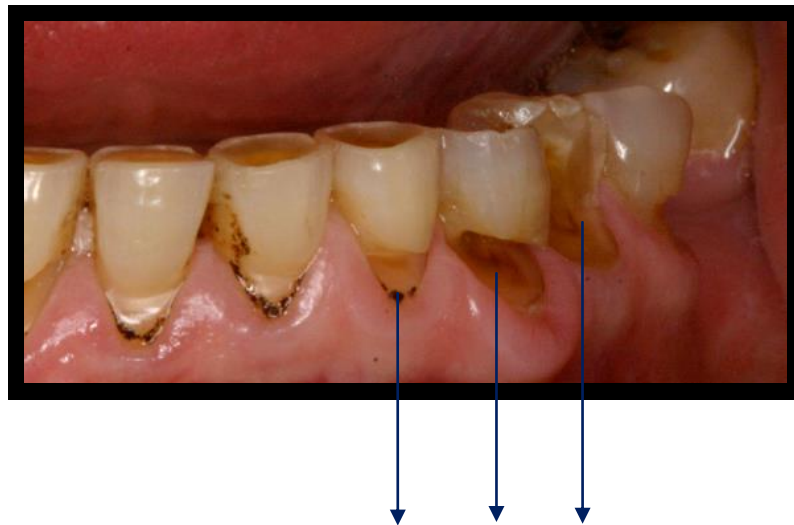
Teeth showing abfraction lesions in combination with occlusal wear facets

Figure 16. Lower left quadrant of a female patient aged 81 years with NCCLs affecting all teeth (black arrows); 33 lesions extending into pulp chamber now filled with reparative dentin; 34 shows bulk loss of buccal enamel and dentin. Attrition affecting occlusal/incisal surfaces with dentin 'cupping' affecting all teeth.

Quantitative measurement systems have traditionally been classified according to the principle by which data are collected, such as contact or non-contact, surface topography or silhouette tracing. The methods reviewed below are:

i. Profile/silhouette tracing

ii. Measuring microscopy

iii. Contact stylus

iv. Photogrammetric

v. Structured light

vi. Laser scanning

vii. Confocal microscopy

viii. Computed tomography and magnetic resonance imaging

Profile / Silhouette tracing:

The progression of NCCLs has been monitored using this method by obtaining profile tracings of silicone (Dow Corning, Alhambra, CA) replicas of teeth.[80] The object or replica are sectioned regularly, typically 1mm , then hand traced, photographed or video graphed Subsequent replicas were orientated manually to the initial replica and three slices, 1 mm thick, were cut through the lesions, parallel to the long axis of the tooth. Profile tracings and measurements of the replicas were obtained at 20x magnification; the slices procured between time intervals were superimposed using the average of three measurements of the lesions of each tooth replica. No accuracy information was reported, but is expected to be low.

Measuring microscopy:

Measuring microscopes consist of a stereo microscope with an internal mark, cross-hair to view an object mounted on an x, y stage. The internal mark is used to locate the x and y coordinates of a point or feature seen through the microscope. The plane of focus can be used to determine the z coordinate where an appropriate recording mechanism is included in the instrument. Height accuracy is increased with increasing magnification, which also narrows the depth of field.[81] Eye fatigue during measurement and examination can be an influencing factor in this technique.

Contact stylus:

Contact stylus systems have been designed and built in a number of different centers. Tooth replicas are typically profiled one at a time with measurement routines taking several hours. Sequential profiles of the same tooth showed reproducibility of ±7µm. [82, 83]

In recent years commercial contact stylus measurement systems have become commonly available and their use is being reported in the dental literature. While they are typically referred to as 'profilometers', they come under the general classification of coordinate measurement machines (CMM) and often have nanometer accuracy. Contact stylus systems are now fully automatic, and while the measurement procedure may take several hours, it does not require actual operator time. However for best results, teeth surfaces need to be mapped individually, using replicas that have to be individually prepared.

Photogrammetry:

At its broadest form, photogrammetry takes measurements from images to generate 2D and 3D data. Measurements are taken from natural features appearing in the images or targets placed into the scene.[84] Traditionally, photography was the means of non-contact imaging and found its major application in aerial based land mapping (aerial photogrammetry) utilizing single, very large format (230 mm x 230 mm) cameras and to a lesser extent land based mapping of architectural and engineered structures (non topographic, terrestial or close range photogrammetry) utilizing single or stereo large format (e.g. 100 mm x 150 mm) cameras.

Digital photogrammetric systems (DPS) [84] follow a sequential process in which either hard-copy photographs are digitized or the images are directly acquired by digital cameras, then automatic matching takes place, where images are compared digitally, the small differences (parallaxes automatically calculated, and 3D coordinate data generated.

Photogrammetry has a significant advantage over all other methods because 3D data acquisition can be instantaneous, giving simultaneous acquisition of images from different directions. [84]

Structured light:

An alternative approach, known as structured light or active pattern projection, employs a light stripe or grid pattern of known geometry projected onto the object surface and photographed. Methods of pattern projection have included a light stripe com-

bined with object movement through the stripe. The CEREC system was not developed as a research tool and at present there is no easy method of recovering raw data from the system. The CEREC system presents a potential clinical method for mapping NCCLs; however its reported measurement accuracy of 25 μm does not match that of contact stylus systems. Further, the reported accuracy is diminished by the need to render the surface of the tooth opaque prior to imaging. It has the advantage of being fully automatic and 3D reconstruction occurs in a matter of seconds.[84]

Laser scanning:

The improved directionality of laser light has been exploited to improve structured light mapping systems, with methods including double-axis laser scanning, telecentric scanning, laser strip projection, optical radar and time of- flight laser rangefinders.[12]

A non-contact profilometer with a LASER line and CCD camera at an angle of 25° was developed to measure tooth wear [85]. The light line full width at half maximum (FWHM) was 22 μm and 512 surface points were measured in one video cycle. A step motor advanced the model in the y direction. The tooth surface was scanned at an interval 25 μm between points in x and y directions (250,000 points) in 20 to 40 seconds. Accuracy of (6.0 ± 0.6) μm was reported and precision was (2.9 ± 0.5) μm.

Confocal Laser Microscopy:

Confocal microscopy generates a common focal plane for both illumination and imaging and generates optical tomograms, giving thin slices (>1 μm) up to 100μm below the surface of enamel and dentin.[84] Reflection imaging of the natural teeth resulted in excessive reflection in many areas, probably sdue to increased reflection from enamel prisms or small sections of tooth surface perpendicular to the laser source causing significantly more reflection than the rest of the surface. This led to the misrepresentation of the surface position at these points. Staining the surface of a replica with fluorescent eosin gave the strongest signal compared to the low amount of auto fluorescence exhibited by natural teeth and was more accurate than depositing a layer of eosin dissolved in oil on the surface.

Computed Tomography and Magnetic Resonance Imaging:

Computed tomography (CT) utilizes x-radiation to produce 2D sections through the body or radiosensitive material. Conventional CT typically records slices 1 to 2 mm in thickness. Two-dimensional slices are assembled to build 3D models. Magnetic Resonance Imaging (MRI) involves applying magnetic fields to tissues under investigation and recording the differential resonance emitted by different tissue components.

Microscale CT has been applied to an extracted maxillary premolar, fixed in an acrylic glass tube, and placed in a μCT scanner (Scanco MicroCT; Sanco Medical) (Verdonschot et al., 2001). A scan grid of 1024 x 1024 was selected with a resolution of 13 μm and a scan slice thickness of 25 μm. The premolar was scanned with 770 slices, and the exposure time was set at 10 ms. No dimensional accuracy testing was reported. Similar data has also been recently reported .[69]

Rationale of the Study

An appreciation of the etiology and cessation of lesion progression should precede treatment and perhaps modifying aggravating factors, such as altering potentially harmful eccentric occlusal contacts, acidic diets, or excessive tooth brush abrasion should be attempted. Kuroe et al[33] advocated the evaluation of occlusal stresses on affected tooth/teeth and the reduction of heavy lateral forces. Coleman, Grippo and Kinderknecht[86] reported significant associations between occlusal hyperfunction, parafunction, dentin hypersensitivity and abfractive lesions; and concluded that occlusal equilibration resulted in long–term resolution of cervical dentin hypersensitivity. However Wood et al[58] reported that occlusal adjustment did not prevent NCCLs progression. In the study by Wood et al, only dynamic occlusal contacts (marked using red articulating paper) were adjusted while the static occlusal contacts or centric stops (marked using blue articulating paper) were left intact, thus jeopardizing the occlusal equilibration because excessive biting forces were not completely eliminated by adjusting both static and dynamic contacts/interferences) . In addition, measurement of lesion progression in this study was done by observing sectioned models under a stereomicroscope, followed by image analysis using the SigmaScan software (Aspire Software International, VA, USA), which requires manual outlining of lesions using a mouse pointer on a computer screen, thus increasing the window for operator variability.

New treatments to control the loss of cervical tooth structure need to be developed based on a firm understanding of the etiology of these lesions. The current

studyexamined relatively healthy patients to determine factors which may influence lesion progression in subjects with acidic diets, improper tooth brushing techniques, abrasive habits, GERDs. Using diet surveys and recording tooth brushing techniques captured factors generally associated with NCCL. Two novel methods were used to quantify and map the distribution of occlusal forces on individual teeth: T-scan and Pressure indicating films. The T-scan produced relative absolute biting force registration and Topaq pressure analysis system measured the absolute biting pressure produced as registered by the color produced from ruptured microcapsules which fracture when a patient bites on the Prescale sensor film. Applying these research methods and specialized instrumentation to the development and progression of NCCL added significant information to effectively understand the etiology of these lesions even in this pilot study.

HYPOTHESES AND AIMS

Null Hypotheses

(1) There is no difference in the volume loss of tooth structure in NCCL in teeth with high or low occlusal biting forces. (2) Teeth with NCCL have the same occlusal bite forces as adjacent teeth with no lesions. (3) Subjects with horizontal brushing techniques have the same NCCL progress as subjects with circular brushing habits.

Specific Aims

The aims of this observational, controlled, prospective clinical trial are to:

1) Measure the depth and volume loss (increase in lesion size) of tooth structure in non-carious cervical lesions (NCCL) in adult teeth over five years.

2) Evaluate the association between bite forces on teeth with NCCL and lesion volume loss

3) Evaluate the influence of cofactors like tooth brushing technique, diet, occlusion and parafunction on the progression of NCCL.

MATERIALS AND METHODS

Patient Population

Subjects recruited for this investigation were selected from 45 participants in a previous clinical study conducted at UAB-School of Dentistry "Clinical Evaluation of Three Dental Adhesive Systems in Class V Restorations", based on certain defined inclusion and exclusion criteria (Tables 3 and 4). This study received approval from the University of Alabama at Birmingham Institutional Review Board with a protocol number of X130816002. Subjects were informed of the study methods and the procedure. After the subject's questions were answered they were asked to participate in the study. Their verbal acceptance was followed by a signed informed consent process.

Table 3. Inclusion criteria

19 years of age and older
Have two non-carious cervical lesions 1 mm in depth and do not require operative intervention
Test teeth should be in occlusion
There should be no clinically detectable mobility of the test or antagonist teeth
Be a regular dental attendee who is able to return for assessments
Be in good medical health and able to tolerate the dental procedure.
Must not have rampant caries
Must not have chronic periodontitis or carious lesions which could compromise tooth retention.
Have normal salivary function

Table 4. Exclusion criteria

They are enrolled in an evaluation of restorative materials.
Have NCCL lesions less than 1 mm deep.
They are irregular dental attendees.
They maintain an unacceptable standard of oral hygiene.
The subject has poor general health.
They have chronic periodontitis (>3 mm pockets) or rampant caries.
Teeth are mobile.
Other restorative treatment on the teeth included in the current study.
They are unable to return for recall appointments.

Non-carious lesions previously examined were included in the study. Teeth must be vital and free of any periapical pathology both clinically and radiographically.

Study design

Casts and scans (Proscan and Topaq scan) from a previous two-year NCCL study were used for the same patients recruited for this novel research project.

Table 5. Study design

Visit 1
Impression + Facebow
Bite force measurement (T-scan and PreScale films)
Dietary and oral hygiene habits assessment

↓

Visit 2 (optional)
Occlusal analysis verification
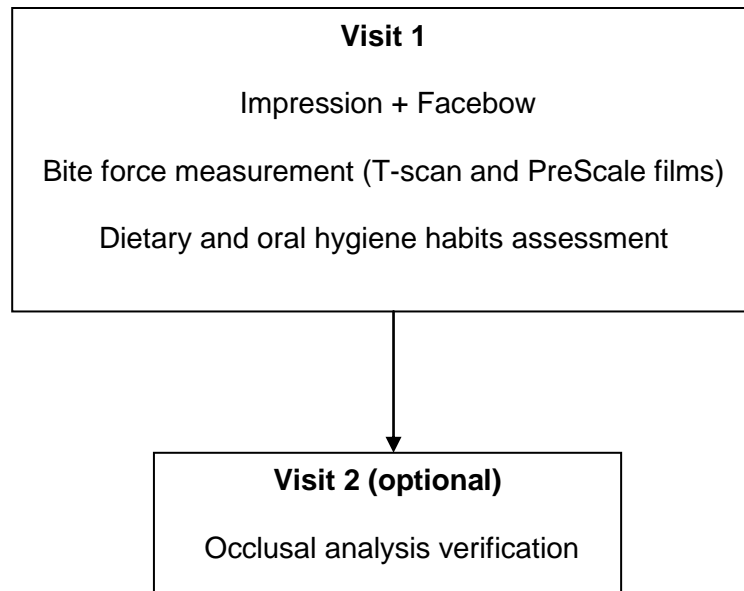
Table 6. Measurements taken and used

Addition silicon impressions and casts.
Bite force measurement using Fujifilm Prescale films and Topaq scanner.
Occlusal force distribution using a T scan reusable sensor.
Occlusal analysis with the casts mounted on semi-adjustable articulator.
Proscan scanned images of cast over baseline and five year period.
Change in lesion shape, size and surface profile: from baseline to five years

This study continued and expanded a previous study measuring biting force and NCCL progression. Since NCCL volume loss is progressive, by using patients with pre-

viously recorded NCCL, the volume loss was expected to be greater at this measure peri-od than the two-year time period previously used. The previous study involved recording of non-carious cervical lesion progression at baseline, one and two years. The addition silicon impressions (Imprint 3, 3 M ESPE, St Paul, MN) and casts were obtained for the subjects at all three visits. The casts were scanned at baseline, one year and two year us-ing Proscan (Scantron/England). The baseline measurements recorded in the previous study were used to significantly increase the evaluation period to follow lesion progres-sion and determine whether greater tooth structure occurred in this 5 year recall.

Table 7. List of materials used

Self adhesive Directed Flow Impression Tray	3M ESPE
Aquasil Ultra Heavy: Type 2: Medium bodied consistency	DENTSPLY Caulk
Aquasil Ultra XLV: Type 3: Light-bodied	DENTSPLY Caulk
Fujirock Type 1V Die & model stone	GC America
Putty impression material	DENTSPLY Caulk
Biotrol disinfectant solution	Biotrol International

Making impressions:

For the current study, the subjects selected from the patient pool of the previous study were appointed for a fifth year recall visit dental examination. Impression of the

subject's maxillary and mandibular arch were made using stock full arch impression

trays (Self-adhesive Directed Flow Impression Tray/3M ESPE) and addition silicone

impression material (Aquasil /Dentsply Caulk). The impression tray was loaded with

Aquasil impression material dispensed from Pentamix 2 (3M ESPE) impression mixing

machine. The teeth were dried with air while the assistant loaded the impression tray.

The occlusal and facial surfaces of the teeth with NCCL were covered with an extra low

viscosity fast set PVS impression material (Aquasil Ultra XLV/Dentsply Caulk). (Figure

17) The tray filled with heavy viscosity impression material was then seated slowly,

using the central incisors as a guide. (Figure 18) The tray was positioned using the sub-

ject's nose as the reference point. Three and half minutes after seating the tray, the im-

pression was removed. (Figure 19) The impressions were disinfected (Biotrol disinfect-

ant solution/Biotrol International) and stored in a coded bag in lab under room tempera-

ture.

Figure 17. Impression making: Covering occlusal and facial surfaces of the teeth

with NCCL with an extra low viscosity fast set PVS impression material

Figure 18. Positioning the tray filled with heavy viscosity impression material using the central incisors and the subject's nose as a guide.

Figure 19: Maxillary & mandibular impressions

Pouring casts:

The impressions were washed thoroughly with tap water, to remove any remaining disinfectant and dried with air water syringe to ensure no excess liquid remains. A 100mg of Fujirock (GC America/USA) Type IV Die & model stone was spatula mixed for 10 seconds followed by vacuum mixing (Whip Mix Corporation/US, Model # 6500) under 27 psi/ for 30-40 sec with 20ml of tap water measured in a measuring cylinder at 23±2 º C. The impression was poured at an ambient temperature of 23 ± 2 ºC and humidity of 34±1 %. Impressions were poured in the order they were made from the patients. Using the stone vibrator set in slow mode, the mixed stone was slowly poured into the impression with the heel of the impression tray touching the vibrator. Care was taken to not touch the tray not the impression on the vibrator to prevent distortion. A small amount of the stone was vibrated through the impression to provide a thin wash of stone in the impression covering the depressions. Subsequent stone was slowly added in small increments to fill the impression while vibrating the impression. The casts were separated from the impression trays after setting for 30 to 40 minutes following manufacturer instructions. Two sets of casts were prepared from each impression. One set of casts was trimmed to a desired shape and based. (Figure 20)

Figure 20. Poured and separated maxillary & mandibular casts

Making a positioning mold or standardizing cast position for scanning:

These casts were positioned using putty impression material so that the scanner would view each cast at the same angle for the baseline and the five-year recall casts. (Figures 21 and 22) Molds were made with putty impression material on the occlusal surface and buccal surface of the same side. The impression materials positioned the cast in the same position to allow repeated impressions of the same patient at the same angle in Z axis. They were positioned in such a way on the surveyor that baseline cast, one year cast, two year cast and five year cast all are angled in the same way. The impression material fixtures were wide enough to hold and position the cast with no movement of the cast during scanning. Occlusal surfaces of 3-4 teeth were covered with putty impression materia and extended lingually and bucally.

Figure 21. Putty material used to angulate the cast to the vertical arm of the surveyor with three notches to position the casts made at baseline, one-, two- and five years at same angle for scanning on Proscan

Figure 22. The surveyor positioning the cast at same angle for base

Proscan imaging:

Aligned casts were placed in the positioning device and scanned using Proscan (Scantron/England), a non-contact three dimensional surface measurement devices. (Figure 23) The various features of Proscan are enumerated in Table 8. Proscan has a resolution as low as 5nm, while measuring up to 1,000 points per second, using its latest non-contact sensor technology. It works by transmitting white light through a lens that has carefully manufactured spectral aberration built into it. It's this effect that divides white light in it into the full spectral field, focusing each of the different colour frequencies at a slightly different point through a defined measuring range. (Figure 24)

Figure 23. Scanning using Proscan
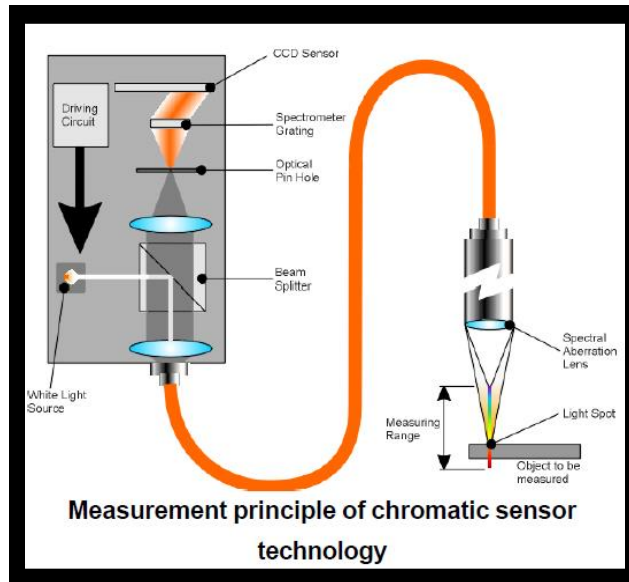
Figure 24. Measurement principle of chromatic sensor technology

Table 8. Proscan features

High speed measurement up to 1,000 points per second coupled with high resolution from 5nm, using chromatic aberration enables the measurement of millions of points on a surface for further analysis within Proscan
Total flexibility with a range of interchangeable sensors with measuring ranges in height from 110μm to 50mm can be used on one system.
Non-contact measurement alleviates damage to highly polished, delicate or soft materials.
Scantron's confocal chromatic sensor technology provides unmatched measuring per-

formance.
With a scanning area of 150mm x 100mm, a diverse range of samples may be measured, making the instrument very versatile and easy to set-up.
Matrix scanning enables arrays of parts to be measured individually or scans can be combined for measuring irregular shapes.
Spot size from just 2μm diameter. Spot size is the diameter of the circle formed by the cross section of the field of view of an optical instrument at a given distance. The size of the spot has a direct relation to the features being measured. If for example the surface has a very fine level of surface roughness, a sensor with a very small spot size would need to be used. Sensor with small spot size is more accurate.
Specialist software for dental applications ProForm .

The Proscan was used to scan all NCCLs while the casts were precisely positioned with a 20μm step size at frequency of 100Hz. When an object is placed within this range, only one particular color frequency reflects back from the surface. This information is then passed back into a processor where a spectrometer analyses the signal and converts it to a measurement. The Proscan combines these measurements with the precise location of a moving X/Y linear table, creating three coordinates from which to create a 3 dimensional profile. Using this system the scan of the subject's tooth at the fifth year recall visit was obtained. Baseline, one and two year maesurments also used the same measurement system, although we used the baseline and 5 year scans for NCCL volume loss measurement.

Superimposition of scans using Proform software:

The scanned images for each NCCL at fifth year recall were superimposed on previous baseline scans using the Proform software (Figure 25). If baseline scan was missing (2 subjects), then one year scan was superimposed with fifth year cast. The Proform software is designed to compare scans made using the Proscan 2000 non-contact surface profilometer. This software is ideally suited to accurately measure the amount and location of material loss for wear or erosion studies. The measurement data can be registered allowing the two surfaces to be easily and accurately aligned in all planes with the differences displayed in a number of different graphic displays. This allows us to measure the change in volume of the non-carious cervical lesions from baseline to five years. The volume difference can be measured separately for the cervical tooth and gingival areas of the lesion, apart from measuring the total volume loss. This provides preliminary information as to the depth and ultimately the progress of the non carious cervical lesion.
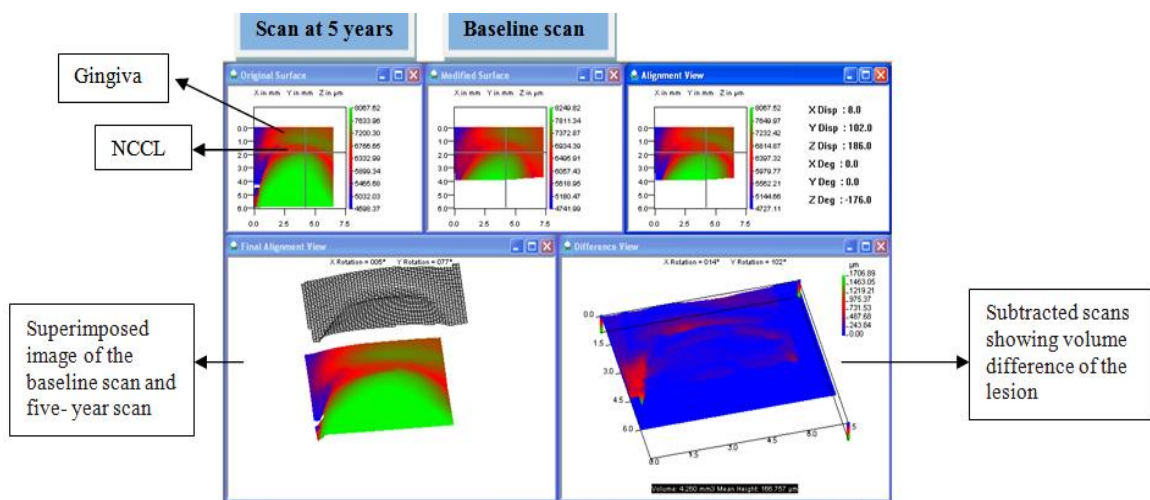
Figure 25. Proform software

The ProForm software enables the comparison of two scans made using the Proscan 2000 non-contact surface profilometer. It is ideally suited for applications where it is important to accurately determine the amount and location of material loss for wear or erosion studies. The measurement data can be registered allowing the two surfaces to be easily and accurately aligned in all planes with the differences displayed in a number of different graphic displays. Once a scan is complete Profom software allows a wide range of analytical tasks to be completed, from calculating the surface area of a sample to ISO standard Roughness and Normalised Peak Count. ProForm software provides dental researchers with a new and easy method to accurately quantify the volume and location of material lost during the study of wear, erosion and abrasion of dental materials.

Key Features of Proform Software:

- Enables complex non geometric shapes to be compared without the need for careful mechanical referencing.

- Simple method of aligning the two sample scans in all planes.

- Calculates the amount and location of material lost in abrasion and erosion studies.

- Fully compatible with Proscan 2000 measurement files.

Applications of Proform software in dental research:

- Measuring the direct effect of erosion of tooth enamel caused by the acidity of food or drink.

- Quantifying the depth and volume of material lost during abrasion studies.

Mounted cast occlusal analysis:

Another set of casts were repoured from the impressions and mounted on a semi-adjustable articulator (Whip Mix #2240Q series) to analyze the bite or occlusion of the patient. The articulator is a mechanical device that represents the temporomandibular joints and jaw members, to which maxillary and mandibular casts are attached. It allows movement of the attached casts into various eccentric relationships, thus simulating the patients' jaw movements outside the mouth. A facebow (Axioquick Facebow/SAM) was used to record the positional relations of the maxillary arch to the temporomandibular joints. A facebow was used because it allows the accurate determination, recording and transfer of jaw relation records from patients to the articulator, which is essential for the restoration of function and esthetics. (Figures 26 and 27) The casts were mounted in maximum intercuspation position (MIP). The patient's bite was registered on the bite fork of the facebow (Figure 28) with Regisil 2x Bite Registration paste/DENTSPLY CAULK to orient dental casts in the same relationship to the opening axis of the articulator as in the patient's mouth (Figure 29). The casts were mounted on to the mounting plates of the articulator using blue colored (for contrast with the yellow casts) mounting stone/WHIP MIX which comes in preweighed packets of 100 grams. The mounting stone was spatula mixed for 10 seconds followed by vacuum mixing for 30-40 seconds.

After articulation of the casts, the subjects were categorized based on the type of occlusion; that is, group function, mutually protected occlusion or cuspid protected. Balancing interferences (balancing side is the opposite side where the jaw moves) on teeth with NCCLs were noted and the magnitude of the interference recorded. Occlusal wear

facets on teeth with these lesions were recorded, as these indicate heavy biting forces on these teeth or habits. It was noted if the anterior guidance was sufficient to disclude the posterior teeth during excursive movements.

Figure 26. Making the bite fork record of the patient

Figure 27. Using a facebow to record the positional relations of the maxillary arch to the temporomandibular joints.

Figure 28. Bite fork record of the facebow for orienting upper and lower casts on

the articulator

Figure 29. Upper and lower casts mounted on the articulator

T-Scan III based occlusal analysis:

Bite force measurements were made using T scan occlusal analysis (Tekscan/USA) where the patient bites on an ultrathin sensor (0.1 mm or 0.004 in). (Figures 30 and 31) The software analyses and displays the occlusal interferences, timings of contact and relative levels of force for both vertical and lateral excursive movements, in the form of graphics. (Figures 32 and 33)

Figure 30. Patient seated in the upright position while making the T-scan record
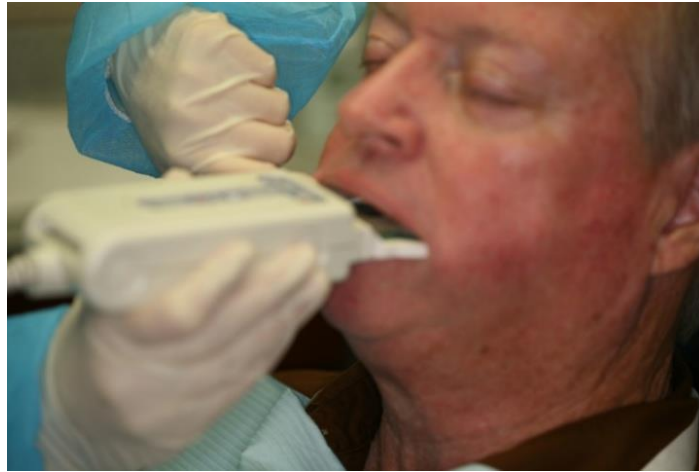
Figure 31. T-scan record made when the patient bites on a thin digital sensor (0.1-0.5 mm)

Figure 32. T-scan device with the digital sensor loaded
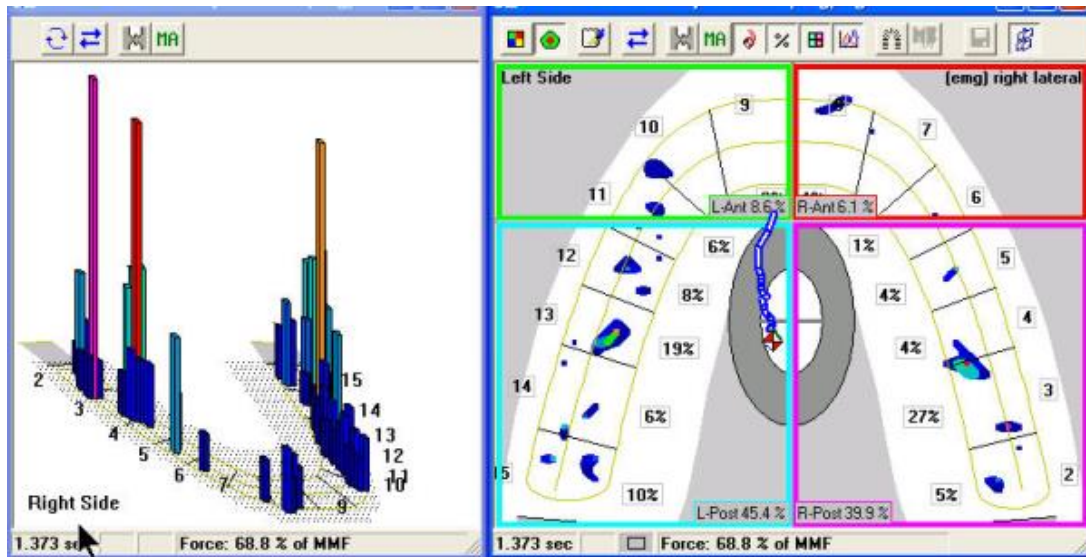
Figure 33. Occlusal force time and % bite force analysis using T-scan

While the T Scan III technology cannot measure absolute force as it cannot describe occlusal forces in Newtons/cm sq. or lbs/sq. in, it gathers force data output from teeth occluding across its recording sensor and is very precise, dynamically changing (in .003 -.005 second increments) relative applied load per occluding tooth. It also produces a variable "percentage of force" at each tooth that changes with each passing.003-.005 second time increment. This data is recorded sequentially as the occluding teeth apply variable load to each other in functional mandibular movements.

The data gathered with this instrument include:

1) % applied force on teeth with NCCL during vertical and lateral excursive movements (Both working and balancing)

2) Distribution of contacts or the pattern in which teeth meet, for instance, which teeth first contact when the patient bites or moves the jaw to one side. The pa-

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tient's teeth may occlude first in the molar area or anterior area or simultaneously. This can help identify any occlusal prematurity associated with teeth with NCCLs.

3) Center of the occlusal force (COF) at any point in time during the jaw movement: This shows whether or not the patient's biting forces are balanced on the left and right sides. All the center of force points during a complete vertical or lateral jaw movement can be plotted to give a center of force trajectory.

4) AOF or Asymmetry of Occlusal Force:

$$\text{AOF (\%)} = \frac{\text{Occlusal force on left side(\%)} - \text{Occlusal force on right side(\%)}}{\text{Total occlusal force}} \times 100$$

5) Lateral and antero-posterior occlusal force distribution:

Lateral occlusal force distribution (LOD)   ___%

$$= |50 - (\text{Right Ant. \% force value} + \text{Right Post. \% force value})|$$

Anteroposterior occlusal force distribution (AOD)   ___%

$$= |50 - (\text{Right Post. \% force value} + \text{Left Post. \% force value})|$$

6) Average occlusion time or duration of tooth contact in excursive movements: can be correlated with higher incidence and progression of NCCLs.

Bite force measurement using Prescale Pressure indicating films:

      Patients were asked to bite normally in maximum intercuspation, using a thin piece of pressure sensitive film (FujiFilm Prescale film, Sensor products Inc, USA) having thickness of 0.1-0.5mm . (Figures 34 and 35)

Figure 34. Patient seated in upright position to obtain a bite force record

Figure 35. Patient instructed to bite on prescale pressure indicating film on tooth numbers #3, 4 and 5

This is a single use sheet containing pressure-sensitive microcapsules which rupture by producing a permanent high resolution "topographical" image of pressure variation across the contact area.(Figure 36)
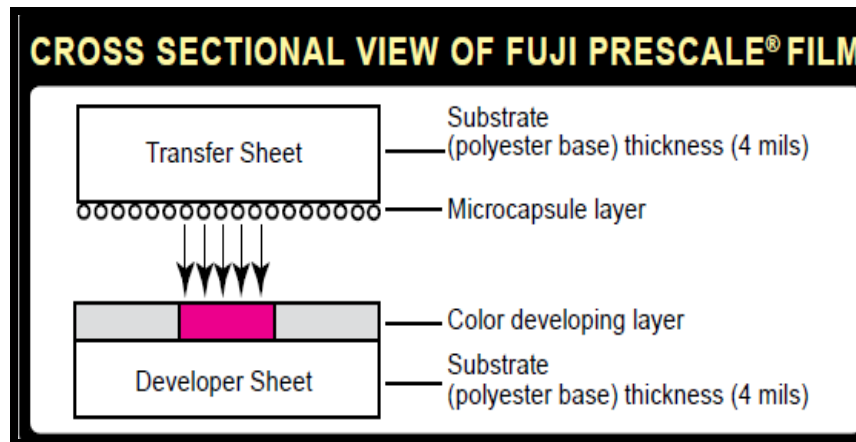
Figure 36. Cross sectional view of PreScale Film

The subjects were seated in upright position and a sheet of PreScale film was placed on occlusal surface of the desired tooth with the NCCL using cotton pliers. The sheet was wrapped in a small plastic film was cut to the size of occlusal surface being measured. The patient occluded on the sheet in the maximum intercuspation position. The subjects were instructed to steadily increase the bite force to its maximum over a period of a few (three) seconds and then release. When pressure is applied to the pressure sensitive film, microcapsules in the sheet burst forming red spots on the sheet. (Figures 37 and 38) When the constituent microcapsules in the sheet collapse, the color former contained in the capsules leaks out to chemically react with the developer. Different densities of color were formed according to the level of the pressure applied to the sheet.

Figure 37. Change in Prescale film color after biting
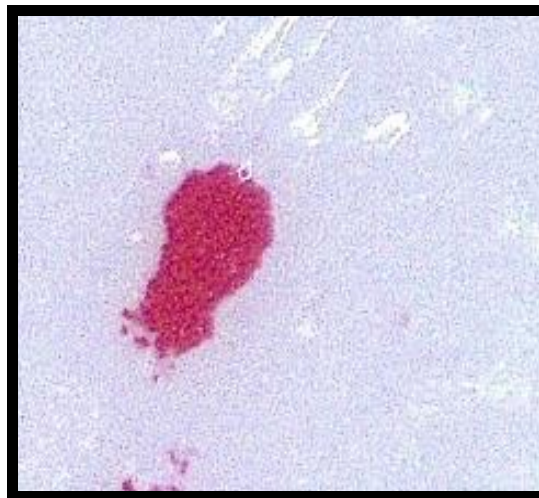
Figure 38. Microscopic Change in color of prescale film to red after biting

The film of "low sensitivity range" of 350-1400 Psi was used for all patients. We used this pressure range since the average tensile stress for enamel, as explained by Bowen and Rodriguezs[87] is 10 MPA, that is around 1450 PSI.

Fujifilm Prescale film is extremely thin which enables it to conform to curved surfaces. It is ideal for invasive intolerant environments and tight spaces not accessible to

conventional electronic transducers. It does not require increased vertical opening and does not slide while recording bite forces.

Analysis of the Prescale Pressure indicating films by Topaq scanner and software:

These pressure-indicating films were analyzed using Topaq pressure analysis system (Sensor products Inc, USA) which generated instantaneous color pressure maps and accompanying statistical data. (Figure 39) Topaq is accurate to within $\pm$ 4%.

Figure 39. Topaq scanner

Topaq consists of a specially calibrated densitimetric scanner and Windows software. An essential component of the Topaq system is the force indicating film: Fujifilm Prescale Film. These sensor films change coloration permanently and instantaneously in response to pressure. The Topaq scanner and software is then used to image and

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interpret the stress marks on the film. From this, Topaq tactile pressure analysis system software (Figure 40) renders high resolution, color calibrated images and a wealth of statistical information pertaining to the analyzed film.
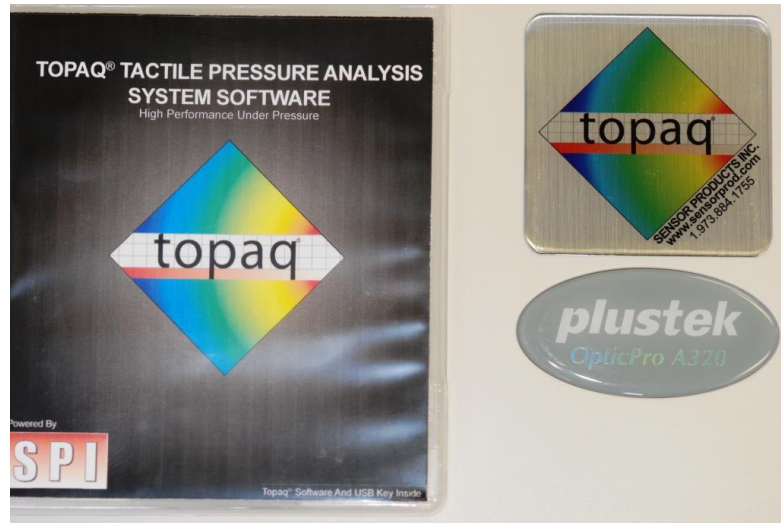
Figure 40. Topaq tactile pressure analysis system software

Once the Prescale film was scanned (Figure 41), the area of interest (with the pressure marks for the tooth having a NCCL) was cropped (Figure 42). The cropped image was modified into 'pseudolor' to obtain pressure statistics of the tooth of interest (Figures 43-46).
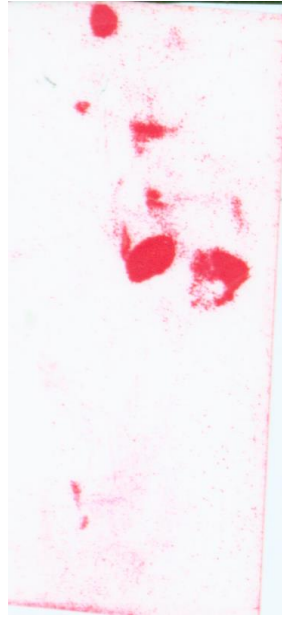
Figure 41. Scanned Fujifilm Pressure Indicating Film
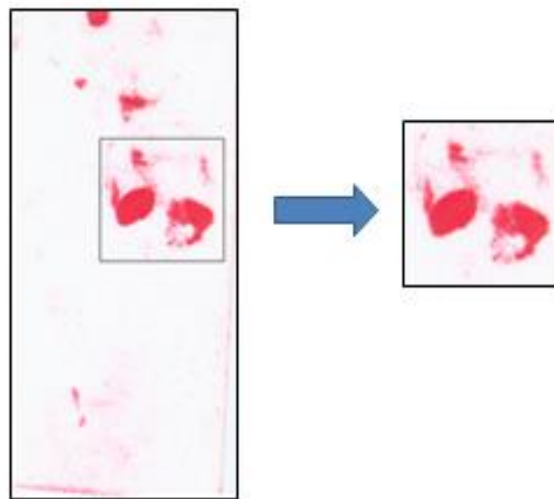
Figure 42. Cropping the tooth of interest (Tooth#3)
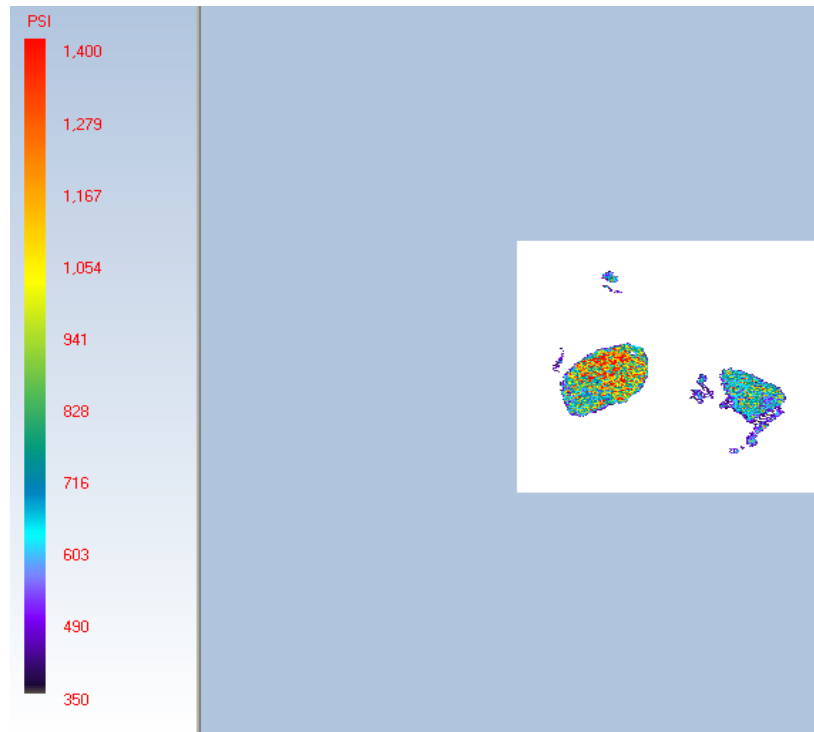
Figure 43. Pseudocolor representation of the cropped tooth (#3)
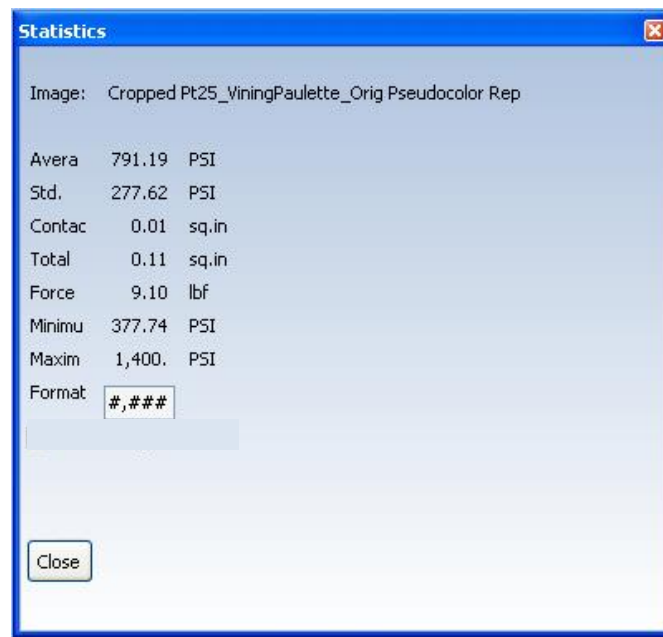
Figure 44. Pressure statistics obtained from the Topaq pressure analysis software
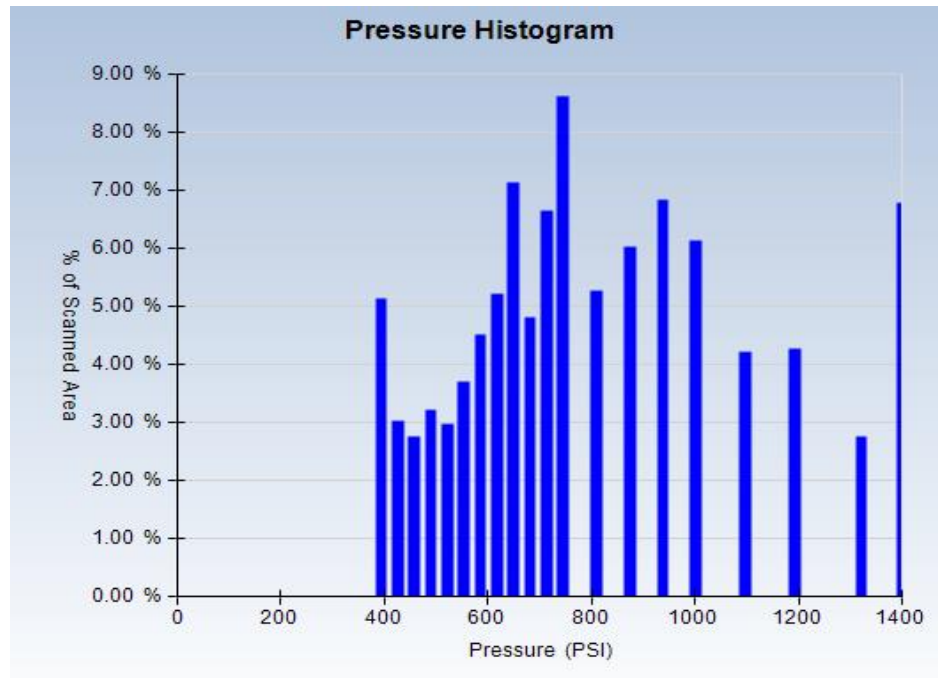
Figure 45. Pressure histogram obtained from the Topaq software
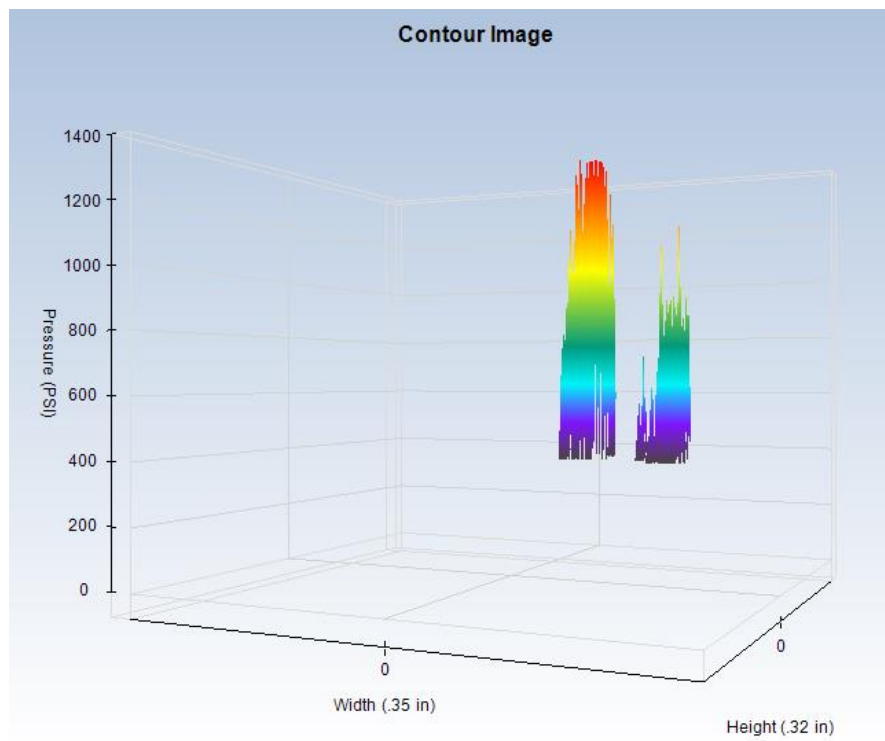
Figure 46. Contour image output from the Topaq software for tooth#3

Diet and tooth-brushing habits evaluation

An assessment of subjects' dietary habits (Appendix 3) and brushing technique (Appendix 4) were recorded to determine dietary and abrasive factors which may influence lesion progression; such as patients with acidic diets, xerostomia, improper tooth brushing techniques, abrasive habits, GERDs, compromised periodontal condition and teeth without antagonists. The subject's dietary habits were recorded as a verbal response to questions asked on Appendix 1. Typical tooth brushing was observed as the patient brushed their teeth (Figure 47) and recorded on Appendix 4.
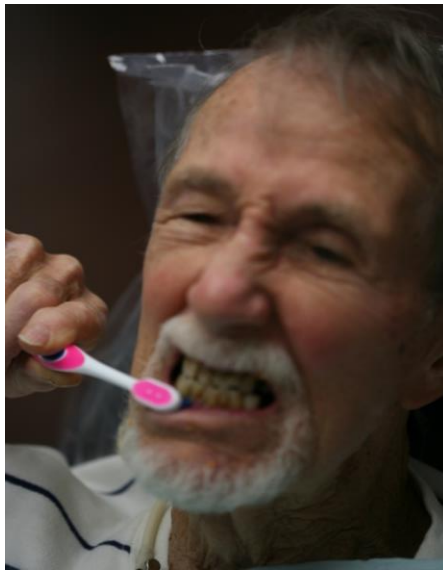
Figure 47. Evaluation of patient's brushing technique

Tooth mobility testing

Mobility of the teeth with non-carious cervical lesions was graded clinically by applying firm pressure with either two metal instruments or one metal instrument and a

gloved finger. (Figure 48) The grade of tooth mobility was ascertained based on Miller's

mobility index.[88] (Table 9)

Figure 48. Mobility testing on teeth with NCCLs

Table 9. Miller's classification of tooth mobility

Grade of mobility	Description
Class I	• Tooth can be moved less than 1mm in the buccolingual or mesiodistal direction
Class II	• Tooth can be moved 1mm or more in the buccolingual or mesiodistal direction • No mobility in the occlusoapical direction (vertical mobility)
Class III	• Tooth can be moved 1mm or more in the buccolingual or mesiodistal direction • Mobility in the occlusoapical direction is also present

Sensitivity testing:

For cold sensitivity testing, a cotton pellet was saturated with a refrigerant spray (Hygenic Endo-Ice Pulp Vitality Refrigerant Spray/ Coltene Whaledent) (Figure 49). The saturated pellet was applied on the tooth with the NCCL in the buccal cervical area. for three seconds as described in Figure 50 and removed. Cold response was measured using a visual analogue test by asking the subject to place an 'X' on a 10 cm line labeled 1 on the left and 10 on the right. They were told that 10 represents the worst pain they can imagine (childbirth, major surgery or kidney stones) and 1 represents no sensation at all. The distance of the 'X' mark on the line represented the level of cold sensitivity of the noncarious cervical lesions.

Figure 49. Saturating a cotton pellet with refrigerant spray

Figure 50. Performing a cold sensitivity test on teeth of interest

Sclerosis evaluation

The evaluation of dentin scleroris on teeth with noncarious cervical lesions was based on the Dentin Sclerosis Scale (Figures 51 and 52; Table 10) developed by the University of North Carolina School of Dentistry. Visual examination and comparison was done by the evaluator to determine the degree of sclerosis in the teeth of interest. [89]

Figure 51. Category 1 dentin sclerosis

Figure 52. Category 4 dentin scelorosis

Table 10. Dentin Sclerosis Scale

Category	Description
1	No sclerosis evident. Dentin opaque in appearance. Dentin light yellow or whitish in color with little discoloration. Little translucency or transparency is evident in the dentin. Typically, these types of lesions occur most frequently in younger individuals.
2	More than 1, but less than 50% between categories 1 and 4.
3	Less than 4, but more than 50% between categories 1 and 4.
4	Significant sclerosis evident. Dentin glassy in appearance. Dentin dark yellow or even discolored (brownish). Significant translucency or transparency is evident in the dentin. These types of lesions occur most frequently in older individuals and are considered a result of the aging process of dentin.

Recording toothpaste abrasiveness:

Abrasiveness of toothpaste used by the patients was determined based on the toothpaste abrasiveness index[90] (Table 11). A toothpaste's abrasiveness is measured by its Relative Dentin Abrasivity (RDA). Toothpastes can be classified as low, moderate or highly abrasive based on the RDA value (Table 12)

Table 11. RDA (Relative Dentin Abrasivity) values for common toothpastes

Toothpaste	RDA Value
Straight Baking Soda	7
Arm & Hammer Tooth Powder	8
Arm & Hammer Dental Care	35
Oxyfresh	45
Tom's of Maine Sensitive	49
Arm & Hammer Peroxicare	49
Rembrandt Original	53
CloSYS	53
Tom's of Maine Children	57
Colgate Regular	68
Colgate Total	70
Sensodyne	79
Aim	80
Colgate Sensitive Max Strength	83
Aquafresh Sensitive	91
Tom's of Maine Regular	93
Crest Regular	95
Mentadent	103
Sensodyne Extra Whitening	104
Colgate Platinum	106
Crest Sensitivity	107
Colgate Herbal	110
Aquafresh Whitening	113
Arm & Hammer Tarter Control	117
Arm & Hammer Advanced White	117
Close-Up with Baking Soda	120
Colgate Whitening	124
Ultra Brite	130
Crest MultiCare Whitening	144
Colgate Baking Soda Whitening	145
Pepsodent	150
Colgate Tarter Control	165

Table 12. RDA based toothpaste absrasiveness index

RDA Value Range	Abrasivity
0-70	Low Abrasion
70-100	Medium Abrasive
100-150	Highly Abrasive
150-250	Regarded as Harmful Limit

RESULTS

For the fifth year recall, 29 patients returned (n=29/45 patients; recall rate=64.4%) with a total number of teeth measured=83. Among the 29 subjects included in the study, the incidence of non-carious cervical lesions was nearly equally distributed among males and females (1:1 ratio), with an average patient age of 60.28 years. The lesions occurred predominantly in premolars (32.2%), followed shortly by canines and molars (23.7% each). The shape of the lesions was mostly obtuse (51.7%) or approximately at right angles to the tooth's facial surface (31%). 34.5% patients had moderate sensitivity on the involved teeth which was determined using the cold test. 86% of the involved teeth had Grade 1 mobility (less than 1mm). Moderate to high degree of sclerosis was observed on 68.9% lesions.

Mean biting force was computed for each patient (Appendix G), as well as mean volume loss at each evaluation period. Lesion progression from baseline to five years was calculated as the slope of total volume loss per tooth at the baseline, one-year, two-year and five-year intervals. Regression was performed on each patient data set to determine the rate of volume loss. The slope of the regression line, dY/dX, represents the regression. (Figure 53)
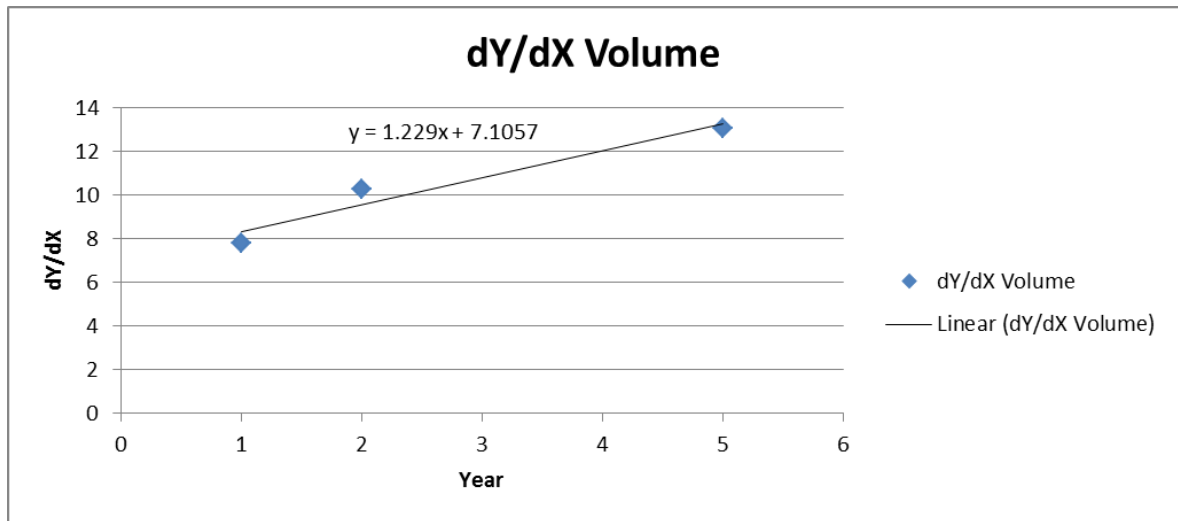
Figure 53. Slope of volume loss representing the progression of NCCLs over a five-year period

The slopes were tested using the KS test for normality. The test revealed a non-normal distribution. The slopes were ranked, and regression was performed. The regression was significant with p- 0.011 (alpha=.05) (Figure 54).
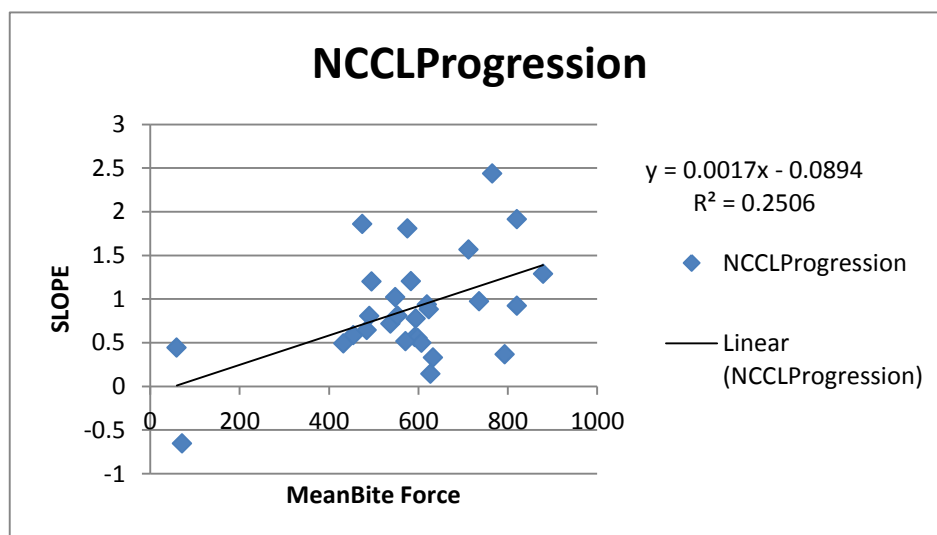
Figure 54. Regression analysis depicting correlation between NCCL progression and absolute biting force (pressure)

Permutation testing was conducted on the untransformed data. Mean bite force values were randomized and 5000 regression iterations were performed, with the target t-value set to 2.924. (Figure 55) The p-value for this procedure was .0098. Thus, null hypothesis #1 is rejected and we conclude that the rate of progression is related to mean bite force.
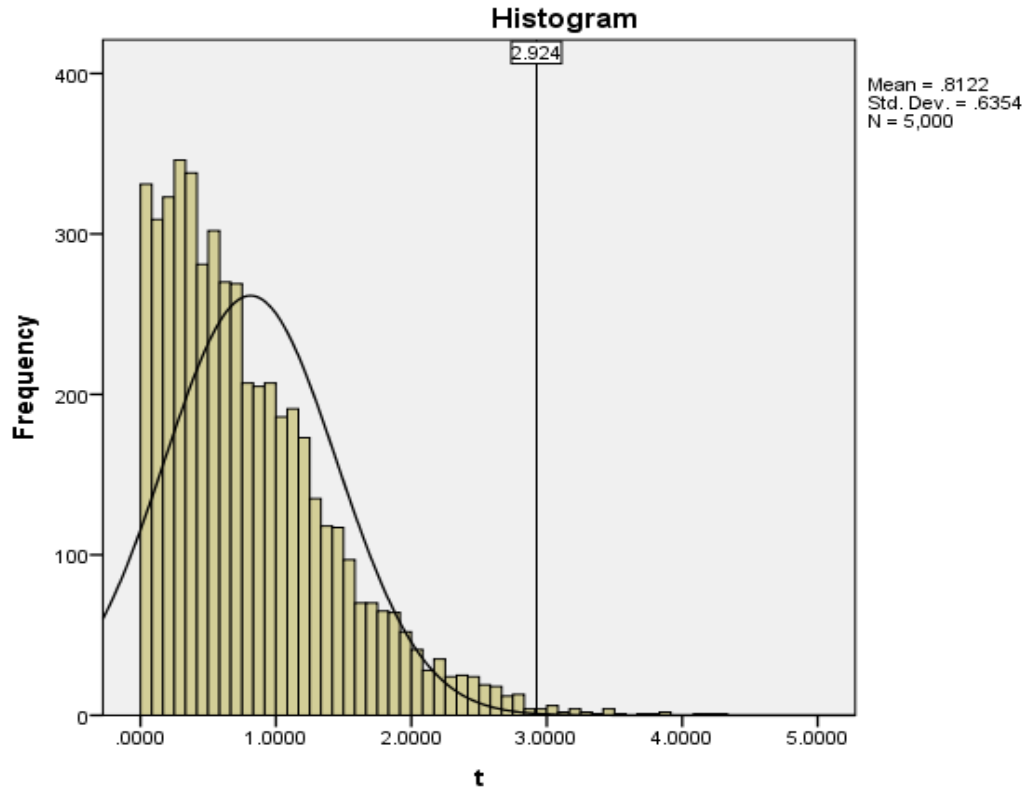
Figure 55. Graph representing the permutation testing for mean bite pres-

sure data over time

One way ANOVA compared lesion progression with toothbrushing techinique and presence of adverse oral habits like nail biting; while Mann-Whitney test was used to correlate NCCL progression with the diet score. Rate of progression is related to mean bite force (p=0.01), presence of adverse oral habits (p=0.02) and consumption of a more acidic diet (p=0.04); but it is not associated significantly with toothbrushing technique (p=0.94), frequency (p=0.58), brushing rigorousness (p=0.54), toothbrush type (p=0.28) or toothpaste type (p=1.00). Thus null hypothesis # 3 is accepted, that is, subjects with horizontal brushing techniques have the same NCCL progression as subjects with circular brushing habits.

The relative bite pressure percentages in excursive movements, obtained from the T-scan, were ranked from lowest (1) to highest (X). This helped to obtain a normal distribution. These relative bite pressure ranks were regressed against absolute bite pressure values, and were significantly correlated. ($p = 0.000048$).
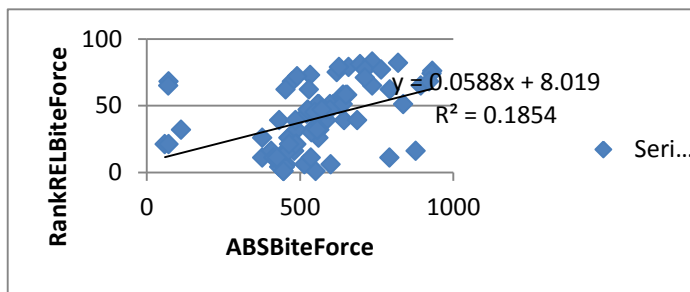
Figure 56. Graphic representation of the regression analysis of relative bite pressure ranks against absolute bite pressure values

From the T-scan based occlusal analysis of a given patient, the percentage bite force distribution was higher in lateral excursive movements to the working side (i.e. the side of the NCCL) compared to the non-working side, which was expected. This was determined by comparing the relative bite force on the working and non-working sides for each patient using the Wilcoxon-matched pair signed ranks test ($p < 0.0001$).

DISCUSSION

The primary goal of this study was to determine if a correlation between occlusal forces, diet and toothbrushing habits and the rate of progression of the non carious cervical lesions was present. Despite all the research and attention that NCCLs have received during the past 30 years, there still remain those who believe that the toothbrush/dentifrice is the main, or only, cause of NCCL etiology. However our study agrees with Babacar Faye et al, who reported that toothbrush/dentifrice abrasion was not a factor in the etiology of NCCLs in a non-toothbrushing population of patients suffering from leprosy. The study found that parafunction could be a contributing factor for NCCLs.[68] Punit Shah[19] suggested that bruxism could be associated with cervical lesion wear, which concurs with our findings which relate adverse oral habits like bruxism and nail biting significantly to NCCLs.

Smith reported that significant associations between NCCLs were present in patients with group function, faceting, clicking joints or those who wore occlusal splints.[69] All these above studies[19, 68, 69] determined that there was a relation between occlusal forces and NCCL. This study examined the prevalence and severity of NCCLs and its relation to occlusal forces and other potential contributing etiological factors. Previous studies have not recorded the rate of progression of non carious cervical lesions by measuring precisely the volume change of the NCCL and co-related those chages with with biting forces (pressure). The major advantage of this technique is that since measuring the progression of lesions under Proscan is an in-vitro procedure, it has the ad-

vantage of standardizing the measuring technique; and then the Proform software allows comparing the baseline cast mesaurement of the NCCL to one year, two year and five-year recall casts. The Proscan 2000 is a fast and accurate non-contact three dimensional surface measurement instrument. It has a resolution in height measurement as low as 5nm, measured at a rate of up to 1,000 points per second, using our latest non contact sensor technology. Faster scanning is achievable with the laser triangulation scanners which can scan at a rate of 10,000 measurements per second to a height resolution of 100nm. This is the first time that this highly accurate Proscan measurement technique has been applied to the field of NCCL volume and depth change analysis. Moreover, ours is one of the few studies in the literature that have studied the progression non-carious cervical lesions for a period of five years.

Takehara et al[37] co-related non carious cervical lesions with bite pressure measured by pressure indicating films. However there was no mention of the pressure range of the pressure indicating films used. In our study, we used the pressure indicating films in the 'Low pressure range', which is 350-1400 Psi, which was close to the average tensile stress of enamel (10 MPa or 1450 Psi) as given by Bowen and Rodriguezs.[87] Takehara et al used the tooth wear index (TWI), which lacked the accuracy of the Proscan (measured in the nm range). This measure was used to correlate lesion changes with occlusal forces. The TWI scores used were 0: no change of contour, 1: minimal loss of contour, 2: defect less than 1mm in depth, 3: defect 1–2mm in depth, 4: defect more than 2mm in depth, or pulp exposure, or exposure of secondary dentin. This score was recorded at a single interval of time and not followed over time to study progression of the

lesions. In our study, the Proscan was used to scan and Proform software allowed precise changes in volume loss of lesions over a five year period. The progression was measured in the form of volume and depth changes, which is more reliable. In addition, that study was restricted to military personnel (all male patients with mean age of 36.2 years) but our study had no such restrictions and can be more easily applied to the general population.

In a study by Wood et al[58], 39 patients having two NCCLs that did not require operative intervention and were in group function during lateral excursion were included. Full-arch impressions were made using a polyether impression material at 6, 18 and 30 month intervals after baseline. The occlusion of the test teeth was marked with red and blue articulating paper and heavy dynamic occlusal markings were checked and removed during follow–up appointments. In this in vivo study NCCL progression was measured over 3 years using a stereomicroscope. No statistically significant difference was found in wear rates between the adjusted and non-adjusted teeth having NCCLs (*p>0.05*). However, the lesion progression was not measured in terms of volume which could be a more precise method. In addition, this study had a shorter evalaution period as our study and did not use an articulator or facebow for a mounted cast occlusal analysis for occlusal adjustment.

Thus we can see that there are various other etiological factors other than biting forces that could be responsible for progression of NCCLs. Our study is in coherence with various other studies that point to the multi-factorial etiology of non carious cervical lesions (Figure 57)[1], therefore when treating these lesions we need to take other factors in consideration as well.
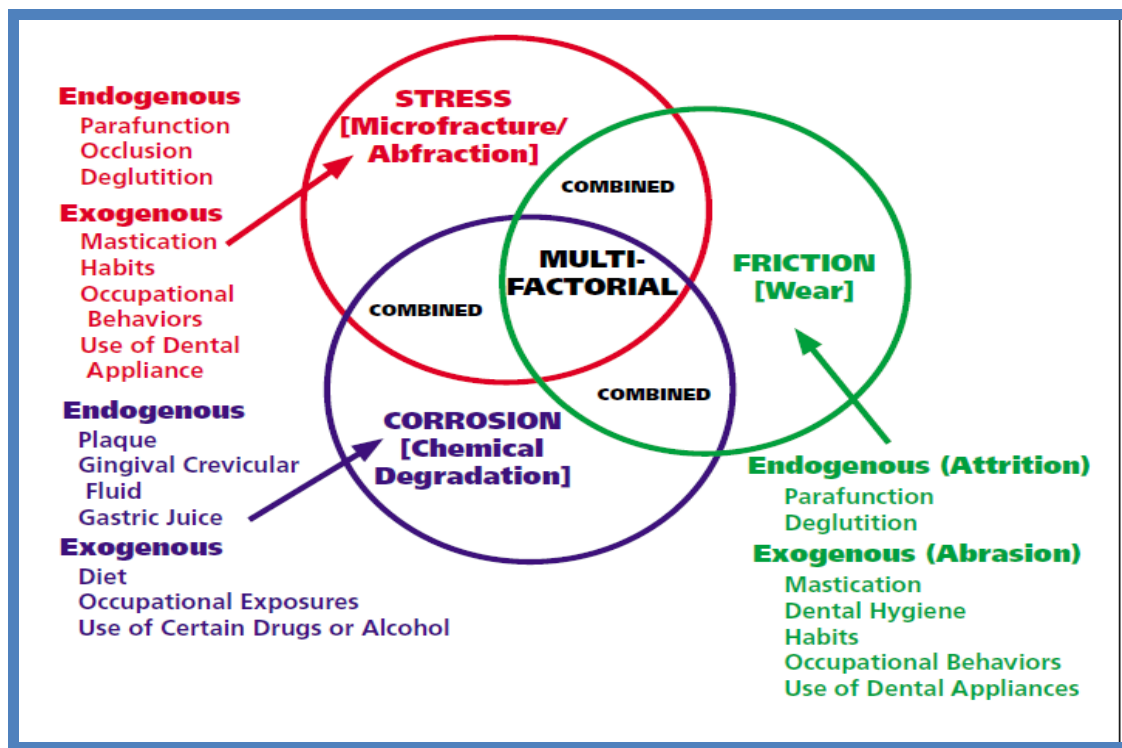
Figure 57. Venn diagram describing the multifactorial etiology for NCCLs[1]

LIMITATIONS OF THE STUDY

1)   Limited number of patients.

2)   Absolute biting force was measured only in maximum intercuspation while rela-

tive biting force values were measured in lateral excursive movements as well.

CONCLUSIONS

Within the limitations of this study, it may be concluded that:

1. NCCL progression (slope of total volume loss) is correlated with biting forces at five years (p= 0.01).

2. Rate of NCCL progression is related to the presence of adverse oral habits like nail biting (p=0.02) .

3. Consumption of a more acidic diet significantly increases the volume loss of non-carious cervical lesions over time (p=0.04).

4. No significant correlation was found between presence of occlusal wear facets, group function, toothbrushing technique/rigorousness, or coarse fibrous diet with NCCL pro-gression.

5. Proscan is a precise tool for measuring tooth volume change.

6. Prescale pressure sensitive films and Topaq image analysis software are accurate bite pressure measuring tools.

FUTURE DIRECTION

1. Use of strain gauges to find strain at cervical area.

2. Measuring absolute bite pressure in lateral excursive movements. This may be a challenge since the Prescale pressure indicating films are a static record and not a dynamic pressure measuring tool.

3. Considering right or left-handedness of subjects

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APPENDIX A

INSTIUTIONAL REVIEW BOARD APPROVAL

THE UNIVERSITY OF
ALABAMA AT BIRMINGHAM

Institutional Review Board for Human Use

Form 4: IRB Approval Form
Identification and Certification of Research
Projects Involving Human Subjects

UAB's Institutional Review Boards for Human Use (IRBs) have an approved Federalwide Assurance with the Office for Human Research Protections (OHRP). The Assurance number is FWA00005960 and it expires on January 24, 2017. The UAB IRBs are also in compliance with 21 CFR Parts 50 and 56.

Principal Investigator:	BURGESS, JOHN O.
Co-Investigator(s):	GIVAN, DANIEL A
	KINDERKNECHT, KEITH E.
Protocol Number:	**X130816002**
Protocol Title:	*Clinical Evaluation of Non-Carious Cervical Lesions – A Five Year Prospective Evaluation*

The IRB reviewed and approved the above named project on _10-1-13_. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services. This Project will be subject to Annual continuing review as provided in that Assurance.

This project received EXPEDITED review.

IRB Approval Date: _10-1-13_

Date IRB Approval Issued: _10-1-13_

IRB Approval No Longer Valid On: _10-1-14_

Marilyn Doss
Marilyn Doss, M.A.
Vice Chair of the Institutional Review
Board for Human Use (IRB)

Investigators please note:

The IRB approved consent form used in the study must contain the IRB approval date and expiration date.

IRB approval is given for one year unless otherwise noted. For projects subject to annual review research activities may not continue past the one year anniversary of the IRB approval date.

Any modifications in the study methodology, protocol and/or consent form must be submitted for review and approval to the IRB prior to implementation.

Adverse Events and/or unanticipated risks to subjects or others at UAB or other participating institutions must be reported promptly to the IRB.

APPENDIX B

RESEARCH SUBJECT INFORMATION AND CONSENT FORM

RESEARCH SUBJECT INFORMATION AND CONSENT FORM

TITLE: "Clinical Evaluation of non-carious cervical lesions- a five year prospective evaluation"

PROTOCOL NO.: ___X130816002___

SPONSOR: UAB Department of Clinical and Community Sciences, Division of Dental Biomaterials

INVESTIGATOR: John O. Burgess, D.D.S., M.S.
Suite 605
1919 7th Avenue South
Birmingham, Alabama 35294
United States

SITE(S): University of Alabama at Birmingham, School of Dentistry
Suite 605
1919 7th Avenue South
Birmingham, Alabama 35294
United States

STUDY-RELATED PHONE NUMBER(S): John O. Burgess, D.D.S., M.S.
205-996-5795
205-934-5022

STUDY COORDINATOR(S): LaTara Rogers

205-996-5747

You are being asked to volunteer as a subject in a research study. This written material is designed to provide you with information about this study and to answer any related questions or concerns you might have. The consent form may contain words or language you do not understand. Please ask the study doctor or the study staff to explain any words or information you do not clearly understand. You may take home an unsigned copy of this consent form to think about or discuss with family or friends before making your decision.

UAB IRB
Date of Approval ___10-1-13___
Not Valid On ___10-1-14___

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PURPOSE OF THE STUDY
The purpose of this study is to assess the role of heavy biting forces on the progression of notched out areas on the sides of your teeth. It will also evaluate the effect of your diet and toothbrushing habits on these notched out areas.

EXPLANATION OF PROCEDURES
This study is a continuation of a previous clinical study conducted at UAB-School of Dentistry "Clinical Evaluation of Three Dental Adhesive Systems in Class V Restorations". The 45 patients aged 19 years or older recruited into the earlier study will be recalled in this study for the evaluation of notched out areas on the sides of teeth examined during the previous study. This will be a five year evaluation of progression of these notched out areas, and will provide additional information on the cause of these lesions.

We will measure the biting force you can make on your teeth using two methods. In one method, a small piece of plastic will be used which slips between your teeth. You will be instructed to bite on this material and after making several jaw movements the plastic will be removed. In the other technique, an ultrathin digital sensor attached to a T-scan handpiece will be used. Digital images and impressions of your teeth and bite will be made. Additionally, you will be asked to answer a few questions about your dietary habits and tooth brushing technique. These appointments will last about two hours and normally one appointment will be required. Sometimes a second appointment may be necessary.

RISKS AND DISCOMFORTS
No invasive procedures are required for this study (no drilling and no injections), thus eliminating the chances of any associated risks and discomforts to the patient.

BENEFITS
While this study will evaluate the cause of the progression of notched out areas on the sides of your teeth, there are no guarantees that you will benefit from this procedure.

COSTS
There will be no costs for the evaluation done in this study.

PAYMENT FOR PARTICIPATION
You will receive a free dental exam and 30 dollars via check for each recall visit for partial reimbursement of traveling and parking expenses. You will receive your check within two weeks after your visit.

ALTERNATIVES
If you do not wish to take part in this study, you can choose to receive standard (routine) dental care.

CONFIDENTIALITY

Information obtained about you for this study will be kept confidential to the extent allowed by law. However, research information that identifies you may be shared with the UAB Institutional Review Board (IRB) and others who are responsible for ensuring compliance with laws and regulations related to research, including people on behalf of the UAB Division of Dental Biomaterials and the Office for Human Research Protections (OHRP). The results of the study may be published for scientific purposes. However, your identity will not be given out.

This consent document will be placed in your file in the UAB School of Dentistry. The document will become part of your medical record and treatment chart.

PAYMENT FOR RESEARCH-RELATED INJURY

If you are injured as a result of a research procedure used in this study you will be treated. In the event of such injury, treatment will be provided, but it will not be provided free of charge. You or your medical insurance will be billed for the cost of such treatment.

VOLUNTARY PARTICIPATION AND WITHDRAWAL

Whether or not you take part in this study is your choice. There will be no penalty if you decide not to be in the study. If you do not wish to take part in this study, you can choose to receive standard (routine) dental care. You are free to withdraw from this research study at any time. Your choice to leave the study will not affect your relationship with this institution. You may be removed from the study without your consent if the notched out areas on your teeth have been filled/restored.

If you are a UAB student or employee, taking part in this research is not a part of your UAB class work or duties. You can refuse to enroll, or withdraw after enrolling at any time before the study is over, with no effect on your class standing, grades, or job at UAB. You will not be offered or receive any special consideration if you take part in this research.

QUESTIONS

If you have any questions, concerns, or complaints about the research or a research-related injury including available treatments, you may contact Dr. John Burgess. He will be glad to answer any of your questions. Dr. Burgess' number is 205-996-5747 or 205-996-5795. Dr. Burgess may also be reached after hours by calling his cell phone #: 504-913-3386).

If you have questions about your rights as a research participant, or concerns or complaints about the research, you may contact the UAB Office of the IRB (OIRB) at (205) 934-3789 or toll free at 1-855-860-3789. Regular hours for the OIRB are 8:00 a.m.

to 5:00 p.m. CT, Monday through Friday. You may also call this number in the event the research staff cannot be reached or you wish to talk to someone else.

LEGAL RIGHTS
You are not waiving any of your legal rights by signing this informed consent document.

SIGNATURES

Your signature below indicates you agree to participate in this study. If you agree to participate in this study, you will receive a signed and dated copy of this consent form for your records.

I have read the information in this consent form (or it has been read to me). All my questions about the study and my participation in it have been answered. I freely consent to participate in this research study.

I authorize the use and disclosure of my health information to the parties listed in the authorization section of this consent for the purposes described above.

_____

Subject Name

_____   _____

Signature of Subject   Date

_____   _____

Signature of Person Conducting Informed   Date
Consent Discussion

_____   _____

Witness   Date

University of Alabama at Birmingham

AUTHORIZATION FOR USE/DISCLOSURE OF HEALTH INFORMATION FOR RESEARCH

What is the purpose of this form? You are being asked to sign this form so that UAB may use and release your health information for research. Participation in research is voluntary. If you choose to participate in the research, you must sign this form so that your health information may be used for the research.

Participant Name: _____ **UAB IRB Protocol Number:** ___X130816002___
Research Protocol: Clinical Evaluation of non-carious cervical lesions- a five year prospective evaluation **Principal Investigator:** John Burgess, DDS, MS.

Sponsor: UAB School of Dentistry, Div of Biomaterials.

What health information do the researchers want to use? All medical information and personal identifiers, including past, present, and future history, examinations, laboratory results, imaging studies and reports and treatments of whatever kind related to or collected for use in the research protocol.

Why do the researchers want my health information? The researchers want to use your health information as part of the research protocol listed above and described to you in the Informed Consent document.

Who will disclose, use and/or receive my health information? The physicians, nurses and staff working on the research protocol (whether at UAB or elsewhere); other operating units of UAB, HSF, UAB Highlands, The Children's Hospital of Alabama, Eye Foundation Hospital and the Jefferson County Department of Public Health, as necessary for their operations; the IRB and its staff; the sponsor of the research and its employees; and outside regulatory agencies, such as the Food and Drug Administration.

How will my health information be protected once it is given to others? Your health information that is given to the study sponsor will remain private to the extent possible, even though the study sponsor is not required to follow the federal privacy laws. However, once your information is given to other organizations that are not required to follow federal privacy laws, we cannot assure that the information will remain protected.

How long will this Authorization last? Your authorization for the uses and disclosures described in this Authorization does not have an expiration date.

Can I cancel the Authorization? You may cancel this Authorization at any time by notifying the Director of the IRB, in writing, referencing the Research Protocol and IRB Protocol Number. If you cancel this Authorization, the study doctor and staff will not use any new health information for research. However, researchers may continue to use the health information that was provided before you cancelled your authorization.

Can I see my health information? You have a right to request to see your health information. However, to ensure the scientific integrity of the research, you will not be able to review the research information until after the research protocol has been completed.

Signature of participant: _____Date: _____

or participant's legally authorized representative: _____Date: _____

Printed Name of participant's representative: _____

Relationship to the participant: _____

_____

APPENDIX C

DIETARY ANALYSIS

Patient Name: _____   Age: _____

FACTORS	HIGH	MODERATE	LOW
Dietary Habits			
How often do you take acidic foods like lemons in a day?	>3 times	1-3 times	Infrequent
How often do you drink sodas/carbonated drinks per day?	>3 times	1-3 times	Infrequent
Do you consume a lot of salad dressings?	Yes		No
How often do you snack between meals a day?	>3 times	1-3 times	Infrequent
Do you indulge in recreational drug abuse/tobacco chewing habits?	Yes		No
How often per day do you eat sugary snacks?	>3 times	1-3 times	Infrequent
Do you chew sugarless gum?	No		Yes
Medical Conditions			
Do you suffer from GERD or acid reflux?	Yes		No
Sjogren's syndrome?	Yes		No
Have you ever had radiation or chemotherapy?	Yes		No
Do you have adequate saliva flow?	No		Yes
Do you consume any hyposalivary medicines?	Yes		No

Fluoride			
Is your water fluoridated?	No		Yes
Fluoride toothpaste?	No		Yes
Fluoride mouth rinse?	No		Yes
Do you drink bottled water?	No		Yes

APPENDIX D

ORAL HYGIENE HABITS ASSESSMENT

Patient Name: _____   Age: _____

FACTORS	HIGH	NORMAL
How often do you brush your teeth in a day?	>2	1
What type of tooth brush do you use?	Hard	Medium/ Soft
What type of tooth paste do you use?	Highly abrasive	Moderate/ Not abrasive
Does your toothpaste contain fluoride?	No	Yes
How rigorously do you brush your teeth?	Very rigorous	Moderate/Gentle
What is your tooth brushing technique?	Horizontal	Bass

APPENDIX E

MOUNTED CAST OCCLUSAL ANALYSIS

OCCLUSAL ANALYSIS OF MOUNTED STUDY CASTS

Patient: _____   Date: _____

Chart #: _____   Dr. _____

mm Vertical	Anterior ☐
1 CO = MIP ☐ CO ≠ MIP ☐	Right ☐
mm Horizontal	Left ☐

2 Centric Occlusion Contacts
Condyles in CR
CO=MIP ☐

3 Mediotrusive Contacts
Right and Left
None ☐

4 Right Laterotrusive Contacts
None ☐

5 Left Laterotrusive Contacts
None ☐

6 Protrusive contacts
None ☐

7 Wear Facets

Mild	1
Moderate	2
Severe	3
Abfraction	A

1	9	17	25
2	10	18	26
3	11	19	27
4	12	20	28
5	13	21	29
6	14	22	30
7	15	23	31
8	16	24	32

8 Tooth Alignment

Missing	X
Diastema	D
Extruded	Ex
Rotated	Ro
Buccalversion	B
Linguoversion	L
Tipted	T

1	9	17	25
2	10	18	26
3	11	19	27
4	12	20	28
5	13	21	29
6	14	22	30
7	15	23	31
8	16	24	32

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OCCLUSAL ANALYSIS OF MOUNTED STUDY CASTS

9 Anterior Interocclusal Relationships

Canine
R / L
- Class I
- Class II
- Class III

Anterior Teeth
- Horizontal Overlap in mm.- Overjet
- Vertical Overlap in mm. - Overbite

Anterior Guidance
R / L
- Ideal
- Adequate
- Correctable
- Inadequate

R / L
- Canine Guidance
- Group Function
- Open Occlusal Relation
- Reverse Occ. Relation

10 Posterior Interocclusal Relationships:

Molar
R / L
- Class I
- Class II
- Class III

Posterior Teeth
- Horizontal Overlap -Overjet
- Vertical Overlap - Overbite

Posterior Support
R / L
- Ideal
- Adequate
- Inadequate

R / L
- Open Occlusal Relation
- Reverse Occ. Relation
- Working Contacts
- Balancing Contacts

11 Orthopedic Analysis:
- Orthognathic
- Retrognathic
- Prognathic

Curve-Spee
R / L
- Normal
- Flat
- Reversed
- Excessive

Plane of Occlusion
R / L
- Normal
- Flat
- Steep
- Reversed
- Canted [R/L]

Curve-Wilson
R / L
- Normal
- Flat
- Excessive
- Reversed

12 Additional Problem Solving or Consultations Indicated:

Problem Solving
- Diagnostic SOA
- Diagnostic Set-Up
- Diagnostic Tooth Preparations
- Diagnostic Pre-Waxing

Consultations
- Prosthodontic
- Orthodontic
- Periodontic
- Oral Surgery
- Oral Path/Medicine
- Orofacial Pain/TMD

APPENDIX F

T-SCAN BASED OCCLUSAL ANALYSIS

OCCLUSAL ANALYSIS BASED ON T-SCAN

Patient: _____   Date: _____

Chart #: _____   Dr. _____

1. Occlusal contact distribution/pattern   Occlude first in:
    ☐ Molar area
    ☐ Anterior area
    ☐ Simultaneously

2. % Contacts on each side   Right side   Left side
    (Or % occlusal force)   ☐ >50%   ☐ >50%
                                  ☐ <50%   ☐ <50%
                                  ☐ ≈50%   ☐ ≈50%

3. Asymmetry of occlusal force (AOF)   ____%

$$AOF (\%) = \frac{\%Occlusal\ force\ on\ left\ side - \%Occlusal\ force\ on\ right\ side}{Total\ \%\ occlusal\ force} \times 100$$

4. Premature occlusal contacts   Right side   Left side
                                      ☐ Present   ☐ Present
                                      ☐ Absent   ☐ Absent

    If yes, tooth # ____

5. Center of Occlusal force trajectory ☐ Hugs the midline
                                        ☐ Deviates **towards** side with NCCLs
                                        ☐ Deviates **away** from side with NCCLs

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10. Average occlusion time   _____sec

12. Lateral occlusal force distribution (LOD)   ___%

   =|50-(Right Ant. % force value + Right Post. % force value)|

13. Anteroposterior occlusal force distribution (AOD)   ___%

   =|50-(Right Post. % force value + Left Post. % force value)|

14. Occlusal force distribution on teeth with NCCLs

Tooth #	Relative biting force in excursive movements (%)			
	IP-CO	Working	Non-working	Protrusion

APPENDIX G

MEAN ABSOLUTE BITING PRESSURE ON TEETH WITH NCCLs

Patient No.	Tooth No.	Absolute Average Biting force (Psi)
		(Mean ± SD)
7	9	447.29 ± 63.20
	10	451.44 ± 63.28
	11	453.34 ± 69.85
	12	465.05 ± 74.56
25	7	515.05 ± 121.51
	8	446.02 ± 55.93
	11	535.78 ± 133.37
	28	894.38 ± 280.80
	29	644.52 ± 191.49
2	3	533.75 ± 110.20
	4	620.91 ± 175.77
	5	474.43 ± 75.35
	7	377.74 ± 0.00
	14	658.84 ± 184.96
	23	453.12 ± 64.23
	24	491.69 ± 95.35
	25	696.63 ± 194.01
16	11	71.40 ± 18.07
3	2	59.82 ± 21.75
31	2	932.76 ± 306.14
	3	712.27 ± 226.50
	11	709.44 ± 209.88
	14	929.01 ± 287.92
30	9	560.13 ± 125.12
	14	687.16 ± 221.66
12	7	551.58 ± 144.03
	10	600.66 ± 171.59
29	19	525.59 ± 103.35
	27	713.61 ± 239.99
36	5	793.73 ± 275.81
37	31	712.60 ± 242.76
9	8	564.29 ± 132.87
	9	627.14 ± 164.47
	28	522.23 ± 105.56
	29	654.73 ± 185.82

40	8	571.31 ± 141.32
39	10	557.43 ± 127.34
	11	465.44 ± 78.18
	19	650.38 ± 207.58
	20	537.68 ± 12.56
	27	556.74 ± 123.69
41	3	627.67 ± 120.38
42	12	921.36 ± 357.54
	14	837.54 ± 347.58
20	2	561.74 ± 151.90
	8	489.21 ± 86.84
	9	481.43 ± 80.84
	22	413.23 ± 43.08
	23	462.16 ± 98.02
	24	425.66 ± 50.93
	27	558.92 ± 134.14
	28	486.05 ± 91.12
15	27	820.94 ± 248.31
32	3	485.84 ± 87.76
	13	641.28 ± 179.25
	14	640.71 ± 192.24
	19	548.23 ± 129.15
	21	377.74 ± 0.00
	29	598.78 ± 151.62
22	2	529.29 ± 113.82
	28	736.52 ± 215.35
33	14	765.40 ± 260.03
18	28	432.73 ± 71.70
10	10	564.89 ± 134.48
	11	549.55 ± 126.06
	20	406.41 ± 34.74
	22	462.39 ± 40.18
19	14	490.21 ± 96.82
4	3	587.78 ± 141.24
	6	449.93 ± 68.30
	8	449.76 ± 76.20
	10	455.06 ± 77.20
	15	432.01 ± 57.31
5	24	736.39 ± 273.05
14	12	598.32 ± 163.07
8	23	877.58 ± 221.59

	26	792.87 ± 162.60
	27	1128 ± 338.22
1	3	641.63 ± 181.40
	4	608.66 ± 170.54
	13	540.70 ± 128.32
	21	541.55 ± 173.65
	29	587.10 ± 155.59