Using Digital Microscopy to Evaluate Enamel Defects in Young Children: A Novel Method

THESIS

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By

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Abstract

Enamel defects in primary teeth predispose children to early childhood caries and are often not detected nor intervened upon until damage from caries has occurred. In this study, we utilized a novel imaging device, the ProScope digital microscope, to assess the enamel quality \textit{in vivo} of young children ages 9 months -3 years. We also used a parental survey and medical record review to elucidate factors leading to defects in our population. Based on clinical exam, patients were separated into intact and defective enamel groups. The final sample included 45 children with intact enamel and 30 children with enamel defects. ProScope images were captured with a 100x lens during the exam and were later assessed based on the modified Developmental Defects of Enamel index by five raters. We found that children in the defective enamel group had higher dft scores of 1.34 vs. 0.29 (p=0.008), more caregivers who smoke in the home at 50% vs. 26.7% (p=0.04), and more parents reporting “soft teeth” in their children at 33% vs. 6.7% (p=0.003). The ProScope, when compared to the gold standard of visual clinical exam for detecting enamel defects, had a sensitivity of 82.7% and specificity of 77.3%. We found an inter-rater reliability of 0.438 among the five raters. We concluded that enamel defects in primary teeth might be the missing link between maternal smoking and offspring caries rates as reported in previous studies. Additionally, children with enamel defects
defects and children identified by their parents as having “soft teeth” had a higher risk of dental caries, and therefore those children should receive increased preventive care and counseling. The ProScope was useful for evaluating enamel defects, but might be best suited for serial evaluation of enamel defects and incipient carious lesions to document progression over time in the same patient.
Dedication

This document is dedicated to my family.
Acknowledgments

Thank you to my advisor, Dr. Ann Griffen, and my committee, Dr. Paul Casamassimo and Dr. Bob Rashid.
Vita

2004.................................Highland Park High School, Dallas, TX
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Publications


Fields of Study

Major Field: Dentistry
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Chapter 1: Introduction

Early Childhood Caries (ECC) remains the most common disease of childhood and impacts multiple areas of life including school performance, child development, family relations, and healthcare costs.\(^1\) Increasing costs, increasing prevalence, and delayed treatment for children with ECC lead to a desire to more fully understand risk factors for this condition.\(^2\) One known risk factor for ECC is the presence of enamel defects including hypoplasia, staining, opacities, fluorosis, and other inherited enamel problems.\(^3,4\) Enamel defects are correlated with dental caries, and there are a host of studies that indicate that defects increase caries risk.\(^5-10\) Quantifying enamel defects can be difficult, but imaging provides a standard way to assess the defects by using multiple raters and identifying defects before they are clinically visible.\(^11\) Our overall objective was to improve prediction of caries in young children by evaluating enamel quality using a novel digital microscope. We hoped it would enhance detection of enamel defects before cavitation developed, allowing for early intervention in children at greater risk of ECC. We also assessed factors affecting enamel quality via parental survey and review of the children’s medical records.
Chapter 2: Materials and Methods

All subjects were recruited from the baby clinic at the Nationwide Children’s Hospital (NCH) dental clinic and IRB approval was obtained from NCH. The children were between nine months and three years old, had maxillary incisors erupted, had a caregiver present, and spoke English for consent purposes. The patients were separated into intact and defective enamel groups based on enamel presentation on visual clinical exam. The final sample size included 45 children with intact enamel and 30 children with defective enamel upon visual exam. A verbal survey (Appendix A) was used to interview parents about potential factors influencing enamel quality along with a review of the medical record to gather data regarding factors that could contribute to enamel defects. One novel aspect we investigated was the relationship between “soft teeth” and enamel defects. In our clinic we have many parents who explain why their children have cavities by stating that they themselves have “soft teeth” or their children have “soft teeth”. With the verbal survey, we wanted to determine if there was any correlation between the claim of soft teeth and actual enamel defects.

The imaging was completed with the ProScope HR digital microscope (Bodelin Technologies, Lake Oswego, OR). The microscope was fitted with a 100x lens with light emitting diode (LED) illumination. The images were captured in the knee-to-knee
position. The maxillary central incisors were imaged because they were accessible to the digital microscope and commonly have defects.\textsuperscript{6,12} The enamel was dried with gauze prior to imaging. The images were stored on the secured hospital network, and the four best images per patient were selected for analysis. Many images were discarded due to the movement of pre-cooperative young children, causing the images to be out of focus or off center.

The ProScope images were scored using the modified Developmental Defects of Enamel (DDE) index.\textsuperscript{13} The defects were scored based on four categories of no defects (intact enamel), opacity defects (a discoloration of enamel), hypoplasia defects (missing enamel), and a lesion containing both opacity and hypoplasia defects (Fig. 1).

![Enamel Rating Scale](image)

Figure 1. Enamel rating scale
Five raters from the department of pediatric dentistry scored the randomized images viewed on a computer monitor with numbers 0-3 corresponding to the above categories respectively.

Statistical Analysis

The ProScope’s sensitivity, specificity, and reliability for detecting enamel defects were tested against the gold standard of visual clinical exam. The modified DDE index ratings were transformed to dichotomous variables (defects present or not) for analysis of reliability, sensitivity, and specificity. Fleiss’ Kappa was used to test reliability among the five raters. Enamel defect risk factors were analyzed using the survey and medical record data. For nominal tests between two groups, the Likelihood Ratio was used. Continuous data between the two groups was analyzed with t-tests. For all tests, we used an \( \alpha \) level of 0.05. All statistical testing was completed using JMP version 10 (SAS Institute Inc., Cary, NC).
Chapter 3: Results

The patients were well matched on age and gender between the intact and defective enamel groups (Table 1). There was a mean age of 31.8 months for the intact enamel group and 32.9 months for the defective enamel group \((p=0.63)\). The youngest subject was 11 months old, and the oldest was 46 months old. More males were enrolled in both groups at 66.6% for the intact group and 60% male for the defective group \((p=0.56)\).

<table>
<thead>
<tr>
<th>Survey Results</th>
<th>Intact Enamel Group</th>
<th>Defective Enamel Group</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>31.8 months</td>
<td>32.9 months</td>
<td>0.63</td>
</tr>
<tr>
<td>Sex</td>
<td>66.6% male</td>
<td>60% male</td>
<td>0.56</td>
</tr>
<tr>
<td>Gestational Weeks</td>
<td>38.8 weeks</td>
<td>38.3 weeks</td>
<td>0.53</td>
</tr>
<tr>
<td>Birth Weight</td>
<td>3.18 kg</td>
<td>3.07 kg</td>
<td>0.55</td>
</tr>
<tr>
<td>Medical Conditions</td>
<td>22.2%</td>
<td>40%</td>
<td>0.1</td>
</tr>
<tr>
<td>dft</td>
<td>0.29</td>
<td>1.34</td>
<td>0.008</td>
</tr>
<tr>
<td>dfs</td>
<td>0.33</td>
<td>1.53</td>
<td>0.014</td>
</tr>
<tr>
<td>Smoking</td>
<td>50%</td>
<td>26.7%</td>
<td>0.04</td>
</tr>
<tr>
<td>Parental &quot;soft teeth&quot;</td>
<td>33%</td>
<td>46.7%</td>
<td>0.25</td>
</tr>
<tr>
<td>Child’s &quot;soft teeth&quot;</td>
<td>6.7%</td>
<td>33%</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Table 1. Parental survey and medical record data
We did not find an association between gestational age or birth weight and enamel defects (Table 1). The average gestational weeks were 38.8 weeks for intact and 38.3 weeks for the defective group (p= 0.53). The birth weights were also very similar at 3.18 kg for intact and 3.07 kg for defective (p=0.55).

Medical conditions were gathered from the parental survey and review of the medical record, and minor conditions were not considered to make analysis clearer. Medical conditions were present in 40% of the children in the defective enamel group, compared to 22.2% of children in the intact group (p=0.1).

Our study revealed several statistically significant findings (Table 1). We found that children with enamel defects were more likely to have caries activity. When analyzing the decayed and filled teeth and surfaces for the children in the intact vs. defective enamel group, we found that children with enamel defects had significantly higher decayed, filled teeth (dft) scores of 1.34 vs. 0.29 for the intact group (p=0.008), and decayed, filled surfaces (dfs) scores of 1.53 for the defective group vs. 0.33 for the intact group (p=0.014).

Another significant finding of the study was the demonstration of an association between cigarette smoke and enamel defects. A high number of children with enamel defects (50%) had caregivers who smoked in the home, while only 26.7% of children without enamel defects had caregivers who smoked (p=0.04).

In the survey data, there was a trend toward more parents thinking their own teeth were soft in the defective group (46.7% vs. 33%), but it was not significant at p=0.25 (Table 1). However, there was a significant association between the parents thinking their
child had soft teeth and actual enamel defects on clinical exam. While 33% of the parents of children in the defective enamel group thought their children had soft teeth, only 6.7% of the parents of children in the intact enamel group thought their children had soft teeth \( (p=0.003) \).

Finally, we compared the ProScope to the “gold standard” of visual clinical exam for detecting defects (Table 2). The ProScope detected enamel defects with a sensitivity of 82.67% and a specificity of 77.33%. The reliability among the five raters overall using Fleiss’ kappa was 0.438.

<table>
<thead>
<tr>
<th>ProScope</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>82.67%</td>
</tr>
<tr>
<td>Specificity</td>
<td>77.33%</td>
</tr>
<tr>
<td>Reliability</td>
<td>0.4375</td>
</tr>
</tbody>
</table>

Table 2. ProScope data
Chapter 4: Discussion

Three main significant findings arose based on the parental surveys and medical records review. First, patients with enamel defects are more likely to have someone in the house who smokes. Maternal smoking is clearly linked to tooth decay in children, although the mechanism is unclear.\textsuperscript{12,14-17} Aligne et al. found a significant association between caries and environmental tobacco smoke (ETS) in primary teeth.\textsuperscript{14} After adjusting for income, race, age, region of the country, and frequency of dental visits, the relationship remained, at an odds ratio of 1.8 for decayed primary teeth.\textsuperscript{14} They also found a population attributable risk of 27\%, indicating that according to their study, over one fourth of children could be caries-free if ETS exposure was eliminated.\textsuperscript{14} Tanaka et al. found both prenatal and postnatal smoking were independently associated with increased caries.\textsuperscript{16} They found a dose response relationship between ETS in the home and dental caries and hypothesized that hypoplasia or hypomineralization could be the link between smoking and caries.\textsuperscript{16} Finally, Shenkin et al. found that children from smoking homes had a significantly higher prevalence of caries, even after adjusting for age, SES, tooth brushing, and sugared beverage intake.\textsuperscript{17} However, only one previous human study has linked smoking and enamel defects.\textsuperscript{18,19} In Needleman et al., exfoliated incisors were evaluated \textit{in vitro}, and smoking was strongly associated with the defects (p
In an animal study, Dong et al., found that cigarette smoke interfered with enamel mineralization in offspring rats from mothers who were exposed to tobacco smoke twice per day until the day of birth, and the exposure was a key factor affecting the quantity of enamel formed. The results suggest that maternal passive smoking causes poor-quality teeth in offspring, and the authors inferred that this link is likely to be present in human children as well. Our findings provide further evidence that smoking is a risk factor for enamel defects, and suggest that enamel defects may be the mechanism, or missing link, between higher caries in children exposed to ETS that has been observed in other studies.

Second, we found that patients with enamel defects are more likely to have caries. This is likely due to the earlier and greater adhesion of bacteria in the defect and the hypomineralized area being thinner, thus making it more susceptible to acid challenge from cariogenic bacteria. Our findings support findings of several other studies. Montero et al. found that children with enamel defects had more than twice as many caries as those with intact enamel surfaces. In a study by Oliveira et al., the presence of defects was the single biggest predictor of caries development. They found that defective teeth had a fifteen times greater risk of ECC, and they proposed that the principal risk factor for ECC is the presence of defects.

Third, we found that parents of children with enamel defects are more likely to think their children have “soft teeth”. It is unclear whether parents who report soft teeth have based their assessment on the presence of caries, or antecedent, predisposing enamel defects. Experience shows that not all children who drink a bottle at night, eat sweets, or
have poor hygiene develop severe caries. We wanted to see if there was any link between parent perception of “soft teeth” and hypoplasia. Caufield introduced the concept of Hypoplasia Associated Severe Early Childhood Caries. He stated these enamel defects provide readily colonizable sites for bacteria and noted that the pattern of decay follows along the same locations as hypoplasia (or defects), along the neo-natal line. His study suggests that the reason this pattern of decay, and in turn ECC, exists is not only due to the child using a bottle or sippy cup, but also to the enamel defects. We propose that these young children identified by their parents as having “soft teeth” may have enamel defects and would benefit from extra preventive measures and more frequent recall.

There have been many studies linking malnutrition, low socio-economic status, preterm birth, and several medical conditions to enamel defects. Needleman et al. found that prematurity and increased weight of mothers during pregnancy were linked with defects. In another study, Li et al. found that almost 24% of the patients studied (3-5 year olds in rural China) had defects, the maxillary central was the most common site, premature babies had four times the defects, and low birth weight babies had a higher number of defects. Nelson et al. found that 19% of Very Low Birth Weight (VLBW) children had defects at 8 months (compared to only 2% of the control) and 31% had defects at 18 months (compared to only 8% of the control). Based on the medical record and parental survey a number of medical conditions were present in study participants including cleft lip and palate, developmental issues, bronchopulmonary dysplasia, various congenital heart defects, severe hemophilia, and
cerebral palsy. Less serious medical conditions such as asthma, obesity, innocent heart murmur, sickle cell trait, and otitis media were not considered in the analysis. The presence of enamel defects was not significantly associated with prematurity, birth weight, or medical conditions. There was a trend toward more medical conditions in the defective enamel group with 40% of the children having medical conditions, compared to 22.2% of children in the intact group, but the difference was not significant (p=0.1). This may be attributed to the small sample size and lack of power since previous studies have consistently shown a relationship. Additionally, our hospital dental clinic population does not reflect the general population as a whole since many medically compromised children are seen in our clinic, and many of the patients in the intact enamel group were born prematurely and/or had severe medical conditions.

The sensitivity and specificity of the ProScope images were good, but did not improve upon direct visual inspection, primarily due to false positive results. We concluded that the ProScope images are most useful as an adjunct to the clinical exam or for assessing the progression of lesions over time in the same patient. Chen et al. also found that photographs identify most of the defects found on exam, but the defects detected include many false positives due to reflection or lack of multiple angles, leading raters to think some teeth have defects when on exam they do not. They determined photographs are useful to avoid the bias that may occur when a patient’s medical condition is known. In our study, the specular highlights, or reflections, created by LED lighting from the ProScope on the enamel surface made it difficult to assess them...
reliably, and due to the high magnification, the rater tended to lose the orientation and the location of the image on the tooth (Figure 2).

Figure 2. ProScope image of specular highlights and irregular surface

Nevertheless, the reliability among the five raters overall was 0.438, which according to Landis and Koch, is considered moderate agreement. Chen et al. found the reliability of the digital SLR camera for imaging enamel defects at the tooth level for al types of DDE in a similar age group (18-20mo) of 0.407. Elfrink et al. evaluated primary molar hypomineralization with an intraoral camera and found the sensitivity was 72.3%, specificity was 92.8%, and inter-observer reliability was 0.62. Our sensitivity
was higher at 82.7% but specificity and reliability were lower (77.3% and 0.438). This difference is likely due to the increased number of raters in our study (5 vs. 2). In addition, when the images are magnified 100x with the ProScope, a small surface irregularity may appear to be hypoplasia. However, some of these hypoplastic defects that the ProScope picked up could have been true defects that could not be seen with the naked eye, which may have impacted the specificity. The ProScope may be best used for serial evaluation of lesion progression on the same patient, much like images from an intraoral camera prove useful in re-evaluating patients at high risk for caries.²⁶,²⁷ The detail and variety of enamel defects are visible in the sample ProScope images in Figure 3.

Figure 3. Sample ProScope images of enamel defects
Limitations

With regard to the ProScope, sample images were not provided in the calibration of the raters because we did not have extra images other than those we were scoring. Having sample images likely would have helped our reliability among raters. There were also magnification and illumination difficulties when rating the ProScope images. As discussed above, the specular highlights on enamel may have masked some defects or caused a false positive rating. Additionally, some parents may not have reported all of their children’s medical conditions due to forgetfulness or unawareness, and they may have underreported smoking habits. We also likely had gaps in the medical records of patients who had been seen outside of the NCH network for treatment. Furthermore, a minority of parents did not understand the term “soft teeth” although “soft teeth” was explained to all parents equally as “the belief that the child gets cavities easily”. Finally, imaging of young children is difficult due to movement of the child and the speed of image capture. Diffuse lighting may help to more accurately examine the enamel surfaces and produce less highlights, but a custom external light source would be difficult to use quickly on small children and impractical in practice.

We hope to have follow-up studies in the future to determine if these children develop caries where the defects are located, or if children with defective enamel develop more caries over time. Additionally, further investigation will be made with respect to
smoking habits and their link to enamel defects on a more objective level, possibly using serum cotinine levels instead of parental report.
Chapter 5: Summary and Conclusions

Based on this study, it can be concluded that:

- Smoking in the home is associated with enamel defects.
- Those children identified as having visible enamel defects on clinical exam are more likely to have dental caries.
- A ProScope or other imaging device is not necessary to assess visible enamel defects, and a practitioner who identifies a child with enamel defects can individualize their treatment and preventive care based on a higher caries risk.
- A parent’s belief that a child has “soft teeth” is associated with a greater likelihood of the child having enamel defects. In practice, if a parent thinks a child has soft teeth, preventive measures may need to be increased.
- Finally, a ProScope or other imaging device may be useful for serial evaluation of a child’s enamel defects to document the progression of the lesion over time.
References


Appendix A: Verbal parental survey

SCRIPT FOR VERBAL INTERVIEW

STUDY TITLE:  Evaluating Enamel Quality in Young Children Using Digital Microscopy: A Cohort Study

PRINCIPAL INVESTIGATOR: Ann Griffen

CONTACT TELEPHONE NUMBER: 614-292-1509 (Dr. Griffen – office phone)
614-690-0717 (Dr. Baxter – pager)

SUBJECT’S NAME: __________________________ DATE OF BIRTH: _________________

1. Has your child ever been hospitalized? YES _________ NO _________
   If so, please explain ____________________________________________
   _____________________________________________________________

2. Does your child have any medical conditions? YES _________ NO _________
   If so, please list them ______________________________________________________________________________________
   ______________________________________________________________________________________

3. Was your child born early (premature)? YES _________ NO _________
   If so, at how many weeks was your child born and were there any complications?
   __________ weeks ______________________________________________________

4. How much did your child weigh at birth? _________ lbs and _______ oz

5. Does anyone in the home smoke? YES _________ NO _________
   If so, who and how much? _____________________________________________

6. Do you think your child has soft teeth? YES _________ NO _________

7. Do you think you have soft teeth? YES _________ NO _________