THE QUALITY OF FIXED PROSTHODONTIC IMPRESSIONS: AN ASSESSMENT OF CROWN AND BRIDGE IMPRESSIONS RECEIVED AT COMMERCIAL LABORATORIES

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ABSTRACT

Clayton T. Rau: The Quality of Fixed Prosthodontic Impressions: An Assessment of Crown and Bridge Impressions Received at Commercial Laboratories
(Under the direction of Terence E. Donovan)

**Purpose:** The objective of this study was two-fold. First, to evaluate and quantify clinically detectable errors commonly seen in impressions sent to commercial laboratories. Second, to determine if impressions from students at the University of North Carolina school of Dentistry are comparable to those made by private practitioners. **Materials and Methods:** Three large dental laboratories and one small dental laboratory were visited over a 12 month period. Impressions were evaluated by one of three calibrated examiners. All impressions were evaluated for errors using 2.5x magnification loupes under ambient room lighting without the aid of additional illumination. **Result:** A total of 1,347 impressions were evaluated. The largest error category evaluated, with a rate of 49.3%, was tissue impinging on the finish line. Multiple logistic regression analysis for factors influencing finish line error was statistically significant for the following variables: provider type (OR 1.68, p<0.001), blood (OR 2.31, p<0.001), tray type (OR 1.68, p<0.001) and restoration requested (p=0.007). **Conclusion:** Within the limitations of this study, marginal discrepancies made up the largest category of error noted in impressions evaluated. Impressions made by private practice dentists were significantly worse than those made by students. Simplified impression techniques such as dual arch impression trays increase the risk of obtaining critical errors. Although students made the same errors as private practitioners, there was a reduced quantity of critical finish line errors in their impressions.
To my fiancé Meridith Pumphrey, it is your understanding, support and love that kept me going throughout this project.

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<tr>
<td>PE</td>
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CHAPTER 1: LITERATURE REVIEW

The transfer of accurate records to the dental laboratory is an important part of prosthesis fabrication in fixed prosthodontics. Obtaining an optimal impression for fixed dental prostheses is still one of the most challenging procedures in dentistry.\textsuperscript{1,2} While there are many steps that must be taken to fabricate an indirect restoration where an error can occur, the technician can only be expected to produce a quality restoration if the impression itself is of adequate quality. All dentists must possess the ability and willingness to analyze the quality of impressions, as this will ultimately determine success or failure of the restoration.\textsuperscript{3}

Accurate transfer of records requires a general understanding of soft and hard tissue anatomy, especially in the area of the cervical finish line. Practitioners also need to understand how to select gingival displacement materials and impression materials.\textsuperscript{3-8} There are numerous studies that demonstrate improvements in handling and accuracy of modern impression materials.\textsuperscript{6,9} However, despite these improvements, the quality of impressions sent to laboratories for indirect restoration fabrication has remained inadequate.\textsuperscript{3,8,10,11} Although differences exist between materials, all require optimum technique in soft tissue displacement, proper placement of the material around the preparation, and correct utilization of impression trays.\textsuperscript{2} One of the major causes of unacceptable indirect restorations is lack of understanding of the principles of impression making, and of what constitutes an acceptable impression.\textsuperscript{7}
1.1. A History Of Impression Quality

Published in vivo studies show a disturbing history in the quality of impressions. This may be a reason the dentist/laboratory relationships tend to be less than ideal and often are relatively short term. Aquilino and Taylor recognized there was a disconnect between what was happening in the institutional setting and private practice practitioners. Their 1984 study suggests that even though most schools require dental students to perform certain fixed prosthodontic laboratory procedures, educators were becoming concerned with the ability of recent graduates to perform these procedures with limited amounts exposure and experience. Concerns were also expressed at how quickly recent graduates abandoned the sound principles they were taught in school. Evaluation of the survey, which the study was focused upon, reveals that dental laboratory technicians were also concerned about this trend as well.

Winstanely et al. later performed a survey of 4 commercial dental laboratories in England to assess the quality of impressions received for crowns and bridges. This research study analyzed a total of 290 impressions and evaluated several factors including the type of tray utilized, presence of contamination, and adequacy of the impressions. A satisfactory restoration could be made for only 57% of the impressions, and making an adequate restoration was doubtful or impossible for 20% of the impressions. The single largest cause of defects in the working impressions was indistinct recording of the preparation margins. Irreversible hydrocolloid was the medium of choice in nearly all of the impressions evaluated at the time of the study.

Albashaireh et al. completed a similar study of impressions sent to 35 various dental laboratories in Jordan. The researchers evaluated 136 impressions obtained for fabrication of fixed partial dentures. Several different factors were evaluated and impressions were rated as
being unusable, unsatisfactory, acceptable, or satisfactory. They found the quality of 50% of impressions and dies to be unsatisfactory or unusable. One interesting finding was the discrepancy in the source of the impression and the satisfactory ratings. Although compromising only 20 impressions in the study, those from providers employed at government or educational institutions were all rated as acceptable or satisfactory. When these impressions were removed from the database, the percentage of acceptable impressions was only 47% for non-institutionalized dentists. Sixty five percent of the impressions utilized irreversible hydrocolloid as the impression medium, but it is not known whether this had any bearing on the quality of the impressions reviewed.

In 2005 Samet et al.\textsuperscript{3} evaluated 193 impressions from 11 different laboratories in Israel. Evaluation criteria in this study were more sophisticated and not only evaluated preparation margins but also included several other variables such as pressure of the tray on the soft tissue, exposure of the heavy body material through the wash, and adhesive usage. Polyether and silicone materials were primarily used; irreversible hydrocolloid was not used for any impression. Eighty-nine percent of all impressions evaluated had at least one detectable error. The authors discussed that these findings were in agreement with previous studies\textsuperscript{8,10,13} despite the differences in criteria. This is mainly based on the fact that 51% of the defects involved the cervical finish line.

Beier et al.\textsuperscript{1} in 2007, reviewed 1,466 impressed preparations from 249 patients receiving care from the departments of prosthetic and restorative dentistry, Innsbruck Medical University, Austria. Criteria were established based on size and location of defects within the preparation impressions. The authors’ data showed a remarkably low unacceptable rate of only 3% which is in contrast to other reports. However, this data must be viewed in context of how the study was
conducted. The impressions were made by “experienced dental clinicians” from the departments from which the patients were recruited. These clinicians followed a careful protocol in which retraction cord was used in all patients and left in place for 10 to 15 minutes. Strict attention to detail continued as the impressions were not made until all evidence of active bleeding had been stopped. Finally, all preparations were thoroughly dried prior to insertion of the impression material. This careful attention to detail was likely the reason for the low failure rate. Unfortunately, based on the findings of other research studies, similar levels of detail may not occur in most practices. This research study is an excellent example of how excellent soft tissue management and impression technique will lead to successful impressions.

The most recent evaluation of the quality of impressions took place in 2009 by Mitchell et al. Although designed to evaluate the impression tray type and manner in which the trays were used, the authors also noted the overall impression quality. The general overview of success rates for impressions varied widely from 44% to 83% depending on the type of tray and preparation location.

1.2. Impression Materials

Extensive impression material research and development has been accomplished in dentistry. Due largely to differences of material improvement, polysulfide rubber and reversible hydrocolloid are rarely used today in fixed prosthodontics. Most impressions are made with polyether (PE) and polyvinyl siloxane (PVS) based impression materials. Therefore the rest of this literature review will focus on the properties and limitations of PE and PVS materials.

1.2.1. General Properties

Polyether impression materials have been on the market since the late 1960s and are recognized by the name brands Impregum®, Permadyne® and Polygel®. PE consists of a base
paste that is composed of long-chain polyether copolymer with alternating oxygen atoms, methylene groups, and reactive terminal groups. The ends of these macromolecular chains are converted into reactive rings, which transform into cross-linked final reaction products. The ether-dominated polymer backbone makes this group of materials the most hydrophilic of all elastomeric impression materials.\textsuperscript{15} PE material is fairly rigid upon completion of polymerization. Newer formulations of “soft” PE are less stiff and, as such, are easier to remove from the impressed teeth than earlier formulations. However, these materials still have an increased tendency to lock into undercuts not properly blocked out and have the potential to fracture delicate gypsum dies.\textsuperscript{16}

Although PEs are the most hydrophilic elastomeric material, they are only moderately hydrophilic and have limited ability to displace fluids in the process of impression making. Therefore the preparation unequivocally must be dry. Due to their hydrophilic nature, these materials also must be handled with strict criteria after setting. Kanehira\textit{ et al}\textsuperscript{17} have shown distortion of PE materials over time. Specifically, Impregum® has the ability to absorb water and deform at relative humidity levels about 50%. Because all PE materials deform when in constant contact with moisture from disinfection fluids, it is recommended that PE impressions should be rinsed, dried, and poured after 10 minutes of disinfectant contact time.\textsuperscript{9,16,17}

PVS materials go by many names, such as vinyl polysiloxane, addition silicone, polyvinyls, vinyls, and polyvinyl siloxanes. These state-of-the-art materials have been on the market since the mid-1970s, have improved greatly over the years and have the best fine detail reproduction and elastic recovery of all available materials.\textsuperscript{6} PVS materials exploit the principle of “addition reaction curing,” which involves the linking of a vinylsiloxane in the base material with a hydrogen siloxane via a platinum catalyst. During the reaction hydrogen is produced as a
byproduct, which is then scavenged by the platinum in the catalyst. The consistency of the material is controlled by the amount of silica filler. More silica filler increases material viscosity and rigidity.\textsuperscript{9,15,16} Unlike PE, PVS materials are dimensionally stable over time and can be stored for several weeks without loss of accuracy.\textsuperscript{6} However, PVS materials are very moisture sensitive in their unset phase and detail loss from contact with blood or saliva can affect their accuracy.\textsuperscript{6,9,15,16}

According to Chai \textit{et al.}\textsuperscript{18} there are three mechanical properties that are clinically relevant when discussing impression materials. First, \textit{yield strength} determines the ability of a material to withstand stress without permanent deformation. Second, \textit{strain at yield point} indicates the amount of undercut that the impression material can overcome without permanent elastic deformation. Finally, \textit{tear energy} indicates the resistance to tear of impression material. The ideal impression material is one which absorbs the most energy not to the point of tearing, but rather just prior to the point of critical, permanent deformation.\textsuperscript{19} No differences in the relative amount of distortion have been detected between PE and PVS when these materials are used with impression techniques that provide adequate bulk of material in the area of the preparation margins.\textsuperscript{20}

\textbf{1.2.2. Effects Of Moisture}

Since the mouth is a generally wet environment, how impression materials interact with moisture is critical. The manner in which this takes place, or does not, is described as the material’s hydrophilic or hydrophobic nature. Hydrophilicity of a material has traditionally been measured by the angle a standardized droplet of water forms with a material. By convention, materials forming angles less than 90 degrees are defined as hydrophilic and those greater than 90 degrees as hydrophobic.\textsuperscript{15} There are definite differences in PVS and PE materials in terms of
their hydrophilic properties. PVS materials are principally hydrophobic because of their chemical structure. They contain hydrophobic aliphatic hydrocarbon groups around the siloxane bond.\textsuperscript{9,15,21,22} PE materials are more hydrophilic because they contain carbonyl (C=O) and ether (C-O-C) groups that chemically attract and interact with water via hydrogen bonding.\textsuperscript{9,22}

Peutzfeldt and Asmussen\textsuperscript{22} evaluated how the properties of hydrophilicity and viscosity affected the ability of hydrophilic and hydrophobic impression materials to displace water and replicate surface characteristics that had been placed onto a ground dentin surface. The materials were injected in such a way that they had to flow across the test surface to displace the water from the periphery, trying to mimic clinical conditions. Their results split the materials into two distinct groups with a 70 degree contact angle as the dividing line between the groups. In the hydrophilic group, those which presented contact angles below 70 degrees, it was found that as materials increased in hydrophilicity, they performed better at displacing the water. The hydrophobic materials, with contact angles over 70 degrees, showed a propensity to displace water more readily with increases in viscosity. The authors stressed that when water was omitted from the dentin surface and testing was repeated, all PE and PVS materials tested achieved 100% reproduction of the groove pattern being evaluated.

In a 2003 study Johnson \textit{et al.}\textsuperscript{23} evaluated the ability of PE and PVS materials to replicate surface detail of a standard, saw tooth pattern metal plate of a predetermined roughness (Ra). Three variables were evaluated during the testing process: material (PE and PVS), surface conditions (wet and dry), and mix technique (mono- and dual-phase). The results of the study indicate that monophase performed better than dual viscosity, PE better than PVS, and dry conditions better than wet conditions. Of note is that the pattern used in the study contained ridge heights of 10µm, while the ISO specification for elastomeric impression materials is 20µm.
Given this, all PE and PVS samples except one, a dual-phase PVS, would have produced acceptable detail to meet the current ISO standards for fine detail reproduction.

During the same year Johnson et al.\textsuperscript{23} published their findings, Petrie et al.\textsuperscript{24} published findings of a very similar study. Rather than evaluating dry and wet conditions only, they made an effort to create what dry, wet, and “moist” surfaces to test the detail reproduction of two PVS materials. Steel dies, similar to those used in ADA Specification 19, were utilized during the experiment. For making impressions in “moist” conditions, a fine mist of water was applied to the surface of the die just before the impression material was added to the surface. For wet conditions, the steel die was immersed in a water bath and the impression was made with the die and impression syringe under water. The research study revealed that, as the moisture level increased from dry to wet, the ability of the PVS materials to reproduce the surface details was significantly affected. This finding was similar to the Johnson et al study.\textsuperscript{23} It was also found that both PVS materials were able to reproduce the steel die without error in dry conditions. Two years later Walker et al.\textsuperscript{25} repeated the study with the addition of two PE materials. It was found that the PVS materials still were unable to reproduce the die details under moist conditions; however the PE materials were able to achieve complete reproduction of the surface under dry and moist conditions. The “wet” test condition with a submerged die was not repeated in the Walker study.

In a series of studies evaluating the hydrophilicity of elastomeric impression materials, Rupp et al.\textsuperscript{26,27} showed that improved PVS materials show initially high contact angles with water. The hydrophilicity develops as a function of time as the surfactants release from the impression materials into water, thereby lowering the surface tension.\textsuperscript{28} During initial setting of the PVS materials tested, none showed lower contact angles with water than the PE tested. After
60 minutes of set time, only 2 of the 6 PVS materials became more hydrophilic than the PE. Therefore, the only added benefits to addition of surfactants to PVS impression materials relates to the process of pouring the impression and not in the impression making process itself.

It can be concluded that PEs are hydrophilic in that they will absorb some moisture in the process of impression making, but still require a relatively dry field. PVS materials, despite the addition of surfactants to make them perform in a more hydrophilic nature, still do not readily interact with moist surfaces. For the present time, it does not seem to matter if the PVS is termed “improved,” “hydrophilic,” or “smart wetting;” as none will compensate for poor control of moisture. Therefore, factors such as those described by Chai et al., moisture control, and rheologic properties of the impression material have the most direct impact on the final quality of the impression.

1.2.3. Interactions With Other Materials

While PEs seem to be largely unaffected by any other materials, it has been shown that PVS materials can have interactions with many items commonly used during restorative procedures. Since PVS requires a small amount of catalyst to initiate the setting reaction, anything that interferes with the catalyst may prevent cross-linking and thereby cause the surface to remain tacky after the bulk of the material has set. Contamination is commonly a result of interaction with sulfur or sulfur containing compounds. This contamination may occur by either direct contact with the unset PVS materials or by indirect contact with compounds that remain adhered to the teeth and soft tissues.

The polymerization inhibition of PVS can be caused by direct contact with 96% of latex products, gloves and rubber dams for example, and indirectly by hands that had previously been wearing latex gloves or intraoral tissues that have come in contact with latex products.
method of inhibition is not clearly known; however, it is thought that the chloroplatinic acid catalyst reacts with unreacted sulfur in the latex products.\textsuperscript{32} While many believe that the interaction is not the same with latex-free, vinyl products,\textsuperscript{6,16} others warn that these products still have the potential to inhibit polymerization because of the sulfur containing stabilizers used in the manufacturing process.\textsuperscript{9} A recent research study demonstrated that two light body PVS materials can be inhibited by direct contact with several latex and latex-free products; however, no indirect contact inhibition was seen between any latex or latex-free product and the PVS materials tested.\textsuperscript{33}

Metal salts, which are found in many hemostatic and retraction solutions, have been thought to inhibit the set of PVS. The result of such an interaction would result in lack of polymerization is the critical area of the preparation margin. The research study of de Camargo \textit{et al.}\textsuperscript{34} evaluated if such an interaction does exist. In the evaluation 3 latex samples, 5 retraction cords and 4 medicaments were allowed to contact PVS during the setting reaction. Neither the retraction cord nor the medicaments inhibited the PVS setting reaction, as opposed to latex control samples. It was concluded that the medicaments and retractions cord tested are safe for use, and that the previous reports of polymerization inhibition were due to handling of the cords with latex gloves. A more recent study by Machado and Guedes\textsuperscript{35} identified that there was no inhibitory affect with any combination of gloves or hemostatic agents tested. This may be the result of improvements in materials to make them less reactive or non-reactive to excess sulfur in dental products.

With the advent of bonded indirect restorations, many clinicians opt for immediate dentin sealing for its purported advantages of increased bond strength and ease of final restoration delivery.\textsuperscript{36} Like any resin material, the adhesive resin in dentin bonding agents is inhibited by the
set of oxygen.\textsuperscript{15} The oxygen inhibited layer has an inhibitory effect on the polymerization of PVS and will result in unset material around any preparation that has been immediately sealed or restored with freshly placed composite resins.\textsuperscript{9,36} To avoid this interaction, the inhibition layer must be removed by curing through a glycerin gel or DeOx (Ultradent, Utah, USA), preparation of the resin coating by fine diamond instrumentation at low speed, airborne particle abrasion, or flour of pumice.\textsuperscript{6,9,16,19,36}

1.3. Impression Technique

The influence of tray selection on successful impression taking is often overlooked. Numerous factors must be taken into consideration when selecting the correct impression tray including size, shape, and rigidity. The importance of correct tray selection cannot be overstated as it can make the difference between success and failure. Gordon et al.\textsuperscript{37} stated that many dentists consistently use less expensive prefabricated plastic trays because of the time and cost associated with the fabrication of custom impression trays. However many dentists are not aware of the shortcomings related to the usage of these trays.

A trend in tray selection can be seen when looking at a history of research studies dating from 1980-2009.\textsuperscript{3,8,10,11,14,38} Since 1980, the usage of stock trays has increased from 75%\textsuperscript{38} to nearly 100%,\textsuperscript{11,14} and the use of quadrant trays has greatly increased from 35%\textsuperscript{38} to 88%.\textsuperscript{14} It is unknown if the use of these alternative trays results in a clinical outcome equivalent to traditional procedures?

1.3.1. Tray Flexure

Trays should be as rigid as possible in order to resist deformation from pressure both during the impression making process and after removal from the mouth. Tray deformation and flexure may negatively affect the marginal integrity of the final restoration, which has the
potential to reduce its overall lifespan. The rigidity of commercially available disposable plastic 
trays, especially with higher viscosity materials, has been questioned. Many clinicians choose 
higher viscosity materials under the assumption that these will compensate for the added volume 
needed when using stock plastic trays and that more rigid materials will resist distortion. Cho and 
Chee\textsuperscript{39} determined that the mean cross arch and cross section change respectively for metal stock 
trays were 0.001 mm and 0.002 mm, for plastic trays these values were 0.099 mm and 0.120 mm. The difference was found to be statistically significant and the authors raised concerns that 
use of plastic impression trays with high viscosity materials may lead to marginal and occlusal 
discrepancies when seating final restorations.

Carrotte et al.\textsuperscript{40} evaluated several different tray systems and classified them as rigid, 
semi-rigid, or flexible mainly based on the approximate thickness of the plastic tray material and 
presence of a reinforcing rolled peripheral border. After each putty wash impression was made, a 
casting was fabricated and the marginal discrepancy was measured. Rigid, 3mm thick, plastic 
trays and metal controls were virtually identical with approximately 50 \textmu m openings. In contrast 
with rigid trays, the marginal opening increased to 151 \textmu m and 208 \textmu m for the semi-rigid and 
flexible trays, respectively. Use of softer putty decreased these numbers to 90 \textmu m and 178 \textmu m, 
respectively, but all results were significantly poorer than with rigid plastic and metals trays were 
used. This data, like that of Cho and Chee,\textsuperscript{39} indicated that more rigid putty may actually be 
worse for the overall restoration than using a heavy body, syringeable material.

Samet et al.\textsuperscript{3} found that 38\% of impressions showed contact between the vertical walls of 
impression trays and the oral soft tissues. If higher viscosity impression materials induce marked 
distortion in impressions, then contact with the oral soft tissues will most certainly result in an 
increased flexure.\textsuperscript{41} While clinically acceptable restorations may still be fabricated from distorted
trays, they are more susceptible to error both in the clinical and laboratory setting and their routine usage should be questioned.\textsuperscript{14}

1.3.2. Custom Trays

It is clear that some stock trays may not provide adequate rigidity and flex during the impression making process, but these trays also do not provide a uniform thickness of the impression materials.\textsuperscript{42} The varying thickness of the material is most commonly a cause of the stock tray not being correctly oriented, yielding inadequate bulk in some areas and too much bulk in others. While bulk may not have been relevant for hydrocolloid impression materials, with non-aqueous impression materials a uniform bulk of material of 2 mm is optimal.\textsuperscript{15,43,44} Eames \textit{et al.}\textsuperscript{43} evaluated the amount of dimensional change that occurred with varying thicknesses of impression materials of a master die and found that not only was distortion increased as the material thickness increased, but over a 24 hour period the initial distortions were magnified. With few clinicians performing their own lab work, it may be that increased distortion resulting from increased delays are likely more representative of reality.

The problems caused by the usage of stock impression trays can be solved by the utilization of custom impression trays. The ideal characteristics of a custom tray include: 1) good adhesion to the impression material, 2) dimensional stability, 3) allowing even thickness of impression material, and 4) sufficient rigidity to resist deformation.\textsuperscript{6,30,39,43} Custom trays improve the chances of producing accurate impressions, especially in situations where several units are being impressed. Christensen\textsuperscript{45} makes note that many dentists assume that custom trays are too expensive, but this is a false assumption. Stock trays, on average, require three to four times as much material as a properly made custom impression tray and will therefore pay for themselves in materials savings alone. Although some authors advocate that there is no clinical difference
between stock and custom trays, many researchers and clinicians still recommend their routine usage.

1.3.3. Dual Arch Trays

Dual arch, or “closed bite”, impressions have been in use in dentistry since they were first mentioned by Wilson and Werrin in the early 1980’s. They are designed to simultaneously obtain an impression of the prepared teeth, the opposing dentition, and the intercuspal relationship while using less material than traditional full arch impressions. They are, however, not without limitations for use. The indications and requirements for their accurate utilization are as follows: 1) a maximum of two prepared teeth, 2) unprepared stops both anterior and posterior to the preparations, 3) stable, reproducible intercuspal position, 4) the patient must be able to close into maximum intercuspal position with the tray in place, 5) existing anterior guidance, 6) the canine must be recorded in the impression, 7) the tray must not impinge on any teeth or soft tissue, and 8) the provider must be familiar with the procedures being performed. Contraindications for the utilization of dual arch trays are 1) group function occlusal pattern, 2) unstable maximum intercuspal position, and 3) a planned alteration of the vertical dimension of occlusion. Some studies have shown that preparations with detailed intra-coronal preparation aspects, such as inlays, are also not reproduced well by the dual arch impression technique.

If the above recommendations for utilization are followed, the technique can be quite successful. A series of studies showed no clinically significant difference in dies made in dual arch trays compared with those made in custom fabricated trays. In fact, Parker showed that while custom impression trays had a horizontal contact error of 72 µm, the dual arch impressions showed only a 5 µm error. This may be attributed to the flexure of the mandible during opening. With regard to tray flexure, the material the tray is constructed from is
important. Cox et al.\textsuperscript{60} and Wostmann\textsuperscript{56} both showed the dimensional accuracy of metal dual arch trays were superior to plastic varieties. Wostmann argues that it is not the primary stiffness of a tray but its tendency to reset after deformation that is the crucial factor that affects impression accuracy. Therefore, it is not the initial deformation, but the elastic recovery of the tray which causes the actual distortion of the preparation.\textsuperscript{56} To avoid the possible effects of soft tissue impingement and the risk of inducing tray distortion, many manufacturers have little or no sidewall on the impression trays. Several potential problems could arise from the lack of sidewall including creep of the material away from the preparation and pressure from the tongue thinning away or removing material from the preparation. Therefore, it is recommended that trays have sidewalls that extend to at least the gingival margin of the preparation.\textsuperscript{54}

Johnson et al.\textsuperscript{63} in a study involving 116 dual arch impressions showed that 64\% of impressions were successful in capturing all relevant aspects of the preparation. However, PVS produced significantly more successful impressions compared with PE, 70\% and 58\% respectively. de Lima et al.\textsuperscript{64} were also able to show greater distortion obtained when using PE material. The most common error in the Johnson et al.\textsuperscript{63} study pertained to the finish line and was attributed to inadequate gingival displacement. The success rate of this study is in general agreement with that of previous studies which evaluated full arch impressions by private practitioners.\textsuperscript{3,8,10,11,14}

Lane et al.\textsuperscript{51} showed that the double arch impression technique is faster, more comfortable, uses less material, and is preferred by 80 percent of patients. Therefore, dual arch impression techniques may provide clinically acceptable restorations, with a cost and time saving to the dental practitioner, so long as the indications and contraindications are respected during the procedure.
1.4. Margin Design and Placement

Clinicians must determine what type of margin is best for a given situation and the location of that margin. Although many factors such as material, esthetics, and access influence the selection, most dentists probably have a “preferred” design they feel comfortable preparing. A discussion in gingival margin design must include a clarification of terminology, as different sources often refer to a similarly termed margin as being prepared in several different ways. For simplification of terminology throughout the remainder of this section, finish line configurations will be discussed as described by Hunter and Hunter and Shillingburg.

The chamfer is the preferred gingival margin design for restorations having a metal margin. This variant of finish line has been shown to exhibit the least stress so the underlying cement will have less likelihood of failure. Preparation of this variety of finish line is most often accomplished with a round-end or torpedo shaped diamond bur. The final preparation should have the geometry of rounded internal angles with an approximately 90 degree cavosurface angle.

Although they are more destructive to the remaining tooth structure than chamfer preparations, shoulder margins have been the finish line of choice for ceramic restorations. The margin geometry consists of an approximately 90 degree cavosurface margin with a wide, butt joint ledge to provide resistance to occlusal forces and allow bulk of porcelain to minimize the risk of fracture. Proper width of the butt joint is critical for restoration contour, strength, and esthetics. Previously a sharp, 90 degree internal angle was advocated, but it is now recommended that the pulpogingival line angle be rounded.

Knife edge finish lines and otherwise beveled margins have been advocated to improve the seal and seating of restorations. Unfortunately, they can create problems if not done properly.
Unless these margins are cut as designed, the axial reduction may “fade out” instead of terminating in a definite finish line. The thin marginal design is harder for the technician to read, wax, and cast compared to other varieties. The thinner area of restorative material is also more susceptible to distortion for metals or fracture for ceramics. Although intraoral finishing is advocated as a benefit to this margin design, it is often difficult, impractical, or simply not attempted. 65-67 Others point out the metals used in metal-ceramic restorations are not suitable for burnishing and attempting to do so may fracture the overlying porcelain. 69

No matter what margin is chosen, the advantages of improved control of contours, esthetics, structural rigidity, ease of evaluating preparations, and clearer impressions allowed by wider margins must be considered. 1,65 Overcontour of restorations, so as to provide adequate bulk of materials, often result in a compromised gingival health by impeding plaque removal. 65,70 Donovan and Chee 68 state that the following criteria for margin selection should be considered: 1) the selected margin must provide a predictable level of integrity, 2) to minimize plaque accumulation, the selected margin must present smooth materials to the gingival sulcus, and 3) in some situations, the margin also must provide acceptable esthetics.

1.4.1. Subgingival Margins

Regardless of margin geometry, proper placement of the gingival margin in relation to the free gingival margin, the epithelial attachment, and the alveolar crest is crucial. 68,71 The best possible situation for a margin is for it to be located in a supragingival position, however in clinical practice subgingival margins are inevitable. Because preparation length is an important factor in resistance and retention form, it is sometimes necessary to extend preparations subgingivally to increase retention. 67 Other factors that dictate the placement of margins
subgingivally include caries, extension over previously existing restorations, trauma, root sensitivity, severe non-carious cervical defects and esthetics.\textsuperscript{67,72,73}

Placement of margins subgingivally for esthetics is a matter of debate. A classic study by Crispin and Watson\textsuperscript{74} evaluated the amount of gingival display among 425 subjects during normal and exaggerated smiles. What they found was that during normal smiling, the gingival margin remained hidden for 44\% of canines, 34\% of lateral incisors, and 50\% of central incisors. For an exaggerated smile, these numbers decreased to 26\% of canines, 16\% of lateral incisors, and 24\% of central incisors. Therefore, it must not automatically be assumed that the patient will show all of the anterior gingival margins when treatment planning for the type of restorations to be placed and margin location.

When subgingival margins are indicated there are numerous theories about where they should be placed. Historically, the location of the margin has been suggested to be 1) the base of the gingival crevice, 2) half the distance between the base of the gingival crevice and the gingival margin, 3) the crest of the gingival margin, and 4) supragingivally.\textsuperscript{70} Today, recommendations have become more limited to universally placing margins 0.5 mm apical to the free gingival margin, or, when situations dictate, sounding of the alveolar crest so as to make sure the biologic width is not violated.\textsuperscript{68,75,76} The latter recommendation comes from Kois\textsuperscript{76} who makes mention of the fact that the relationship of the margin location to the bone is more critical than the distance below the free gingival margin.

1.4.2. Biologic Width

The concept of biologic width was first described by Gargiulo \textit{et al.}\textsuperscript{77} in 1961 when he measured the average length of the gingival attachment to the root, the junctional epithelium, and the sulcus depth in human cadavers. However, it wasn’t until Loe\textsuperscript{78} published an article on the
reaction of gingival tissues to restorative procedures that the profession started looking at the iatrogenic biological damage done to the periodontium when this area was violated.\textsuperscript{75} Generally it is thought that there is a need for 1 mm of gingival attachment to the root, 1 mm of junctional epithelium and 1 mm of sulcus depth to maintain normal gingival and osseous health immediately adjacent to each tooth. Most consider the total biologic width to be approximately 2-3 mm but this depends on the reference point and if the depth is considered as originating from the depth of the sulcus or the free gingival margin. The average is not a true measure though, as junctional epithelium measurements vary widely in length.\textsuperscript{75,77} Sounding the osseous crest has been recommended as the most accurate determinant of how far subgingivally, if at all, margins can be placed without violating the biologic width, and still allow the space needed for a healthy gingival attachment, junctional epithelium and gingival.\textsuperscript{76}

Numerous studies exist that show how subgingival margins can negatively affect the periodontium when the aspects of biologic width are not considered. Newcomb\textsuperscript{79} demonstrated increasing levels of inflammation in anterior teeth with direct correlation to the distance remaining between the crown margin and the base of the sulcus. Interestingly in this research study, the crown margins had lower plaque indexes compared to the control teeth. This is not saying that bacteria are not a potential cause of the inflammation, because they can exist in the niche between the restoration and tooth, but simply stating that the margin location can directly affect inflammation.

Felton et al.\textsuperscript{80} later evaluated the effect of marginal discrepancy of the gingival index and crevicular fluid flow rates. Their data showed a strong correlation between the amount of marginal discrepancy and both the gingival index and crevicular fluid flow rates, both of which are indicators of gingival inflammation levels. Interestingly, there was no correlation between
amount marginal discrepancy and measured pocket depths in the same locations. The authors’ stated that the current methods of judging subgingival margin discrepancies are inadequate, which is in agreement with Christensen\textsuperscript{81} who showed that providers generally do not detect subgingival margin discrepancies until they are greater than 120 μm. When looking at the Felton\textsuperscript{80} and Newcomb\textsuperscript{79} research studies together, it may be concluded that the margin location or the bacterial accumulation may increase gingival inflammation.

Richter and Ueno\textsuperscript{82} placed mandibular first molar crowns with each crown containing a facial margin which was located half supragingivally and half subgingivally. They were unable to show any difference in the gingival index scores for the areas that were supra- or sub-gingival regardless of plaque levels. The authors’ of the research study mentioned that meticulous detail was given to make sure margins were sealed and that the restorations were not over contoured. Ultimately Reeves\textsuperscript{83} summarized the findings on subgingival margin placement by stating that the degree of inflammation is influenced by a confluence of four factors: 1) failure to maintain proper emergence profile, 2) inability to adequately finish subgingival margins, 3) placement of the margin in an area with minimum to no attached gingiva, and 4) violation of biologic width. Although metal allergies and reactions to dental cements due occur, the inflammation resulting from subgingival margin is generally not a reaction to the materials themselves.

Biologic width violations are primarily a function of margin placement and are independent of margin design.\textsuperscript{68} The natural architecture of the osseous crest must be considered during preparation as well. There is frequently a disparity between the facial and interproximal bone height. This disparity is more pronounced in the anterior regions of the mouth, which has a narrow alveolar process, as compared with the posterior areas where the alveolar process has a tendency to widen and flatten to accommodate the larger root surfaces of molars and
premolars. Inexperienced clinicians have a tendency to extend the tooth preparation to one circumferential depth, disregarding this disparity in height, and will likely violate the interproximal biologic width.

1.4.3. Bacterial Accumulation

Perfect restoration marginal adaptation is nearly impossible, especially in the subgingival area. Placement of preparation margins subgingivally compromises the ability to record margins during the impression making process, which ultimately limits the accuracy of the marginal fit of the restoration. Compromised subgingival marginal fit will adversely affect the health of the periodontium. Beier et al. showed that increasing the depth of a margin subgingivally significant increased the risk of obtaining an unacceptable impression. Therefore, all subgingival margins present a potential point of bacterial colonization.

Lang et al., in a classic article, showed an increase in bleeding, inflammation, and an increase in bacterial flora in conjunction with overhangs of 1 mm. The predominant species of bacteria were noted as Gram-negative, anaerobic bacteria and black pigmented bacteria. It was also noted that the anaerobic:facultative ratio was increased, indicating a shift away from periodontally healthy bacteria. The most interesting outcome of the study was that when the overhang restoration was replaced with one having margins that restored normal anatomic contours, the bacteria in the subgingival area returned to that seen healthy periodontal tissues.

The design of the preparation margin has a direct impact on the ability to create normal anatomic contours with a restoration. Many individuals have suggested that there may be benefits from using a knife edge margin design. Their rationale includes claims that restorations fabricated for these preparations will always be sealed, even if the preparation margins were not captured completely by the impression or even if the laboratory technician over trimmed the die
resulting in restoration margins short of the original preparation margins. Beier et al.\textsuperscript{1} showed in their study that, in addition to the subgingival depth having an effect, beveled margins significantly increased the risk of obtaining an unacceptable impression as compared with preparations having a definitive finish line. The clinical ramifications of these findings is that subgingival knife-edge/beveled marginal design may result in an areas of tooth structure that has been roughened during the process of preparation that not will not be covered with the final restoration. These roughened (damaged) areas thereby predispose the patient to constant, localized gingival inflammation problems.\textsuperscript{80}

Bacterial colonization can occur easily in these areas of roughened “bur-cut” dentin because the bacteria are sheltered in the gingival sulcus from normal mechanisms of cleansing. Factors that affect that bacteria’s ability to bind to a surface include roughness and surface free energy. Studies by Quirynen et al.\textsuperscript{86,87} have concluded that the roughness of the surface is significantly more important than the surface free energy. The threshold limit of surface roughness needed for bacteria colonization to occur has been determined to be an R\textsubscript{a} value of 0.2 \textmu m.\textsuperscript{86,88,89} Simply put, R\textsubscript{a} is the average of a set of individual measurements of a surfaces peaks and valleys away from a mean line. To put this number into perspective, it has been found that the average surface roughness R\textsubscript{a} values for dentin and enamel after preparation range from 8.1-8.6 \textmu m for carbide burs and 6.6-6.8 \textmu m for medium course diamonds. If finishing burs are utilized the R\textsubscript{a} value drops to only 1.2-2.1 \textmu m.\textsuperscript{90,91} All values are clearly above the 0.2 \textmu m threshold. The negative impact of increased surface roughness cannot be over-stated. For example, when subgingival dental implant surface roughness is increased from R\textsubscript{a} 0.2 \textmu m to 0.8 \textmu m the available surface area for bacterial adhesion increases by a factor of 3 and the rougher surface harbors 20 times more bacteria.\textsuperscript{88} Dental caries and periodontitis, both of which have a
bacterial component in disease progression, are among the most common complications experienced with prosthodontic work that successfully restores normal anatomic contours. Increased bacterial colonization that occurs secondary to the failure to properly prepare and record the knife-edge/beveled margin even further predisposes the patient to caries and periodontitis in the area.

Subgingival margins are an often wanted and sometimes a needed part of clinical dentistry. Great care must be taken in placing and properly recording these margins to ensure long term health of the restoration and periodontium. When done correctly, ill effects will result; however, when poorly done, even patients with excellent home care and receiving regular, professional preventive care, will experience perpetual problems. 

1.5. Gingival Displacement

According to *The Glossary of Prosthodontic Terms*, gingival displacement is defined as “the deflection of the marginal gingiva away from the tooth.” The basic criteria for what would be considered acceptable gingival displacement material have been defined by Nemetz *et al.* as: 1) the creation of sufficient lateral and vertical space between the finish line and gingival tissues to allow the preparation margin to be recorded in an impression medium, 2) provide absolute control of gingival fluid seepage and hemorrhage, 3) no significant, irreversible soft or hard tissue damage resulting from the procedure, and 4) not produce any potentially dangerous side effects. To accomplish this task, the provider may choose a technique classified as mechanical, chemical, surgical, or utilize a combination of the methods.

It is generally agreed that optimal tissue health must be obtained prior to any definitive preparation or impression procedures. Sorensen *et al.* describe a method of utilizing 0.12% chlorhexidine gluconate (CHX) rinse to optimize tissue health prior to fixed prosthodontic
procedures. They recommend twice daily rinses 2 weeks prior to crown preparation, during the provisionalization period, and 2 weeks after final prosthesis delivery. Compared to the study’s control group, which required remaking 6 of 15 (40%) of impressions due to inadequate quality, none of the experimental CHX treatment patients required a remake. Additionally, the plaque and gingival index levels in the experimental CHX group were significantly better than the control group.

1.5.1. Gingival Retraction Cords and Medicaments

A variety of different gingival retraction cords have been advocated over the years. Currently braided and knitted retraction cords have become the primary ones reported as being used by clinicians.\textsuperscript{4,38,104,105} Braided retraction cords are characterized by a consistently tight weave pattern which makes them resistant to separation or fray during placement. This feature makes them easy to manipulate with smooth or serrated edge packing instruments.\textsuperscript{106} Knitted retraction cords require the use of non-serrated instruments to prevent fraying or dislodgement of the cord, but have been shown to increase in size after placement in the sulcus leading to an increase in their popularity.\textsuperscript{101} There is an overall lack of standardization in cord size and efficacy between manufacturers and no scientific evidence to suggest a difference in performance; therefore the selection of cord type is mainly a matter of handling characteristics preferred by the provider.\textsuperscript{4,100}

In addition to cords, there are numerous medicaments which can serve as useful adjuncts during displacement procedures. Currently the list of medicaments that are available impregnated in cord or as a separate solution are: aluminum chloride, aluminum sulfate, aluminum potassium sulfate, ferric sulfate, ferric subsulfate, and epinephrine.\textsuperscript{4,107} As was discussed previously in this review, the above mentioned medicaments do not seem to have an inhibitory effect on the
polymerization PVS or PE materials.\textsuperscript{6,34,35} A trend in decreased usage of epinephrine as a medicament has been noted over the years.\textsuperscript{38,104,105,107,108} Epinephrine has been linked to adverse clinical side effect such as anxiety, tachycardia, and increased respiratory rate.\textsuperscript{38,102,107,109,110} In a recent survey of prosthodontists, one third reported that their patients experienced symptoms consistent with reaction to epinephrine.\textsuperscript{105} The severity of these adverse reactions seems to be increased when the epithelial lining of the sulcus is damaged. Researchers have noted spikes in blood levels of epinephrine upon initial placement and removal of retraction cords containing epinephrine.\textsuperscript{108} There is clinical data to suggest no difference in the gingival displacement efficacy between safer materials, like aluminum chloride, and epinephrine.\textsuperscript{103,111} Given the evidence at hand, the routine use of epinephrine in conjunction with gingival displacement procedures is not recommended.

1.5.2. Classical Displacement Methods

The most traditional form of gingival displacement taught in dental institutions is the chemicomechanical as described by Schillingburg\textsuperscript{67} in his text “Fundamentals of Fixed Prosthodontics.” By convention this involves the utilization of 1 or 2 cords placed in the gingival sulcus with the addition of a hemostatic medicament. These are known as the single- or double-cord techniques and they are the method utilized by 98\% of prosthodontists.\textsuperscript{105} No clinical study has demonstrated superiority of one technique over another as long as the techniques were used correctly for the given clinical situation.\textsuperscript{100}

As the name implies, the single cord technique achieves gingival displacement with the utilization of only one cord. It is recommended that this technique be utilized when making an impression for one to three teeth, with healthy gingival, no signs of hemorrhage, and margins less than 0.5 mm subgingivally.\textsuperscript{4,99,100} The largest diameter cord that fits the sulcus should be
used and is removed just prior to impression making. Christensen\textsuperscript{5} believes this method to be the most often used, and one of the least successful methods, owing to the frequent presence of blood and lack of proper management. Many providers choose to leave the single cord in place during impression making. If the clinician’s choice is to leave the single cord in place, secondary evaluation of the margins is required to ensure proper exposure.

In the double cord technique an initial, smaller cord is placed into the sulcus prior to placement of the second, larger diameter cord. This technique is indicated for all situations, but is specifically recommended for situations which involve multiple abutment teeth, compromised soft tissue health, margins that extend beyond 1 mm subgingivally and when a single cord does not provide sufficient lateral tissue displacement.\textsuperscript{4,99,100} Many dentists and laboratories consider this technique to be the standard by which all other gingival retraction methods should be compared and is the method of choice for 43\% of prosthodontists surveyed.\textsuperscript{5,102} Just prior to making the impression the second, larger diameter cord is removed leaving the smaller cord in place. The advantage of the small cord remaining in place is that it can absorb moisture from the gingival crevice, reduce the collapse of tissues against the preparation and provide continued control hemorrhage via the presence of medicaments in the cord.\textsuperscript{4,99}

There are several principles which should be adhered to in order to improve the chances for a successful impression when using both the single and double cord techniques. Laufer \textit{et al.}\textsuperscript{20,112} demonstrated that a sulcular width of less than 0.2 mm resulted in an increased incidence of voids along the margin and greater probability of impression material distortion. Finger \textit{et al.}\textsuperscript{113} later showed that irrespective of the type of material, a 0.2 mm sulcus was able to be fully reproduced, and showed for sulcular widths of less than 0.2 mm, the combination of light body wash materials with higher viscosity tray material produced more accurate sulcus reproduction
than monophase impression techniques. Some researchers advocate that if a sulcus width of 0.2 mm is required, then the clinician should aim to open the crevice by at least 0.3-0.4 mm.\textsuperscript{7}

In order to obtain the critical sulcular width of 0.2 mm that will remain present for up to 20 seconds after cord removal, Baharav \textit{et al.}\textsuperscript{114} showed the retraction cord needs to be left in place for a minimum of 4 minutes. In this same research study a significant difference was not seen when leaving the cords in beyond 4 minutes, however the sulcular width remained above the 0.2 mm width for nearly twice as long in cords left in place for 8 minutes. Laufer \textit{et al.}\textsuperscript{115} showed at the transitional line angle the sulcus was closed an average of 35\% at 20 seconds and 53\% at 40 seconds after cord removal when using the double cord technique for 6 minutes. In the area of the mid-buccal sulcus the closure was measured at 11\% and 19\% for these same time periods.

Concerning the treatment of the cord itself, several items need to be taken into consideration. First is the application of hemostatic medicaments to the cord. Csempesz \textit{et al.}\textsuperscript{116} calculated an optimal time of 20 minutes a retraction cord needs to be soaked in the medicament for it to become completely saturated. Any time beyond this point does not yield significant increases in medicament uptake and they warn increased soaking may damage the physical properties of the cord if soaked beyond 24 hours. Second, numerous authors recommend thoroughly wetting the retraction cord prior to removal from the sulcus based on the work of Anneroth and Nordenram.\textsuperscript{117} When the cord is not properly wetted prior to removal it will result in traumatic damage to the gingival epithelium and induce hemorrhage, negating most of the effects of the hemostatic treatment. Finally, it is recommend that the cord be inserted into the gingival sulcus with gentle pressure. Loe and Silness\textsuperscript{118}, in a study on the effects of tissue
reactions to retraction cord, noted the cord was often packed into the supra-alveolar connective tissue attachment, indicating excessive pressure when placing cords.

1.5.3. Alternative Methods

Although retraction cord is the most utilized method of gingival displacement, the discussion would not be complete with mentioning the alternative treatments currently available. Historically, electrosurgery has been used to reduce hyperplastic tissue, expose gingival margins and control hemorrhage. According to the review by Baba et al.⁴ electrosurgery accomplishes gingival retraction by the removal of several layers of cells to expose the gingival margin and, when used appropriately, has no adverse effects on wound healing. Electrosurgery is strongly contraindicated in patients with pacemakers and/or implanted cardioverter defibrillators, and should be used with caution around metallic restorative materials and implants. Electrosurgery removes tissue and therefore could potentially have permanent effects on the soft tissue contours.⁵,⁷,¹¹⁹

Soft tissue lasers can be used as another alternative method with less inflammation, less hemorrhage, and faster, painless healing when compared to mechanochemical methods.¹¹⁹,¹²⁰ However, the amount of time taken to complete the procedure with lasers has been reported to be much longer.⁵ Soft tissue lasers, similar to electrosurgery, also removes gingival tissue and therefore may potentially have permanent effects on the soft tissue contours.⁵,⁷,¹¹⁹

The most recent alternative to traditional methods are the so called “cordless” impression systems. These are meant to be injected into the gingival sulcus where they expand to apply lateral pressure on the tissue and provide hemostasis through incorporated medicaments.⁴,¹⁰⁰,¹²¹-¹²⁴ The kaolin based produce Expa-Syl® is the most researched material in this category. These materials are easier, faster, and less painful to the patient, often requiring little to no additional
anesthesia.\textsuperscript{4,125} Compared to mechanochemical methods there is no difference in measured crevicular fluid flow\textsuperscript{124} or achieved lateral gingival displacement,\textsuperscript{121} but there is a compromised ability of these materials to move vertically in the sulcus and displace deeper gingival margins.\textsuperscript{123,125} Comparatively, these materials produce less hemorrhaging than treated cords,\textsuperscript{122,124} however, the studies mentioning this difference removed the retraction cord in a dry state and may have induced bleeding that would not have occurred if the cord was wet.\textsuperscript{117}

1.6. Conclusion

Achieving excellent results with an indirect restoration absolutely depends on obtaining an accurate representation of the preparation and soft tissue. Modern impression materials, when used properly, are very accurate. Correct impression technique includes proper tray selection, adequate moisture control, effective gingival displacement, and appropriate choice of impression material. Each clinical situation will require changes in one or multiple factors in order to ensure successful transfer of preparation specifics to the dental laboratory technician. One broad method will not work for all situations.

New materials and techniques are constantly being introduced, many with the potential to improve overall quality. Improved materials are not able to compensate for poor clinical technique as even the smallest error can make the difference between restoration success and failure. The clinician, laboratory technician, and, ultimately, the patient will all benefit from time and frustration saved when the clinician takes the time to recognize shortfalls in their use of materials and modify their methods of daily practice accordingly.
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CHAPTER 2: MANUSCRIPT

The Quality of Fixed Prosthodontic Impressions: An Assessment of Crown and Bridge Impressions Received at Commercial Laboratories

1.1. Introduction

The transfer of accurate records to the dental laboratory is an important part of prosthesis fabrication in fixed prosthodontics. Obtaining an optimal impression for a fixed dental prosthesis is still one of the most challenging procedures in dentistry.\(^1\), \(^2\) While there are many steps that must be taken to fabricate an indirect restoration at which an error can occur, the technician can only be expected to produce a quality restoration if the impression itself is of adequate quality. All dentists must possess the ability to identify and analyze the quality of impressions, as this will ultimately determine success or failure of the restoration.\(^3\)

Accurate transfer of records requires a general understanding of soft and hard tissue anatomy, especially in the area of the cervical finish line. Practitioners also need to understand how to select and manipulate gingival displacement materials, and impression materials.\(^3\)-\(^8\) There are numerous studies that demonstrate improvements in handling and accuracy of modern impression materials.\(^6\), \(^9\) However, despite these improvements, the quality of impressions sent to laboratories for indirect restoration fabrication apparently been remained inadequate.\(^3\), \(^8\), \(^10\)-\(^13\)

Dentist/laboratory relationships tend to be less than ideal and often are relatively short term.\(^14\) A survey of 4 commercial dental laboratories in 1997 found that 36% of the 290 impression evaluated had some sort of visible defect in the impression.\(^8\) Two years later, another
study found the quality of 50% of impressions and dies to be unsatisfactory or unusable. In 2005 an evaluation 193 impressions from 11 laboratories and found 89% of all impressions to have at least one appreciable error. This raises the question, if materials are improving constantly, why are impressions actually getting worse?

Although differences exist between materials, all require optimum technique in soft tissue displacement, proper placement of the material around the preparation, and correct utilization of available impression trays. One of the major causes of unacceptable impressions is poor gingival displacement. Another of the major causes of unacceptable indirect restorations is lack of understanding of the principles of impression making, and understanding of what constitutes an acceptable impression. Proper manipulation of the impression material is arguably more important in determining the final accuracy of the impression than any characteristic of the material itself. Based on conversations with the lab owners, many technicians claim they are noticing a drop in the quality of work they have been receiving over the years.

All dental students are trained in the correct way to make impressions and oversight is given by clinical faculty. This oversight provides a checkpoint at which a licensed dentist can reject impressions made by the student before prostheses are fabricated. Once these students graduate they lose all oversight and are required to perform self-evaluation of their impressions before sending them to the laboratory. Aquilino and Taylor recognized there was a disconnect between what was happening in the institutional setting and in private practice. Their study suggests that even though most schools require dental students to perform certain fixed prosthodontic laboratory procedures, educators were becoming concerned with the ability of recent graduates to perform these procedures with limited exposure and experience. Concerns
were also expressed at how quickly recent graduates abandoned the sound principles they were taught.

The objective of this study was two-fold. First, to evaluate and quantify clinically detectable errors commonly seen in impressions sent to commercial laboratories. Second, to determine if impressions from students at the University of North Carolina school of Dentistry are comparable to those made by private practitioners.

1.2. Materials and Methods

Three large dental laboratories and one small dental laboratory, known to receive fixed prosthodontic impressions, were visited over a 12 month period from October 2013 to October 2014. Additionally, impressions from the student clinics at The University of North Carolina at Chapel Hill School of Dentistry were evaluated over a 6 month time period from April 2014 to October 2014. All impressions from these facilities on the days they were visited which required non-implant, conventional fixed dental prostheses were evaluated. Impressions for veneers, resin bonded fixed partial dentures and implant abutments were excluded. Impressions were evaluated immediately following standard disinfection protocol, or in the case of student impressions before being sent to a laboratory for prosthesis fabrication. Beyond disinfection, no other work had been completed before impressions were examined. If impressions had been poured with stone before being evaluated, they were excluded from the study population. No attempts were made to identify the dental offices from which the impressions originated. Due to this fact, the present study qualified for exemption from the Institutional Review Board of The University of North Carolina at Chapel Hill (IRB Exemption number 14-2040).

Impressions were evaluated by one of three calibrated examiners. Inter-operator calibration was achieved by having examiners inspect 10 impression rejected from the student
clinics as being unacceptable for prosthesis fabrication. After initial evaluation, errors noted were discussed among the examiners; standards were established and are listed in Table 1. In a manner described by previous studies,\textsuperscript{3, 8} statistical analysis of the calibration was not performed since each listed error was objectively identifiable and agreed upon by all examiners. A standardized form was created for the pilot portion of the study that included 130 impressions, after which the form was modified to its present form which can be seen in Figure 1. All impressions were evaluated for errors using 2.5x magnification loupes under ambient room lighting without the aid of additional illumination. In cases which had multiple abutments impressed, a defect on any abutment was scored as a defect for the entire impression.

For each impression examined, the following criteria were evaluated: type of tray used, size of tray, type of impression material, impression material combination, number of units impressed, type of tooth involved in the prosthesis, use of adhesive, type of prosthesis ordered, errors involving the abutment finish line, errors in tray/material usage, errors with soft tissue management, and errors in dual arch impression technique. Criteria were either graded as acceptable/unacceptable or belonged to a predetermined list of options as seen in Figure 1. Unacceptable error examples can be found in Figures 2-14. No attempts were made to identify the cause of noted defects in each impression evaluated. No attempts were made to evaluate the casts fabricated, restorations fabricated, or complaints/remakes with specific regards to these impressions.

1.3. Statistical Analysis

The main purposes of the statistical analysis were to assess frequencies of each factor evaluated and assess whether a critical error of the finish line was correlated by any of the factors evaluated. A Chi-square test of independence was performed using SPSS version 21 to examine
the relation between each evaluated factor. Because of the numerous factors being evaluated, some factor data were combined, as low values in certain variables were preventing further analysis of data.

For continued statistical analysis several modifications to the data were made. 1) Due to the low sample size, custom impression tray data was omitted from further analysis. 2) Restoration types were consolidated into PFM, Zirconia Based, Full Cast, Lithium Disilicate, Die, and Other. 3) Due to low sample size, restorations requested described as “Other” were omitted from further analysis. 4) Single arch and dual arch trays were combined into separate factors in group “Tray Type.” 5) Full arch and sectional arch trays were combined into separate factors in group “Tray Size.”

Chi-square test was repeated for the newly established variable groups. Items that showed significance in Chi-square analysis were further subjected to a multiple logistic regression analysis using SAS version 9.3. Odds ratios for all pairwise comparisons within each explanatory variable were then calculated.

1.4. Results

1.4.1. Descriptive Statistics

A total of 1,347 impressions were evaluated, including 1,157 from private practice and 190 from students. Frequencies of errors evaluated can be seen in Table 2. Data for an error in recording the canine and unprepared teeth anterior/posterior to the abutment(s) include both sectional dual arch trays and single arch trays as the same principles apply to both from a laboratory standpoint. Data for lack of capture of maximum intercuspal position is for dual arch trays only.
The most common errors noted for private practitioners were tissue over the finish line (49.3%), pressure of tray on the soft tissue (25.2%), finish line void/bubble (24.5%) and show through of occlusal/incisal edges (17.4%). When voids at the preparation finish line and tissue over the finish line were combined to establish a critical error rate, the resultant error rate was 55.0%.

For students the most common errors were pressure of tray on the soft tissue (54.7%), show through of occlusal/incisal edges (53.7%), tissue over finish line (22.1%), and the presence of blood or foreign materials (11.1%). The critical error rate for the student impressions was calculated to be 25.3%.

The frequency of prostheses ordered can be seen in Table 3. The two predominant prostheses types requested by private practitioners were porcelain fused to metal and zirconia based restorations, 34.9% and 38.9% respectively. Zirconia based restorations included monolithic zirconia and porcelain fused to zirconia. A surprisingly low number of practitioners, 3.2%, requested their dies be returned for the practitioner to trim and mark margins.

Data for the type of impression trays used to make the impression are located in Table 4. A large portion of the impression trays used were plastic (82.8%) and the dual arch impression technique was the preferred method among private practitioners (62.6%).

1.4.2. Factors Effecting Finish Line Errors

Chi-square analysis yielded significant differences in finish line error (p<.05) for the following factors: provider type, preparation void, occlusal show through, retraction cord attached, blood, prosthesis requested, tray size and tray type. Multiple logistic regression data can be seen in Table 5. The global test was statistically significant (p<0.001) and each of the
following explanatory variables was statistically significant: provider type, preparation void, blood, tray type and restoration requested.

Considering the comparison of the trays type, the likelihood of a critical error (versus no critical error) for dual-arch is about 1.68 more likely than that for single arch (95%CI: 1.32–2.13). Considering the provider type, the likelihood of a critical error (versus no critical error) for private practitioners is about 2.79 times more likely than that for students (95%CI: 1.88–4.15). Considering the factor of blood, the likelihood of a critical error (versus no critical error) for blood present is about 2.31 times more likely than that for blood absent (95%CI: 1.67–3.18). In the case of the restorations ordered, significant odds ratio estimates were observed only for the comparison of Die and PFM, and of Die and Zirconia Based. The likelihood of critical error (versus no critical error) for Die requested is about 0.38 times less likely than for PFM (95%CI: 0.18–0.77) whereas the likelihood of a critical error (versus no critical error) for Die requested is about 0.37 times less likely than Zirconia Based (95%CI: 0.18–0.76).

1.5. Discussion

This study aimed to evaluate the quantity and correlation of errors observed in impressions sent to commercial laboratories in a select area of the United States as determined by a preselected set of criteria (Table 1 and Figure 1). The ability for the dentist to self-evaluate the quality of impressions made is a demanding, yet essential step for clinical success of restorations. Numerous factors must be considered when making a final impression and each of these must be considered separately in order to accurately obtain an acceptable result.

This study showed that 86% of impressions sent to the participating dental laboratories had at least one detectable error. These findings are in agreement with previous studies.\textsuperscript{3, 8, 13, 17,
However, they are in contrast to the findings of a study by Beier et al.\textsuperscript{1} who reviewed a total of 1,466 impressed preparations from 249 patients. The authors’ data showed a remarkably low unacceptable rate of only 3%. The impressions were made by “experienced dental clinicians” with proper gingival displacement and moisture control. This careful attention to detail was the reason for the low failure rate, but may not represent what happens in most private practices\textsuperscript{3, 8, 13, 17, 18}. The cervical finish line area had at least one detectable error in 55\% of the impressions evaluated, a finding again in agreement with other studies\textsuperscript{3, 8, 13, 17, 18}. Accurate impressions of the margins can only be expected with proper gingival displacement, margin placement, margin design, and moisture control. It should be noted that although the student impressions had fewer critical errors than those of private practitioners (25.7\% vs 55.0\%), the number is still disappointingly high given these impressions must be approved by an instructor.

The first step in recording a cervical margin is determining what type of margin and margin location is best for a given situation. Although many factors such as material, esthetics, and access influence the selection, most dentists probably have a “preferred” design they feel comfortable preparing.\textsuperscript{19} Donovan and Chee\textsuperscript{20} state that the following criteria for margin selection should be considered: 1) the selected margin must provide a predictable level of integrity, 2) to minimize plaque accumulation, the selected margin must present smooth materials to the gingival sulcus, and 3) in some situations, the margin also must provide acceptable esthetics. Regardless of margin geometry, proper placement of the gingival margin in relation to the free gingival margin, the epithelial attachment, and the alveolar crest is crucial as biologic width violations may result from erroneous subgingival placement.\textsuperscript{20, 21} Additionally, subgingival margins are significantly harder to accurately capture in an impression, even with proper technique.\textsuperscript{1}
The 15% of impressions visibly soiled with blood on the impression provides a source of potentially infectious material. Additionally, the presence of blood on the impression was found to significantly increase the probability of an error on the cervical finish line (p<.0001, OR=2.31). Moisture has repeatedly been found to affect the accuracy of all elastomeric impression materials.\textsuperscript{22-25} It is recommended that retraction cord be placed to minimize trauma to gingiva during preparation and that optimal tissue health be obtained before any preparation or impression procedure is attempted.\textsuperscript{4, 5, 26-30} Sorensen \textit{et al.}\textsuperscript{28} describe a method of utilizing 0.12% chlorhexidine gluconate (CHX) rinse to optimize tissue health prior to fixed prosthodontic procedures that many other authorities also recommend.

It is highly likely that inadequate gingival displacement and isolation are responsible for the poor results regarding accurately recording the prepared cervical margin. For both the single and double cord techniques there are several principles which should be adhered to in order to improve the probability of a successful impression. Laufer \textit{et al.}\textsuperscript{31, 32} demonstrated that a sulcular width of less than 0.2 mm resulted in an increased incidence of voids along the margin and greater probability of distortion. It has also been shown that irrespective of the type of material, a 0.2 mm sulcus is fully reproduced, and for sulcular widths less than 0.2 mm, the combination of light body wash materials with higher viscosity tray material produced more accurate sulcus reproduction than monophase impression techniques.\textsuperscript{33} Some advocate that if a sulcus width of 0.2 mm is required, then the clinician should aim to open the crevice at least 0.3-0.4 mm.\textsuperscript{7} In order to obtain the critical sulcular width of 0.2 mm that will remain present for up to 20 seconds after cord removal, Baharav \textit{et al.}\textsuperscript{34} showed the retraction cord needs to be left in place for a minimum of 4 minutes.
Concerning the treatment of the cord itself, several items need to be taken into consideration. First is the application of hemostatic medicaments to the cord. The optimal time for knitted retraction cord to be soaked in medicament is 20 minutes for complete saturation. Any time beyond this point does not yield significant increases in medicament uptake and may damage the physical properties of the cord itself if soaked beyond 24 hours. Second, numerous authors recommend thoroughly wetting the retraction cord prior to removal from the sulcus. When the cord is not properly wetted prior to removal it will result in traumatic damage to the gingival epithelium and induce hemorrhage, negating most of the effects of the hemostatic treatment.

The most widely used impression trays were plastic stock trays (82.8%), which is an increase over previous reports. The widespread utilization of these trays may be related to their low cost and/or lack of dentist knowledge about their shortcomings and limitations. Trays should be as rigid as possible in order to resist deformation from pressure both during the impression making process and after removal from the mouth. Many clinicians choose higher viscosity materials under the assumption that they will compensate for the added volume needed when using stock plastic trays and that these more rigid materials will resist distortion. Unfortunately, this is an incorrect assumption as studies have shown that more rigid PVS materials actually result in an increase in flexure of the trays and marginal opening of restorations. If higher viscosity impression materials induce marked distortion in impressions, then contact with the oral soft tissues, as was found in 25.2% of cases examined in this study, will most certainly result in an increased flexure. The higher incidence of soft tissue pressure by students, 54.7%, can be attributed to the trays utilized in student clinics having a
rather thick rim lock design that was the point of contact in all noted errors. This design, however, reduces the risk of distortion by increasing rigidity in the tray.\textsuperscript{18}

Dual arch impression trays accounted for 62.6\% of impressions received at the commercial laboratories. These are designed to simultaneously obtain an impression of the prepared teeth, the opposing dentition, and the intercuspal relationship while using less material than traditional full arch impressions.\textsuperscript{39} The dual arch impression technique is faster, more comfortable, uses less material, and is preferred by 80 percent of patients.\textsuperscript{39} They are, however, not without limitations for use. The indications and requirements for their accurate utilization are as follows: 1) a maximum of two prepared teeth, 2) unprepared stops both anterior and posterior to the preparations, 3) stable, reproducible intercuspal position, 4) the patient must be able to close into maximum intercuspal position with the tray in place, 5) existing anterior guidance, 6) the canine must be recorded in the impression, 7) the tray must not impinge on any teeth or soft tissue, and 8) the provider must be familiar with the procedures being performed.\textsuperscript{6, 7, 40-42} When used correctly, the dual arch technique can provide clinically acceptable restorations, with a cost and time saving to the dental practitioner.\textsuperscript{39, 43-50} Our data shows that over one third of dual arch impressions violated at least one of the above limitations and a significant correlation was noted between finish line errors and the utilization of dual arch trays (p<.0001, OR=1.68).

Although the type of restoration ordered should not have a significant effect on the quality of impression, in this study a difference was noted (Tables 5 and 6). Practitioners who requested their master casts returned so they could trim their own dies had significantly better impressions than providers who requested PFM and zirconia based restorations. This is perhaps because these practitioners have to see the result of their impressions, and take the additional
steps needed to ensure quality of work. Interestingly enough, although significance was not established, the error rate for less costly restorations tended to be higher.

No attempt was made to evaluate the quality of dies or restorations made from the impressions evaluated. It is therefore not possible to determine if restorations fabricated from faulty impressions were considered acceptable by the dentists. All laboratories in this study verify that dentists are contacted and asked how they wish to proceed in the event a faulty impression is received. It is however unknown what the individual criteria are for each laboratory in determining what constitutes a faulty impression. Many times, the laboratory will proceed with processing the restoration and fabricate the margins as best they can. With the appalling amount and variety of errors seen in the impressions evaluated, it is shocking that the laboratory remake rate is only 3-4% (personal communication with laboratories involved in this study).

1.6. Limitations

- The laboratories selected for this study were not chosen randomly, but selected based on the ability of examiners to access them geographically. The data are therefore only a cross sectional representation of a select region of the United States.
- Dentists’ identities were not recorded due to conflict of interest agreements with the participating laboratories and in agreement with the Institutional Review Board of The University of North Carolina at Chapel Hill (IRB Exemption number 14-2040). This information may have proved valuable in determining if years in practice or level of training influenced error rates.
- All impressions were made using elastomeric impression material, but the examiners were not able to determine the classification of materials used for impressions. This was due to
the amount of impressions being evaluated and the number of available impression materials on the market.

1.7. Conclusions

Within the limitations of this study, marginal discrepancies made up the largest category of error noted in impressions evaluated. Impressions made by private practice dentists were significantly worse than those made by students. Simplified impression techniques such as dual arch impression trays increase the risk of obtaining critical errors. Although students made the same errors as private practitioners, there was a reduced quantity of critical finish line errors in their impressions.

Dentists have ethical, moral, and legal obligations bestowed upon them by the profession and need to critically evaluate the work they send to laboratories. An improvement in technique and reviewing of all impressions can be strongly recommended.
Table 1. Unacceptable Criteria Description and Examples

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description of Error</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finish Line, Void/Bubble</td>
<td>Any detectable void on the cervical finish line of a preparation.</td>
<td>Figure 2</td>
</tr>
<tr>
<td>Finish Line, Lack of Wash Material</td>
<td>Cervical finish line recorded in heavy body or putty material with no wash above or below the finish line. Monophase excluded from error.</td>
<td>Figure 3</td>
</tr>
<tr>
<td>Tray, Inadequate Retention of Material</td>
<td>Impression material pulling away from tray or not engaging tray retention features.</td>
<td>Figure 4</td>
</tr>
<tr>
<td>Tray, Pressure of Tray On Soft Tissue</td>
<td>Vertical tray flanges exposed by displacement of impression material. Any occurrence within 2 teeth of preparation(s) or on the preparation(s).</td>
<td>Figure 5</td>
</tr>
<tr>
<td>Tray, Show Through of Occlusal/Incisal Edges</td>
<td>Horizontal tray areas visible by displacement of impression material. Any occurrence within 2 teeth of preparation(s) or on the preparation(s).</td>
<td>Figure 6</td>
</tr>
<tr>
<td>Material, Inadequate Fusion of Viscosity</td>
<td>Lack of complete fusion between body and wash materials.</td>
<td>Figure 7</td>
</tr>
<tr>
<td>Material, Void on Preparation</td>
<td>Voids not located on the finish line greater than 1 mm in size</td>
<td>Figure 8</td>
</tr>
<tr>
<td>Material, Lack of Polymerization</td>
<td>Impression material visibly unset or tacky to the touch.</td>
<td>Figure 9</td>
</tr>
<tr>
<td>Gingival Displacement, Tissue Over Finish Line</td>
<td>Lack of flash beyond the cervical finish line, detected by change of reflection or visible horizontal bur marks on the preparation for ill-defined margins.</td>
<td>Figure 10</td>
</tr>
<tr>
<td>Gingival Displacement, Blood On Impression</td>
<td>Blood, coagulant, or any foreign materials around the cervical finish line.</td>
<td>Figure 11</td>
</tr>
<tr>
<td>Dual Arch, Lack of MIP</td>
<td>No thinning of impression material over occlusal contacts. Detected by holding impression against light source.</td>
<td>Figure 12</td>
</tr>
<tr>
<td>Dual Arch, Unprepared Stops</td>
<td>Lack of unprepared teeth anterior and posterior to the preparation(s).</td>
<td>Figure 13</td>
</tr>
<tr>
<td>Dual Arch, Canine Recorded</td>
<td>Lack of registering the complete maxillary and mandibular canine teeth.</td>
<td>Figure 14</td>
</tr>
</tbody>
</table>
Table 2. Frequency of Observed Errors, Private Practice and Student Breakouts

<table>
<thead>
<tr>
<th>Error Type</th>
<th>Private Practice</th>
<th>Student</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finish Line, Void/Bubble</td>
<td>282</td>
<td>15</td>
<td>297</td>
</tr>
<tr>
<td></td>
<td>24.50%</td>
<td>7.90%</td>
<td>22.10%</td>
</tr>
<tr>
<td>Finish Line, Lack of Wash Material</td>
<td>60</td>
<td>18</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>5.20%</td>
<td>9.50%</td>
<td>5.80%</td>
</tr>
<tr>
<td>Tray, Inadequate Retention of Material</td>
<td>30</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>2.60%</td>
<td>0.00%</td>
<td>2.20%</td>
</tr>
<tr>
<td>Tray, Pressure of Tray On Soft Tissue</td>
<td>290</td>
<td>104</td>
<td>394</td>
</tr>
<tr>
<td></td>
<td>25.20%</td>
<td>54.70%</td>
<td>29.30%</td>
</tr>
<tr>
<td>Material, Inadequate Fusion of Viscosity</td>
<td>121</td>
<td>15</td>
<td>136</td>
</tr>
<tr>
<td></td>
<td>10.50%</td>
<td>7.90%</td>
<td>10.10%</td>
</tr>
<tr>
<td>Material, Void on Preparation</td>
<td>154</td>
<td>19</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td>13.40%</td>
<td>10.00%</td>
<td>12.90%</td>
</tr>
<tr>
<td>Tray, Show Through of Occlusal/Incisal Edges</td>
<td>201</td>
<td>102</td>
<td>303</td>
</tr>
<tr>
<td></td>
<td>17.40%</td>
<td>53.70%</td>
<td>22.60%</td>
</tr>
<tr>
<td>Tray, Cotton Roll Attached</td>
<td>199</td>
<td>22</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>17.30%</td>
<td>11.60%</td>
<td>16.50%</td>
</tr>
<tr>
<td>Gingival Displacement, Retraction Cord Attached</td>
<td>27</td>
<td>23</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>2.30%</td>
<td>12.10%</td>
<td>3.70%</td>
</tr>
<tr>
<td>Gingival Displacement, Tissue Over Finish Line</td>
<td>568</td>
<td>42</td>
<td>610</td>
</tr>
<tr>
<td></td>
<td>49.30%</td>
<td>22.10%</td>
<td>45.40%</td>
</tr>
<tr>
<td>Gingival Displacement, Blood On Impression</td>
<td>176</td>
<td>21</td>
<td>197</td>
</tr>
<tr>
<td></td>
<td>15.30%</td>
<td>11.10%</td>
<td>14.70%</td>
</tr>
<tr>
<td>Dual Arch, Unprepared Stops (Sectional Trays Only)</td>
<td>256</td>
<td>9</td>
<td>265</td>
</tr>
<tr>
<td></td>
<td>25.60%</td>
<td>29.00%</td>
<td>25.70%</td>
</tr>
<tr>
<td>Dual Arch, Canine Recorded (Sectional Trays Only)</td>
<td>135</td>
<td>0</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>13.50%</td>
<td>0.00%</td>
<td>13.10%</td>
</tr>
<tr>
<td>Dual Arch, Lack of MIP (Dual Arch Trays Only)</td>
<td>61</td>
<td>2</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>8.50%</td>
<td>20.00%</td>
<td>8.70%</td>
</tr>
</tbody>
</table>
Table 3. Frequency of Restorations Requested, Private Practice and Student Breakout

<table>
<thead>
<tr>
<th>Restoration Requested</th>
<th>Private Practice</th>
<th>Student</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFM</td>
<td>398</td>
<td>123</td>
<td>521</td>
</tr>
<tr>
<td></td>
<td>34.50%</td>
<td>64.70%</td>
<td>38.80%</td>
</tr>
<tr>
<td>Full Cast</td>
<td>73</td>
<td>47</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>6.30%</td>
<td>24.70%</td>
<td>8.90%</td>
</tr>
<tr>
<td>Zirconia Based</td>
<td>448</td>
<td>12</td>
<td>460</td>
</tr>
<tr>
<td></td>
<td>38.90%</td>
<td>6.30%</td>
<td>34.30%</td>
</tr>
<tr>
<td>EMax®</td>
<td>185</td>
<td>7</td>
<td>192</td>
</tr>
<tr>
<td></td>
<td>16.00%</td>
<td>3.70%</td>
<td>14.30%</td>
</tr>
<tr>
<td>Other</td>
<td>12</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>1.00%</td>
<td>0.00%</td>
<td>0.90%</td>
</tr>
<tr>
<td>Die</td>
<td>37</td>
<td>1</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>3.20%</td>
<td>0.50%</td>
<td>2.80%</td>
</tr>
<tr>
<td>Total</td>
<td>1153</td>
<td>190</td>
<td>1343</td>
</tr>
<tr>
<td></td>
<td>100.00%</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
Table 4. Frequency of Type of Impression Tray Utilized, Private Practice and Student Breakout

<table>
<thead>
<tr>
<th>Tray Type</th>
<th>Private Practice</th>
<th>Student</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Custom</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>0.20%</td>
<td>2.10%</td>
<td>0.40%</td>
</tr>
<tr>
<td>Metal Dual Arch</td>
<td>185</td>
<td>5</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>16.00%</td>
<td>2.60%</td>
<td>14.10%</td>
</tr>
<tr>
<td>Metal Single Arch</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>0.90%</td>
<td>0.00%</td>
<td>0.70%</td>
</tr>
<tr>
<td>No Tray</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.10%</td>
<td>0.00%</td>
<td>0.10%</td>
</tr>
<tr>
<td>Plastic Dual Arch</td>
<td>535</td>
<td>5</td>
<td>540</td>
</tr>
<tr>
<td></td>
<td>46.20%</td>
<td>2.60%</td>
<td>40.10%</td>
</tr>
<tr>
<td>Plastic Single Arch</td>
<td>424</td>
<td>176</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>36.60%</td>
<td>92.60%</td>
<td>44.50%</td>
</tr>
<tr>
<td>Total</td>
<td>1157</td>
<td>190</td>
<td>1347</td>
</tr>
<tr>
<td></td>
<td>100.00%</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
Table 5. Factors Leading to Critical Error, Multiple Logistic Regression Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>df</th>
<th>Chi-Sq.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dentist vs Student</td>
<td>1</td>
<td>17.461</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Preparation Void</td>
<td>1</td>
<td>23.514</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Occlusal Show Through</td>
<td>1</td>
<td>2.950</td>
<td>0.086</td>
</tr>
<tr>
<td>Retraction Cord Attached</td>
<td>1</td>
<td>1.375</td>
<td>0.241</td>
</tr>
<tr>
<td>Blood</td>
<td>1</td>
<td>21.669</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Restoration Requested</td>
<td>4</td>
<td>15.842</td>
<td>0.007*</td>
</tr>
<tr>
<td>Full Arch vs Sectional Tray</td>
<td>1</td>
<td>0.649</td>
<td>0.421</td>
</tr>
<tr>
<td>Single vs Dual Arch Tray</td>
<td>1</td>
<td>13.841</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

* Indicates statistical significance below the p=.05 level.
Table 6. Odds Ratios for Significant Variables from Logistic Regression Data

<table>
<thead>
<tr>
<th>Explanatory Factor</th>
<th>Odds Ratio</th>
<th>95% CIs Lower</th>
<th>95% CIs Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Practitioner</td>
<td>2.79</td>
<td>1.88</td>
<td>4.15</td>
</tr>
<tr>
<td>Preparation Void</td>
<td>2.60</td>
<td>1.84</td>
<td>3.68</td>
</tr>
<tr>
<td>Presence of Blood</td>
<td>2.31</td>
<td>1.67</td>
<td>3.18</td>
</tr>
<tr>
<td>Utilization of Dual Arch Tray</td>
<td>1.68</td>
<td>1.32</td>
<td>2.13</td>
</tr>
<tr>
<td>Restoration Requested</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Die vs. EMax®</td>
<td>0.49</td>
<td>0.23</td>
<td>1.04</td>
</tr>
<tr>
<td>Die vs. Full Cast</td>
<td>0.46</td>
<td>0.21</td>
<td>1.03</td>
</tr>
<tr>
<td>Die vs. PFM*</td>
<td>0.38</td>
<td>0.18</td>
<td>0.77</td>
</tr>
<tr>
<td>Die vs. Zirconia Based*</td>
<td>0.37</td>
<td>0.18</td>
<td>0.76</td>
</tr>
<tr>
<td>EMax® vs. Full Cast</td>
<td>0.95</td>
<td>0.58</td>
<td>1.55</td>
</tr>
<tr>
<td>EMax® vs. PFM</td>
<td>0.77</td>
<td>0.54</td>
<td>1.09</td>
</tr>
<tr>
<td>EMax® vs. Zirconia Based</td>
<td>0.76</td>
<td>0.54</td>
<td>1.07</td>
</tr>
<tr>
<td>Full Cast vs. PFM</td>
<td>0.81</td>
<td>0.53</td>
<td>1.25</td>
</tr>
<tr>
<td>Full Cast vs. Zirconia Based</td>
<td>0.80</td>
<td>0.51</td>
<td>1.25</td>
</tr>
<tr>
<td>PFM vs. Zirconia Based</td>
<td>0.99</td>
<td>0.75</td>
<td>1.29</td>
</tr>
</tbody>
</table>

* Indicates statistical significance between groups
Figure 1. Impression Evaluation Form

<table>
<thead>
<tr>
<th>Type of tray used:</th>
<th>Adhesive used:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal stock</td>
<td>□ Yes □ No</td>
</tr>
<tr>
<td>Plastic stock</td>
<td></td>
</tr>
<tr>
<td>Custom</td>
<td></td>
</tr>
<tr>
<td>Plastic dual arch</td>
<td></td>
</tr>
<tr>
<td>Metal dual arch</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of tray used:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ant quad</td>
</tr>
<tr>
<td>Post quad</td>
</tr>
<tr>
<td>Full arch</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of impression material used:</th>
<th>Blue registration sent:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastomer</td>
<td>□ Yes □ No</td>
</tr>
<tr>
<td>Alginate substitute</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Materials combination:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body/Wash</td>
</tr>
<tr>
<td>Putty/Wash</td>
</tr>
<tr>
<td>Monophase</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of units requested:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single crown x 2-4 FPD</td>
</tr>
<tr>
<td>5+ FPD</td>
</tr>
<tr>
<td>Inlay/Onlay</td>
</tr>
<tr>
<td>Anterior</td>
</tr>
<tr>
<td>Canine</td>
</tr>
<tr>
<td>Premolar</td>
</tr>
<tr>
<td>Molar</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Errors in the finish line:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voids/Bubbles</td>
</tr>
<tr>
<td>Lack of wash material</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Errors in the tray/material:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate retention</td>
</tr>
<tr>
<td>Pressure of tray on soft tissue</td>
</tr>
<tr>
<td>Inadequate fusion of viscosity</td>
</tr>
<tr>
<td>Lack of polymerization</td>
</tr>
<tr>
<td>Void on the preparation</td>
</tr>
<tr>
<td>Show through of occlusal/incisal edges</td>
</tr>
<tr>
<td>Cotton roll attached</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Errors with gingival displacement/hemostasis:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retraction cord attached</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Errors in dual arch technique:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of MIP</td>
</tr>
<tr>
<td>Unprepared stops present</td>
</tr>
<tr>
<td>Canine recorded</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Restoration requested:</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFM (HN)</td>
</tr>
<tr>
<td>PFM (N)</td>
</tr>
<tr>
<td>PFM (BM)</td>
</tr>
<tr>
<td>Full Cast</td>
</tr>
<tr>
<td>PFZ</td>
</tr>
<tr>
<td>Mono Zr</td>
</tr>
<tr>
<td>Captek</td>
</tr>
<tr>
<td>Empress</td>
</tr>
<tr>
<td>E-max</td>
</tr>
<tr>
<td>Feldspathic</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>
Figure 2. Finish Line, Void/Bubble
Arrows indicate site of error
Figure 3. Finish Line, Lack of Wash Material
(a) Minimally acceptable appearance, (b) Unacceptable appearance
Figure 4. Tray, Inadequate Retention
Arrows indicate site of error
Figure 5. Tray, Pressure of Tray on Soft Tissue
Arrows indicate site of error
Figure 6. Tray, Show Through of Occlusal/Incisal Edges
Arrows indicate site of error
Figure 7. Material, Inadequate Fusion of Viscosity
Arrows indicate site of error
Figure 8. Material, Void on Preparation
Arrows indicate site of error
Figure 9. Material, Lack of Polymerization
(a) Undisturbed material, (b) Material tacky to the touch
Figure 10. Gingival Displacement, Tissue Over Finish Line
Arrows indicate site of error
Figure 11. Gingival Displacement, Blood on Impression
Arrows indicate site of error
Figure 12. Dual Arch, Lack of MIP
(a) MIP recorded acceptably (b) MIP not recorded
Figure 13. Dual Arch, Unprepared Stops
Arrows indicated prepared abutment teeth
Figure 14. Dual Arch, Canine Recorded
REFERENCES


44. Ceyhan JA, Johnson GH, Lepe X, Phillips KM. A clinical study comparing the three-dimensional accuracy of a working die generated from two dual-arch trays and a complete-arch custom tray. J Prosthet Dent 2003;90(3):228-34.


