RESISTANCE FORM OF LITHIUM DISILICATE FULL COVERAGE RESTORATIONS MILLED WITH 3-AXIS AND 5-AXIS MILLING UNITS

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

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Distribution Statement

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To my supportive wife Brooke, and parents, Timothy and Laureen Fitzharris.

Thank you to Madeleine Domenech for her assistance with this research.

ABSTRACT

RESISTANCE FORM OF LITHIUM DISILICATE FULL COVERAGE RESTORATIONS MILLED WITH 3-AXIS AND 5-AXIS MILLING UNITS

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Introduction: Caputo and Standlee stated “resistance form is the most important factor of restoration success.” Currently, the most popular means of fabricating a CAD/CAM full coverage restoration is by subtractive manufacturing utilizing either a 3 or 5-axis milling unit. There is a lack of literature to support whether one or the other produces restorations with superior resistance form. Objective: To compare the resistance form of lithium disilicate restorations milled with a 3-axis (Sirona inLabMCXL) or 5-axis milling unit [Amman Girbach (AG) Ceramill Motion 2]. It was hypothesized the 5-axis unit would provide superior resistance form. Materials and Method: A chrome cobalt master die was scanned by a 3-axis (Sirona Omnicam) and a 5-axis system (AG Ceramillmap400). A lithium disilicate restoration was digitally designed using each system’s digital software (Sirona CEREC 4.3 and Exocad) and milled ten times (N=10). The 20 restorations were polished, crystalized, and individually cemented on the master die with calcium hydroxide (Dycal) using a cementation jig under 10lbs of pressure. They were loaded with an off axis load at crosshead speed of 0.02mm/sec until dislodgement (MTS Insight Universal Testing Machine) and the peak loads were recorded.

Results: The results revealed a median peak load of 114.1N for the 3-axis system and 120.7N for the 5-axis system. The p-value was 0.23. Statistical significance could not be determined due to the wide range of failure loads for each milling unit. Conclusion: This study found no significant difference in resistance form of full coverage lithium disilicate restorations milled with a 3 or 5 axis milling machine.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

INTRODUCTION

All ceramic crowns have been utilized in dentistry since the early 1900s[1] and are becoming more popular due to increasing esthetic demands by the patient and improvements in material properties. Glass ceramic, though highly esthetic, is limited by its brittle nature. Through the addition of crystalline particles, the flexural and fatigue strength of the glassy matrix has greatly improved. The crystalline particles commonly used are lucite and lithium disilicate. In 2005 and 2006, Ivoclar released two lithium disilicate based glass ceramics, IPS e.maxPRESS and IPS e.maxCAD. The products have shown to be esthetic and have a high flexural strength of 360-400MPa.

The ability to use lithium disilicate as a CAD (Computer Aided Design) product further increased its popularity. Today, restorations are readily milled either chairside or within the laboratory using a 3-axis or 5-axis milling unit. This avoids a physical impression and several laboratory steps necessary to fabricate the restoration. With these more efficient methods of manufacturing, comes questions about the clinical quality and longevity of the restorations. Much of the clinical success is associated with the internal fit of the restorations. One of the major factors that can affect internal adaptation of milled restorations is the access of the milling burs to the internal aspect of the restorations.

In 2014, Hogan[2] compared the internal gap, or cement space, found under lithium disilicate crowns fabricated using 3-axis and 5-axis milling systems. This study is a continuation of Hogan's research; comparing the resistance form of CAD/CAM restorations milled using a 3-axis and 5-axis milling unit.

BACKGROUND

PRINCIPLES OF TOOTH PREPARATION

The basic principles of tooth preparation take into account the esthetic, biologic, and mechanical demands of the tooth being restored. Esthetic considerations depend on the location of the tooth in the arch, the type of prosthesis being fabricated, the contour, reduction of tooth structure, and margin placement of the prosthesis, as well as the doctor's and patient's expectations. Biologic factors include the pulpal and periodontal health, and conservation of tooth structure. Mechanical considerations involve the structural durability of the tooth, masticatory forces applied, cement strength, as well as the retention and resistance form of the preparation.

Resistance form is defined as "the features of a tooth preparation that enhance the stability of a restoration and resist the dislodgement along an axis other than the path of placement."[3] Resistance to off-axis forces applied to a tooth can be related to crown fabrication and/or tooth preparation design.[4] Caputo and Standlee[5] emphasized that resistance form was the most important factor for restoration success.

Merle H. Parker and colleagues published a series of articles in which they evaluated resistance form and its effects. In one of the earlier articles, Parker and colleagues[6] stated that a preparation provided resistance form if the side of the preparation interfered with the arc of the casting pivoting about a point on the opposite side of the preparation. They also discussed the "on-off" nature of resistance - that for each point there either is resistance or there is not. Based on the arc of rotation and the "on-off" concept they went on to further discuss and define the concept of the "limiting taper." Limiting taper is the average taper of a line perpendicular to a radius starting from any point of rotation on the preparation margin. Therefore, if a point on the preparation has a taper less than the limiting taper it will have resistance form.

In a 1991 study, Parker and colleagues[7] evaluated the "on-off" nature of resistance form in prepared incisors, canines, premolars, and molars. They again concluded that resistance form is a discontinuous function in which there is an exact height in which the preparations switch from having no resistance form to having resistance form and that it was determined by the limiting taper. For prepared teeth, they found 96% incisors, 92% canines, 81% premolars, and 46% molars had resistance form. In 1993, Parker and colleagues[8] expanded on their "on-off" nature of resistance form and mathematically determined the limiting taper (T), to equal one-half the arcsine of height to base ratio ($T = 1/2\arcsin(H/B)$), which should be the standard of minimal acceptability. Using this equation, it was mathematically determined that the limiting tapers were 29° for incisors, 33° for canines, 10° for premolars, and 8.4° for molars.

In a natural progression of the theoretical, an analysis was completed of dislodged crowns and retainers and resistance form in 1997.[9] A total of 44 uncemented castings were included; 28 molars, 15 premolars, and 1 incisor. Of the castings, 95% of the molar castings and 93% of the premolar castings lacked resistance form. Only 1 incisor and 3 other castings had resistance form.

With the "on-off" concept, resistance form could be tested as simply as with a finger roll of the crown off the die.[7] If the crown easily rolls off the die with tipping pressure from fingers, it lacks resistance form. Various other methods to analyze resistance form were discussed by Parker in 2004.[10] He found that uneven margins can make even a preparation with parallel walls lack resistance form. He also discussed the rounding of sharp occlusal surfaces will decrease resistance from. Methods that can enhance resistance form include crown lengthening, shoulder margins, proximal boxes or grooves, occlusal isthmus, pins or posts.[3, 11, 12, 13, 14]

Instead of using the "on-off" concept, Weed[15] quantified resistance form by loading posterior full coverage cast restorations on an Instron testing machine and recording the force required to dislodge the restorations. Machined stainless steel dies were prepared with 3.5mm of height and convergence angles of 10, 13, 16, 19, and 22 degrees. The samples were loaded at an angle of 60 degrees at a crosshead speed of 0.5mm per minute. To verify displacement of the crowns, the results from the testing machine were used along with visual observation to confirm unseating. The castings with 19 or less degrees of convergence were deformed and those with 22 degrees were not. He concluded that preparations with a convergence angle of less than 19 degrees could be considered to have adequate resistance form.

It has been determined that 96% of anterior incisors when prepared for full coverage restoration, have resistance form.[7] One of the critical factors for adequate resistance form lies in the favorable occlusal cervical to faciolingual dimension ratio of incisors. When prepared, the incisor's overall height compared to its width provides resistance form, making the need for auxiliary grooves often unnecessary. Parker and colleagues[7] determined that the OC/FL ratio should be 0.4 or higher for all teeth.

Gerald J. Chiche[16] describes the parameters of the ideal preparation for an all ceramic anterior restoration in his textbook, *Esthetics of Anterior Fixed Prosthodontics.* The ideal incisal reduction ranges from 2 mm to one third the anatomic crown[17] taking into consideration the thickness of the incisal edge. If the incisal edge is too thin, it should be flattened and reduced for incisal support as long as the reduction does not exceed one third the anatomic crown. Short preparations should be avoided because they do not provide enough support for the ceramic.

Also, these preparations lack resistance form, subjecting the crown to tipping forces and dislodgement.

Studies have shown that for an all ceramic restoration, a shoulder margin provides the greatest strength for ceramic.[16] However, if the restoration is to be cemented with resin cement, other laboratory studies indicate there is no significant reduction in strength when comparing a shoulder margin to a chamfer finish line.[5] Line angles of a preparation should be smooth. Sharp internal line angles create focal tensile stress areas that can cause fracture of the ceramic. Facial reduction should be at least 1.0 mm and lingual reduction 1.0-1.3 mm with an absolute minimum of 0.8 mm for adequate thickness of ceramic for esthetics and strength of the material.[16]

CAD/CAM TECHNOLOGY

Dental companies are developing CAD/CAM systems that offer both an optical scanner for digital intraoral impressions as well as the ability to mill restorations chair-side. Cerec by Sirona is one of the systems available today. Other direct acquisition systems available are the iTero System (Cadent) and LAVA Chair-side Oral Scanner (Brontes).[18] Some of the laboratory milling machines that do not have their own intraoral scanning device include: the Everest (KAVO) and the Ceramill (Amann Girrbach). These have the added benefit of being 5-axis units, versus the 3-axis Cerec chair-side and inLab milling units.

The number of axes in a milling machine can vary from two to nine. In 3-axis milling machines, the bur is usually in the vertical or “z” axis and the chuck holding the material to be milled can move in the transverse and longitudinal axis. In a 5-axis machine, there is still present the X, Y, Z axes as well as the C and B axis. The “C” axis is normally associated with the rotation of the product and the “B” axis is associated with tilting of the product.[19] The advantages of more axes include: increased accuracy, expanded production capacity, machining of more complex parts, better surface finish, and allows the tool to reach difficult places.[20]

Hamza *et al* (2013) compared a 3-axis milling machine to a 5-axis milling machine.*[21]* In this study, zirconia and lithium disilicate crowns were milled with the Cerec and Everest systems and the marginal discrepancies were evaluated. All restorations were determined to have a clinically acceptable marginal fit, however the crowns milled with the Cerec system had significantly higher marginal gap mean values than those milled with the Everest. They concluded the fabrication technique affected the marginal fit of CAD/CAM ceramic restorations, regardless of ceramic type. It was rationalized that 5-axis milling machines have improved productivity and precision by using the machine's additional axes. These findings were consistent with a study done by Bosch *et al*[22] and a review by Alghazzawi.[23] They also concluded that the 5-axis milling units were the most accurate method of producing CAD/CAM restorations.

CAD/CAM technology is the future of restorative dentistry. The advantages include speed, ease of use, digital imaging, and improved quality. Due to increasing popularity, a greater variety of restorative materials are being developed which are compatible with today's milling systems. A partial listing of available materials include: monolithic blocks of feldspathic porcelain, leucite-reinforced glass-ceramic, lithium disilicate glass ceramic, zirconia, PMMA, and composite resin blocks for both final and temporary restorations.[24]

LITHIUM DISILICATE

In 1998, Ivoclar introduced IPS Empress 2, a lithium disilicate ($Li_2Si_2O_5$) glass-ceramic as a solution for the need of a high strength and a highly esthetic glass-ceramic. IPS Empress 2 had a predominant crystalline phase of lithium disilicate with a lower volume of lithium orthophosphate crystals than previous dental porcelains.[25,26] The interlocking structure of the elongated lithium-disilicate crystals improved the elastic modulus over the leucite-based IPS Empress 1. The interlocking structure of the lithium-disilicate crystals plays a major role in hindering crack propagation and elevating the flexural strength and fracture toughness of IPS Empress 2. In the presence of cracks, the fiber-like crystals impart crack growth resistance by entrapping them resulting in a higher Weibull modulus material.[27]

Then in 2005, Ivoclar introduced a new and improved lithium disilicate glass-ceramic, IPS e.maxPRESS. IPS e.maxPRESS was developed with smaller crystals increasing flexural strength and fracture toughness by 10%, and provided greater translucency when compared to IPS Empress 2.[28] The following year, in 2006, Ivoclar introduced IPS e.maxCAD, a monolithic block for milling units. The favorable high strength properties of fully crystallized lithium disilicate make it difficult to mill so it is milled in a partially crystallized form, or "blue state," which reduces wear of the milling burs.[29] Following the milling procedure, the restorations are tempered to complete crystallization of the lithium disilicate that imparts the final shade and desired high strength. The IPS e.maxCAD has a slightly lower flexural strength of 360±60 MPa compared to its heat-pressed counterpart, IPS e.maxPRESS at 400 ±40 MPa. It also has a lower fracture toughness of 2.0-2.5 $\mathrm{MPam}^{0.5}$ compared to Press 2.5-3.0 MPa. The modulus of elasticity of 95±5 GPa and coefficient of thermal expansion of $10.15\pm0.4\ \mathrm{x}10^{-6}\mathrm{K}^{-1}$ are the same for both e.maxPRESS and CAD.[27]

Lithium disilicate is a favorable material for all-ceramic restorations because it provides esthetics, light translucency, biocompatibility, high strength, and high fracture toughness.[30,31, 32, 33,34] Recent literature supports the use of all-ceramic restorations, citing a

90% success rate irrespective of the observation time or materials used.[35] Gehrt *et al* (2013) reported a cumulative survival rate of 97.4% after 5 years and 94.8% after 8 years of clinical service for IPS e.max all-ceramic restorations.[36] Guess PC *et al* (2010) also reported low failure rates (100% survival) for all-ceramic restorations citing their improved flexural strength as well as the homogeneity of the material.[33] The benefit of a monolithic material is that it is homogenous and dense, i.e. without porosity or voids, which maximizes its' physical properties.[24]

With the increasing use of digital design and milling systems, the availability of lithium disilicate as a CAD ingot has obvious benefits. The use of CAD/CAM is more economical due to a reduction in fabrication of steps, less waste of material and a reduction in labor overall.[25] However, the physical properties of press versus CAD are not the same as noted in the previous paragraph. Heat-pressed lithium disilicate has shown to have a higher Weibull modulus than the CAD form. This means that CAD techniques may produce specimens with lower reliability.[37] Other studies have explained that some of the differences could stem from the machining process. Machining the ceramic with diamond-coated instruments induces surface damage in the form of microcracks. Pores from processing of the material, combined with machining induced flaws, may induce early crack formation and reduce the fracture strength.[38,39] Bindl and Mormann (2005) also showed that milled restorations had poorer internal fit compared to press; with 75 μm internal gap for press versus 116 μm for CAD.[40]

While Gehrt *et al* (2003) concluded that location of the restoration affected success of the all-ceramic restorations, the majority of studies contradict this.[36] Full coverage restorations on molars have been found to have greater risk for failure than anterior and premolar teeth.[33,41,42,43,44] Goodacre *et al* (2003) listed clinical fracture rates for all-ceramic restorations as

21% for molars, 7% for premolars, and 3% for anterior teeth.[45] **Error! Bookmark not defined.** The posterior region is subject to greater masticatory forces which accounts for the higher failure rates of molar full coverage restorations. This is often compounded with inadequate occlusal surface reduction of prepared teeth leading to thin material. The minimum proximal thickness of lithium disilicate is 0.8 mm. Baltzer (2008) analyzed 50 anterior and 50 posterior preparations and found on average only 1.1 mm occlusal reduction of posterior teeth and 0.9 mm incisal reduction for anterior teeth; far less than the ideal 1.5-2.0 mm occlusal reduction recommended by the manufacturer.[38] Malament (1999), while agreeing that location was a factor in survival, did not believe that the thickness of the restoration was related to survival. He argued that in ceramic science a thicker material has greater strength. However, at some point, the increase in thickness offered little improvement within the limits of stresses generated by masticatory muscles.[46] In general, it is better to have thicker glass-ceramic restorations because as the square of the thickness increases, so does the load required to cause bulk fracture.

INTERNAL ADAPTATION AND CEMENTATION

In 1960 Jorgensen stated there were four major factors that affected cementation: preparation taper, cement viscosity, placement force, and available cement space.[47] Holmes et al[48] defined the internal gap, or cement space, as the perpendicular measurement from the axial wall of the preparation to the internal restoration surface.

Controversy surrounds what is considered the ideal internal gap for a ceramic restoration.[49,50,51,52,53] Studies have shown that restorations with minimal internal gap may not completely seat because of the hydrostatic pressure generated during seating. In 1994, Wilson stated that increased axial space decreased “spring-back” of the crown after the seating force was removed.[54] Excessively thin layers of resin cement are subject to extreme stresses which may cause loss of adhesion. Overly thick layers are detrimental to the bond as well. Voids may result from air entrapment during seating and the greater volume of resin may be subject to more forces as a result of polymerization shrinkage. One of the limitations of CAD-CAM technology, especially with early milling machines, is the diameter of the milling burs that creates over-milling of the intaglio surface of the restoration and therefore, a larger internal cement space.[55,56,57,58,59,60,61,62,63,64,65]

Most of the literature agrees on a film thickness of 50-100 μm as an acceptable space for resin cement.[66,67,68] This would theoretically provide an ideal film of luting material that could be homogeneously distributed along the entire prepared surface and of sufficient thickness to prevent wear at the margins and preserve efficacy of adhesion.[68]

Hogan[2] compared the internal gap of maxillary central incisor crowns fabricated using the Amman Girrbach (5-axis) and Cerec (3-axis) CAD/CAM systems. She found the mean internal gap of the Girrbach milled crowns to be 110 µm on the buccal, 180 µm on the incisal, and 193 µm on the lingual. The mean internal gap of the Cerec crowns were 108 µm on the buccal, 192 µm on the incisal, and 37 µm on the lingual.[1] All of these means fell outside of the ideal range of cement thickness for resin cements (50-100 µm).[26,27] The only area that was under milled was the lingual surface of the Cerec crowns; all other areas were over milled.

SUMMARY AND PURPOSE

The trend in dentistry is clear; digital CAD/CAM systems are here to stay. Improvements will continue, but 3-axis and 5-axis machining systems are what are being utilized today. These have the benefit over lost-wax, heat-pressed systems in high production, speed, reliability, and repeatability aspects. However, there is some pause for concern on how well these systems can produce a restoration that has adequate resistance form.

The anterior preparation form is arguably more challenging for a CAD/CAM system to produce a well-adapted restoration due to the thin incisal edge and curvature of the lingual surface. The notion that these shortcomings can be overcome by resin adhesion is not proven in literature. In fact, many studies have shown that there are limitations to resin adhesion from a thin film thickness to an over-bulked thickness. If CAD/CAM processes continue to create restorations with “over-milled” intaglio surfaces this would lead to greater thickness of resin cement and presumably lower resistance form of the restoration.

This study is a continuation of Hogan’s[2] research that evaluated the internal gap thickness of milled ceramic restorations. The purpose of this study is to compare the resistance form of anterior milled lithium disilicate full coverage restorations fabricated using a 3-axis and 5-axis milling unit.

MATERIALS AND METHODS

1. Digital STL files of an ideal #8 crown preparation, and all ceramic crown were attained from previous research completed at the Naval Postgraduate Dental School by Jacqueline Hogan, DDS, MS in 2014. The crown preparation was milled in cobalt chrome and polished; this served as the master die. The crown was milled in lithium disilicate and served as the master crown.

2. **Test Group 1 (3-axis System):**

   The master die was sprayed with Cerec Optispray (Sirona Dental Systems, GmbH; Bensheim, Germany) to reduce the reflective nature of the metal and scanned with the Cerec Omnicam scanner (Sirona), to generate a digital die. The master crown was then seated on the master die and scanned again with the Omnicam. The two STL files were merged and a test crown was digitally designed in the Cerec 4.3 software (Sirona). The cement spacer was left at the default of 50μm and cameo surface of the master crown was duplicated using the "Biogeneric Copy" feature in the software. The digital crown was then exported to the inLabMCXL 3-axis milling unit (Sirona) and 10 lithium disilicate e.maxCAD crowns (Ivoclar) were milled in the presintered state using the "1-step" milling mode.[69] New "12S step" and "12S cylindrical pointed" diamond burs were used for each restoration to eliminate bur wear as a possible variable.

3. **Test Group 2 (5-axis System):**

   The same process was completed with the Ceramill map400 scanner (Amann Girrbach AG; Koblach, Austria) and Exocad software (Exocad Dental 2015.07). The cement spacer was left at the default of 80µm and the cameo surface of the master crown was duplicated in the test crown design. The digital crown was then exported to the Ceramill Motion 2 5-axis milling unit (Amann Girrbach AG; Koblach, Austria) and 10 lithium disilicate IPS e.maxCAD crowns (Ivoclar Vivadent, Inc.; Amherst, NY) were milled in the presintered state. A new set of Diamant diamond burs (size 1.8mm, 1.4mm, 1.0mm, and HD) were used to mill each restoration to eliminate the variable of bur wear.

4. The sprue was removed from each crown using a fine diamond bur (Henry Schein, Melville, NY) and the crowns were uniformly polished using rubber polishers (Red and yellow Dialite LD, Brassler, Savannah, GA).

5. The presintered crowns were then crystallized in a Programat P700/G2 (Ivoclar Vivadent, Inc.; Amherst, NY) porcelain furnace. The crystallization process involves a two-stage firing process of the porcelain under vacuum to complete the crystallization of lithium disilicate.

   The crystallization program for IPS e.maxCAD is:

   a. Stand-by temperature: 757ºF
   b. Closing time: 6 minutes
   c. Heating rate t_1: 162ºF
   d. Firing temperature T_1: 1508ºF
   e. Holding time H_1: 10 seconds
   f. Heating rate t_2: 54ºF/minute
   g. Firing temperature T_2: 1544ºF

    h. Holding time H_2: 7 minutes
    i. Vacuum 1: 1_1 820ºF, 12 1508ºF
    j. Vacuum 2: 2_1 840ºF, 22 1540ºF
    k. Long-term cooling L: 1292ºF
    l. Cooling rate t: 0ºF/minute

6. All 20 restorations were individually luted to the single metal master die and load tested. Cementation and loading of the groups 1 and 2 were alternated until all the crowns were tested. The cementation and loading was conducted as follows:

7. The intaglio of the test crown and master die were scrubbed with rubbing alcohol using a microbrush for 15 seconds and allowed to dry. Dycal Calcium hydroxide (Dentsply, York, PA) was mixed for 5 seconds and uniformly applied to the intaglio of the crowns for 5 seconds and seated on the master die. The crown was immediately subjected to a 5kg cementation force using a cementation jig and the calcium hydroxide allowed to set for 20 minutes.[70] The excess cement was removed with a curette and a visual inspection completed to ensure full seating of the crown.

8. The master die was then secured in a custom printed titanium jig that positioned the crown 45 degrees off axis from the loading force. The crowns were loaded on the Instron testing machine (Instron Corp., Canton, Mass) with a sheer pin at a crosshead speed of 0.02mm per second. The pin contacted the crown on the lingual concavity 3mm apical to the incisal edge.

9. The peak load before crown unseating was recorded (Newtons) by the Instrom testing machine. The moment of failure was also confirmed by an observer who visualized when the lingual margin was opened. The peak loads were recorded and the results analyzed.

RESULTS

The raw data is listed in Table 1. Averages are listed in Table 2. A graph comparing the two medians is shown in Figure 1. No tests were dropped. The t-test revealed a median peak load of 114.1N for the 3-axis system and 120.7N for the 5-axis system. The 3-axis system yielded a minimum of 81.9N and a maximum of 131.2N with an interquartile range of 99.8N to 121.6N. The 5-axis system yielded a minimum of 100.9N and a maximum of 129.6N with an interquartile range of 112.4N to123.6N. The p-value was 0.23 with no significant difference between the groups.

Scan #	**Sirona (3-axis) Peak Load (Newtons)**	**Amann Girbach (5-axis) Peak Load (Newtons)**
1	81.99	120.716
2	120.464	126.544
3	114.893	124.022
4	111.641	120.625
5	95.91	112.523
6	81.91	108.455
7	122.014	120.698
8	113.369	112.385
9	125.463	129.607
10	131.187	100.943

Table 1: Raw data

3-Axis:		**5-Axis:**	
Min.	81.9	Min.	100.9
1st Qu.	99.8	1st Qu.	112.4
Median	**114.1**	**Median**	**120.7**
3rd Qu.	121.6	3rd Qu.	123.2
Max.	131.2	Max.	129.6

Table 2: Averages

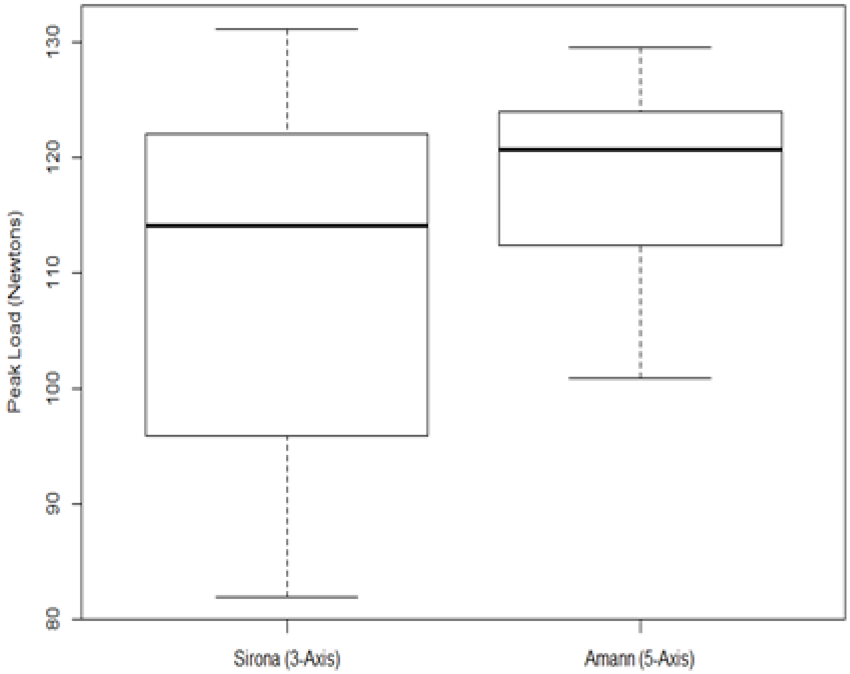

Figure 1: Graph of peak loads

DISCUSSION

One might assume the 5-axis mill produces restorations with a more intimate adaptation due to the higher median peak load. However, statistical significance could not be determined due to the wide range of failure loads for each milling unit.

Inconsistent values could have been attributed the study design. Some flaws of the study include:

1. Lithium disilicate restorations are typically bonded to teeth with a resin cement. In this study they were cemented with calcium hydroxide. It provided a week enough adherence to allow for dislodgement before the restoration fractured or the die deformed. Bonding would have likely increased the peak loads for both the 3 and 5 axis systems.
2. Properly mixed calcium hydroxide calls for equal amounts of base and catalyst. In this study a precise 1:1 ratio was not confirmed. Small differences in the two parts may have led to the inconsistent results.
3. The test die was made of cobalt chrome. It has a much higher modulus of elasticity than dentin. A lack of flexture in the die may have affected the results of the study.
4. The cameo surface of the restorations were hand polished. The degree of polish was not standardized between restorations. A restoration with a rougher finish would have likely engaged the sheer pin more readily and been dislodged with a lower peak load.
5. In a class I dental occlusion the average angle by which a maxillary and mandibular incisor contact is 135 degrees. In this study, the restorations were loaded at 45 degrees to provide more of an unseating force. This allowed for dislodgment of the restoration before it fractured or the master die deformed.

CHAPTER VI: CONCLUSION

In conclusion, this study found no significant difference in resistance form of full coverage lithium disilicate restorations milled with a 3 or 5 axis milling machine. This information can be useful for institutions looking to buy a CAD/CAM system. The decision should be based on other factors, such as initial purchasing and maintenance costs, customer support, or space requirements. In addition, further well designed studies are needed to compare the resistance form of restorations produced using the two systems.

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