CLINICAL COMPARISON OF WEAR CHARACTERISTICS OF CONVENTIONAL AND BULK-FILL RESIN COMPOSITES OVER TIME

Eduard S. Epure

A thesis submitted to the faculty at the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Science in the Department of Operative Dentistry in the School of Dentistry

Chapel Hill
2017

Approved by:
Ricardo Walter
Lee W. Boushell
André V. Ritter
Ibrahim Duqum
ABSTRACT

Eduard S. Epure: Clinical Comparison of Wear Characteristics of Conventional and Bulk-Fill Resin Composites Over Time
(Under the direction of Ricardo Walter)

**Objective:** To comparatively assess the vertical and volume wear of a conventional incremental-fill and a novel bulk-fill nanocomposite using an indirect method (3D analysis of gypsum replicas) and a novel direct method (intraoral scanner), in parallel.

**Methods:** Each patient recruited for this randomized, controlled clinical trial received one- or two-pairs of Class II restorations using an incremental-fill (Filtek Bulk Fill Posterior, 3M ESPE) and a bulk-fill (Filtek Supreme Ultra, 3M ESPE) resin composite. Baseline and 6-month recall impressions were taken with conventional VPS material (Imprint 3, 3M ESPE) and with an intraoral scanner (3M True Definition, 3M ESPE). Gypsum replicas of the conventional impressions were digitized using a laboratory scanner (Lava Scan ST, 3M ESPE). Vertical wear and volume loss for each material and wear-measuring method was calculated.

**Results:** Premolars restored with the bulk-fill resin composite had a statistically significant greater mean depth loss (17±8 μm) versus the incremental-fill group (11±5 μm) (p=0.043). Measurements made with the direct method had good to excellent agreement with the indirect method (ICC 0.734 – 0.997).

**Conclusion:** Within the limitations of this study, the intraoral scanner used may be suitable for clinical assessment of wear. Three-body abrasive wear of Filtek Bulk Fill Posterior (3M ESPE) was greater than that of Filtek Supreme Ultra (3M ESPE) in the premolar group.
To my loving parents, for always pushing me to become a better person, for believing in my dreams and for their unconditional love.

To my MacBook Pro, whose hard drive did not fail during the redaction of this thesis.
ACKNOWLEDGEMENTS

I am very thankful to Ricardo Walter for offering me the opportunity of participating in exciting clinical research. This study could not have been accomplished without exceptional mentoring provided by Ricardo Walter, Lee Boushell, André Ritter, Ibrahim Duqum, Ralph DeLong, and Terry Donovan. I am grateful for the kind assistance of Alex Fok, Bonita VanHeel, Wendy Lamn, Barbara Walton, Christopher Weisen and Cathy Zimmer. I would also like to thank Rolf Halvorson and 3M™ for providing the materials for this research project.
TABLE OF CONTENTS

LIST OF TABLES ........................................................................................................ viii
LIST OF FIGURES ........................................................................................................ ix
LIST OF ABBREVIATIONS .......................................................................................... x
CHAPTER 1: LITERATURE REVIEW ............................................................................. 1
  1.1. Introduction ........................................................................................................ 1
  1.2. Fundamental Wear Mechanisms ....................................................................... 1
    1.2.1. Abrasive wear ............................................................................................. 2
    1.2.2. Surface fatigue wear .................................................................................. 3
    1.2.3. Corrosion wear / tribochemical wear / dental erosive wear ..................... 3
    1.2.4. Adhesive wear .......................................................................................... 3
  1.3. Dental Terminology ........................................................................................... 4
  1.4. Location-based wear nomenclature for posterior restorations ......................... 5
  1.5. In vitro wear measurements ............................................................................. 5
  1.6. In vivo wear measurements ............................................................................. 6
  1.7. Methods for evaluating in vivo wear .................................................................. 6
    1.7.1. Qualitative methods .................................................................................. 6
    1.7.2. Semi-quantitative methods ...................................................................... 7
    1.7.3. Quantitative methods ............................................................................... 8
    1.7.4. Indirect quantitative methods ................................................................... 11
    1.7.5. Direct quantitative methods .................................................................... 11
  1.8. Accuracy of digital impression devices ............................................................ 14
1.8.1. Single tooth accuracy of intra-oral impressions ........................................ 14
1.8.2. Multiple-unit accuracy of intra-oral digital impressions .......................... 14

1.9. Wear of resin composite restorations .......................................................... 17
1.9.1. Historical perspective on the clinical wear of posterior resin composites .... 17
1.9.2. Clinical wear of resin composites measured with 3D digital mapping ........ 19

1.10. Wear of enamel ......................................................................................... 24
1.11. Bulk-fill resin composites ......................................................................... 25

CHAPTER 2: MANUSCRIPT ............................................................................... 26

2.1. Introduction ................................................................................................. 26

2.2. Material and methods ................................................................................ 27
2.2.1. Research Study population ...................................................................... 27
2.2.2. Inclusion criteria ..................................................................................... 28
2.2.3. Exclusion criteria .................................................................................... 28
2.2.4. Restoration placement ............................................................................ 29
2.2.5. Data collection and recall ....................................................................... 30
2.2.6. Wear analysis ........................................................................................ 30
2.2.7. Statistical analysis ................................................................................ 31

2.3. Results ........................................................................................................ 32

2.4. Discussion .................................................................................................. 35
2.4.1. Limitations ............................................................................................. 38

2.5. Conclusion .................................................................................................. 40

TABLES ............................................................................................................. 42

FIGURES ........................................................................................................... 45

REFERENCES .................................................................................................... 46
**LIST OF TABLES**

Table 1: Resin composite systems used .......................................................... 42

Table 2: Measured outcomes of Class II restorations after 6-month recall ........... 43

Table 3: Measured outcomes of Class II restorations in premolars after 6-month recall .......... 44

Table 4: Measured outcomes of Class II restorations with varying intensity of occlusal contacts after 6-month recall .............................................................. 44
LIST OF FIGURES

Figure 1: Various types of wear on a posterior tooth and restoration........................................ 45

Figure 2: Leinfelder standards for cast evaluation........................................................................ 45
LIST OF ABBREVIATIONS

CT: computed tomography
OCA: occlusal contact area wear
CFA: contact free area wear
CFOA: contact free occlusal area wear
FCA: functional contact area wear
ICC: intraclass correlation coefficient
LVDT: linear variable displacement transducer
SEM: scanning electron microscopy
RMS: root-mean-square
SOD: School of Dentistry
STL: stereolithography
UNC: University of North Carolina
USPHS: United States Public Health Service
VPS: vinyl polysiloxane
CHAPTER 1: LITERATURE REVIEW

1.1. Introduction

Wear of posterior resin composites was once considered a major concern.[1] However, changes in formulation such as reduction in filler size have led to a substantial reduction in wear. Indeed, recent microhybrid and nanofilled resin composites wear at a rate similar to that of enamel.[2] While it is true that wear is no longer a major concern for small to moderate size restorations, some evidence exists that wear of very large posterior resin composite restorations may still be a concern.[3, 4] Furthermore, little is known about the wear performance of these restorations in patients with parafunctional habits such as bruxism, because they are often excluded from clinical trials.[2, 5, 6] However, some authors have reported unacceptable wear in occlusal contact areas of patients who were severe bruxers.[7] Nonetheless, more than 500 million direct restorations are placed worldwide each year, out of which about half are direct resin composite restorations.[8] In this light, the wear of resin composites continues to be studied by many researchers. This is especially relevant due to the arrival of new resin composites, namely bulk-fill resin composites, about which relatively little information is known with regards to its wear properties.

1.2. Fundamental Wear Mechanisms

Wear is a complex phenomenon, resulting in the loss of material structure caused by the “overall effect” of several interrelated processes.[9] In general, there are 4 types of wear mechanisms involved in dental wear: abrasive wear, surface fatigue wear, corrosive wear, and adhesive wear.[10] Their definitions vary depending on different authors.[9-14] Generally,
metals are susceptible to adhesive, corrosive and three-body wear, whereas polymers are susceptible to abrasive and fatigue wear.[10] For the purpose of this document, the following definitions of wear will be used.

1.2.1. **Abrasive wear**

Abrasion involves a *harder* material cutting into a *softer* material. It can be subdivided into two-body and three-body abrasive wear.

**Two-body abrasive wear**

In two-body abrasive wear, surfaces are rubbed away by direct contact. Because surfaces are rough at a microscopic level, their asperities (from Latin *asper* – rough, i.e. their rough, uneven surfaces) must either fracture or deform during movement while in contact with each other.[15] This type of abrasion results in the creation of well-defined mating surfaces or wear facets. In the case of tooth-to-tooth contacts, this can result in the wearing away of dental tissues. This is commonly referred to as *attrition*[11] and predominantly occurs during non-masticatory tooth movements. It can be caused by physiological movements or parafunctional movements, such as bruxism.[9]

**Three-body abrasive wear**

Three-body abrasion occurs when abrasive particles are free to move between two surfaces, cutting away the asperities of these surfaces as they move. This type of wear predominantly occurs during mastication, and is especially prevalent in patients who eat abrasive diets.[9] As the occlusal surfaces are separated by the food bolus, the slurry of particles abrades the whole surface of the tooth. However, it predominantly affects *food shedding pathways* because of the shearing action of food on contact stress.[15] This can be commonly seen in the buccal or palatal extensions of restorations, since they take the majority of the force of the
masticatory slurry as it escapes through the groove. Three-body abrasive wear predominantly affects the softer regions on a surface, such as the softer polymer matrix of resin composite filling materials. This phenomenon exposes the filler particles, making them more susceptible to two-body abrasive wear.

1.2.2. Surface fatigue wear

In surface fatigue wear, asperities or free particles with small areas of contact create high localized stresses and produce surface or subsurface cracks.\[10\] Cyclic loading and sliding cause the subsurface cracks to eventually unite at the surface, leading to loss of a material fragment.\[9\]

1.2.3. Corrosion wear / tribochemical wear / dental erosive wear

Corrosive wear is caused by chemicals, which weaken only the surface molecules of the outer layer of the material. By weakening the inter-molecular bonds of this outer layer, chemicals potentiate the other wear processes.\[9\] Subsequently, the weakened molecules are rubbed away by the mechanical movement on the surfaces. In the oral environment, these chemicals are usually acids from intrinsic or extrinsic sources. With regards to dental erosion specifically, it is agreed that these acids do not come from bacteria.\[11\]

1.2.4. Adhesive wear

Adhesive wear results from friction when one solid material slides over the surface of another material.\[14, 16\] Adhesive wear occurs when surfaces are highly attracted to each other at a molecular level. Micro-regions are pulled away from one surface and transferred to the other, creating cold welds.\[9\] As the surfaces move, these micro-regions fracture. Adhesive wear is usually associated with metals, but has been shown to occur in polymethylmethacrylate polymers as well.\[15\] Furthermore, adhesive wear is also present in dental attrition, during tooth-to-tooth contacts.\[17\]
1.3. Dental Terminology

The terms attrition, abrasion and erosion have been used to describe wear of dental tissues at the occlusal surface. Some confusion exists due to the use of these terms when describing wear of dental materials. A thorough explanation of these terms has been described by Mair and is beyond the scope of this thesis, therefore only specific aspects will be described below.[14]

*Dental attrition* occurs in areas of direct dental contact. Therefore, it has contributions from two-body abrasive wear, fatigue wear and adhesive wear. In addition to these wear mechanisms, three-body abrasion wear and corrosive wear are superimposed. Thus, dental attrition is the sum of all the wear mechanisms described above. However, dental attrition is usually referred to as two-body wear in the literature.

*Dental abrasion* has been described as wear that occurs in areas without occlusal contact. This is indeed confusing because it can be caused by a variety of abrasives, such as toothbrush abrasion, pipe smoking, hair-grip biting or dietary abrasive slurry. However, when describing dental restorations, abrasion usually refers to three-body abrasive wear and is characterized by the generalized wear of the restoration and the subsequent exposure of enamel margins around it when an abrasive slurry is moved between two surfaces.

*Dental erosion* is a misnomer. The essential characteristic of *erosion* is gradual destruction, over time, as a result of the flow of a physical abrasive medium (e.g. sand or water) over a substrate. The abrasive medium shapes (i.e. erodes) the substrate. In dentistry, dental erosion is in fact dental *corrosion*. Indeed, dental erosion involves the weakening and degradation of dental tissues or materials by a chemical, usually an acid. The affected, and
weakened, surface is then physically removed by coming in contact with the moving surface of another material.

1.4. Location-based wear nomenclature for posterior restorations

Wear of posterior restorations can be classified based on location, according to five types: 1- contact-free area wear (CFA), 2- occlusal contact area wear (OCA), 3- functional contact area wear (FCA), 4- proximal contact wear (PCA), and 5- wear from oral prophylaxis methods (Figure 1).[18]

Firstly, CFA wear is usually associated with wear caused by food. Secondly, OCA wear is associated with tooth contacts in centric, whereas FCA wear is associated with sliding tooth contacts in function. Thirdly, proximal contact wear is caused by rubbing of adjacent proximal tooth surfaces. Finally, wear from oral prophylaxis can be caused by toothbrush or dentifrice abrasion.

1.5. In vitro wear measurements

Because wear measurements in vivo are complicated and time-consuming, efforts have been made to develop wear simulation devices that imitate the processes that occur in the oral cavity during mastication.[19] However, laboratory simulations are set up to monitor simple mechanical relationships, leave out biological factors and, therefore do not replicate clinical reality. The wear of restorative materials is complex and involves multiple elements such as abrasive, adhesive, thermal, fatigue and corrosive components.[20] Furthermore, there are regularly changes on the same restoration in temperature, saliva contact, plaque coverage, or mechanical loading. These micro-environments may produce unusual distributions of strain within the restoration.[21] Heintze et al.[19, 22] have demonstrated that the same materials tested in different wear simulators give different results. Also, they showed that most of the
laboratory methods to test conventional resin composite materials do not reflect the amount of
clinic wear that occurs. Perhaps one of the explanations for the limited value of these simulators
is that the complex nature of the intraoral environment is not able to be reproduced.

1.6. **In vivo wear measurements**

Since no *in vitro* test is available which can perfectly simulate the complex oral
environment, *in vivo* clinical trials are necessary in order to assess the wear characteristics of
new posterior restorative materials.[23] Because modern materials wear at a much slower rate,
the method by which wear is measured must be very accurate, reliable and reproducible.

1.7. **Methods for evaluating *in vivo* wear**

1.7.1. **Qualitative methods**

The first generations of resin composite materials exhibited rapid and excessive wear.
Therefore, these large changes could be detected by visual observation. Direct clinical evaluation
methods such as the criteria-based USPHS system established by Cvar & Ryge[24] were used to
evaluate wear. Calibrated examiners directly assessed the restorations and classified them
depending upon the extent of material loss. Traditionally, wear was evaluated using the criteria
of *loss of anatomic form*, which was classified as either clinically ideal, acceptable, or
unacceptable using terms Alfa, Bravo and Charlie, respectively. Although this method was
clinically relevant and easy to use, it was not effective in evaluating small early changes and did
not provide quantitative information about material loss.[25]

Scanning electron microscopy (SEM) can also be used to characterize the microstructure
of posterior resin composites *in vivo* using a replica technique.[26] It can help confirm OCA and
CFA wear, micro-gap formation and fatigue cracks.[27] Impressions are taken, epoxy models are
made and evaluated under high-magnification optical microscopy. SEM views of the casts can
then be obtained as photomicrographs for further qualitative interpretation. The advantage of this method is to allow the study of the dynamic process of wear, such as observing fatigue crack growth and propagation, but is time consuming, costly and technique sensitive. Even so, artifacts are frequently seen, when replicas are studied under SEM, that examiners failed to recognize during clinical examination.[28-30]

1.7.2. **Semi-quantitative methods**

*Visual methods*

In order to achieve a more objective evaluation, Goldberg *et al.*[31] proposed that material loss should be assessed by obtaining an impression and creating a model of the restored tooth. He compared the model with a series of four casts with four different levels of known wear that served as reference standards to estimate the amount of wear.

This technique was later refined by Leinfelder *et al.*[25] who employed six standard casts, with an approximate distance from the cavosurface margin of the standards to the resin composite surface ranging from 0-500 µm (Figure 2). The Leinfelder system required a light source to cast light at a low angle across the surface of the standards and the tooth being evaluated. The size of the contrasting shadow adjacent to the exposed cavity wall, in the area of the margin of the restoration, enabled estimation of the level of wear (i.e. wear was defined as the extent to which the walls of the original cavity preparation were exposed, as visualized by the apparent size of the shadow). However, wear is not equal across the whole restoration surface. Therefore some authors[23] have argued that these manual cast comparison methods are not representative because they only measure a few points or rely on the visual acuity of the evaluator and their ability to mentally compare the amount of wear between the sample being assessed and the standards.
Although arguably semi-quantitative, the Leinfelder cast comparison method can only detect changes in increments of 100 µm. This level of accuracy was acceptable when evaluating resin composites manufactured in the 1980’s which wore at a much faster rate than modern resin composite materials. However, the Leinfelder method is not precise enough for evaluating contemporary resin composite materials. For example, nanofill resin composites such as Filtek Supreme, for instance, are reported to average 84 µm of vertical wear after 5 years.[2] Therefore, more accurate methods for measuring wear are needed.

1.7.3. Quantitative methods

Measuring devices/methods

A variety of devices/methods have been described in the dental literature to objectively and quantitatively measure wear. These include:

- Stereomicroscopy [32]
- Extensometers [33, 34]
- Laser interferometry [35]
- Three-dimensional microscopy [36, 37]
- Mechanical sensors such as linear variable displacement transducer (LVDT) [38]
- Moiré contouring [39]
- Contacting laser profilometry [40]
- 3D optical scanners [20]

 Such devices/methods can be classified as contact or non-contact systems.[41] Contact devices, commonly called contact profilometers, rely on the movement of a physical stylus across the surface of the object measured. These devices are limited by the size and shape of their stylus[42], which can vary from 10-100 µm. They are less costly than other systems and are
not affected by the color or transparency of the object measured. However, they are slow and require solid objects.

Non-contact measuring devices require opaque, diffuse reflective surfaces and can be classified by the size of the capturing area: point, line, area, or volume.

Non-contact point profilers use a light source or microscope focused on the surface of the object measured. Resolution of such systems relies on the size of the focus light source, which is typically less than 0.025 mm.

Non-contact line systems typically use a laser to project a straight line on the surface of the object, which is deformed by the geometry of the object. An optical camera measures the line as it moves across the surface and calculates the geometry based on triangulation.

Non-contact area scanners are similar to line scanners but they project a pattern on the surface which is being measured. They are significantly faster than line or point systems but have lower resolution because the pattern cannot be focused as sharply. They rely on phase shifting, moiré fringe patterns, triangulation, interferometry or a combination of these techniques to digitally reproduce the three-dimensional location of the surface of the object.

Volume scanner such as computed tomography (CT) scanners or micro-CT systems can also be used, but they are costly and use radiation. Accuracy is typically 0.1 mm or better. However, with highly accurate systems, only small objects can be digitized because of the smaller field of view. Therefore, some micro-CT systems may not be suitable for digitizing full arch impressions.

Initially, some of these devices have been used to measure the heights of the exposed cavity wall in posterior restorations, which was essentially a quantitative version of the Leinfelder technique. However, such investigations only measure one of several clinically
relevant wear parameters, specifically the wear at the cavosurface margin.[27] This type of metric was useful for older resin composites, which wore so rapidly that the preparation margin was quickly exposed due mainly to three-body abrasive wear.[43] However, newer nanofilled and microhybrid resin composites exhibit higher wear resistance and vertical wear rates are similar to enamel.[2] Therefore, different methodologies must be employed.

Digital mapping methods

By far the best way to measure wear is to use 3D digital mapping methods to compare sequential 3D images of the restorations.[41] This allows measurement of both clinically relevant parameters for wear: vertical loss at OCAs and volume loss along the entire surface. These parameters act as metrics for the two-body and three-body abrasive wear of the material, respectively, and compare it to that of enamel.[27]

Three main digital mapping methods have been described to measure the clinical wear of teeth. [44] They differ primarily by the type of measuring device used. The system developed by Clinical Research Associates (CRA) [45] uses a modified laboratory microscope, whereas the Minnesota system uses a computer-driven contact profilometer,[46] and the 3D laser digitizing method uses a 3D laser-line scanner.[47]

Regardless of the measuring device used, all present with some restrictions.[36] The method can achieve high accuracy or demonstrates ease of use, but rarely both.[27, 42] When comparing a 3D laser scanning device with an optical sensor and a computer driven-contact profilometer, Heintze et al. concluded that there was very good agreement (on a scale of poor, fair, moderate, good and very good agreement) between the devices.[48] Indeed, all three methods ranked the materials similarly. However, the 3D laser sensor was preferable due to its speed and simplicity. Most authors agree that three-dimensional scanning is currently the
preferred method of measuring wear[23, 27, 41, 48], with Heintze, Lambrechts, Palaniappan, Van Meerbeek and Peumans specifically recommending the 3D laser sensor system.[27, 48]

1.7.4. **Indirect quantitative methods**

Hickel et al.[23] proposed that indirect techniques are required to properly evaluate the clinical wear. They recommend making impressions and models of the restored teeth in order to evaluate them using sophisticated 3D scanning of the whole occlusal surface of the restoration. This is in agreement with the findings of Perry et al.[44] reported that conventional methods of evaluating wear such as the direct clinical criteria-based methods (USPHS) or indirect calibrated cast-based methods (Moffa-Lugassy) systematically underestimated wear when compared to a 3D laser digitizer.

1.7.5. **Direct quantitative methods**

Direct intra-oral acquisition of quantitative information would certainly be preferred over indirect acquisition. Indeed, it would be advantageous because of its increased accuracy and smaller number of steps. Güth et al. have shown that direct digitalization with a chairside intra-oral scanner was statistically significantly more accurate than indirect scanning of the referring gypsum cast.[49] Furthermore, the referring impression was statistically significantly more accurate than the gypsum cast. This shows that accuracy is lost during each of the steps (impression, model casting and digitizing) required for indirect quantitative methods.

Only two methods exist for direct intra-oral acquisition: cone beam CT scanners and chairside intra-oral impression devices.[41] Putting aside the implications of irradiating patients, CT scanners are limited in their ability to measure wear by their insufficient accuracy of a few hundred microns.[50]
Some concerns have been raised regarding the use of spraying teeth with reflective powder during intra-oral impressions, such as in an early version of the CEREC system (Sirona Dental Systems).[41] Indeed, one 1989 study on CEREC showed it can create an addition error of 27-85 µm.[51] This is certainly a valid concern, due to the heavy powdering required by older intra-oral scanners. A recent study reported that powdering with CEREC Bluecam (Sirona Dental Systems) is responsible for an increase in height of approximately 20-40 µm.[52]

However, this same study found that slight powder dusting did not show an additional layer or thickness in the data sets obtained with a Lava C.O.S. scanner (3M ESPE).[52] This finding was confirmed by Hack et al., who found that the light dusting of titanium-oxide powder did not appear to influence the accuracy of a newer device from the same manufacturer, the 3M True Definition Scanner (3M ESPE).[53] This phenomenon is best explained by Patzelt et al.[54], who reports that 3M’s intra-oral scanner, unlike the CEREC Bluecam system, does not use powder as an antireflective coating. Instead, the powder particles on the tooth surfaces, required by 3M’s Lava C.O.S. and 3M True Definition scanners, act as reference points, or connectors, so that the multiple images can be stitched together more accurately. It seems that because the 3M intra-oral scanners scan between the powder particles, accuracy is not lost. However, the “light” powdering technique remains subjective and it remains to be seen if technique sensitivity affects the accuracy when 3M intra-oral scanners are used clinically.

Nonetheless, the trend in the industry appears to move away from powdering. Several newer intra-oral scanners, like the CEREC Omnicam (Sirona Dental Systems), TRIOS (Heraeus Kulzer), PlanScan (Planmeca USA) and iTero (Align Technology Inc.) are powder-free. Interestingly, the accuracy and precision of such powder-free systems are not always superior to that of systems that require powdering.[53] Indeed, an in vitro study found that the powder-free
CEREC Omnicam and PlanScan were significantly less accurate and less precise than the 3M True Definition scanner, which does require powder. Therefore, not all 3D scanners are equivalent in levels of accuracy and precision. However, no statistically significant difference was found between the most accurate and precise intra-oral scanners in the study: 3M True Definition and three other powder-less systems [TRIOS, iTero and CS 3500 (Carestream Health, Inc.)].[53] This supports the notion that light-powdering does not affect accuracy.

To this author’s knowledge, intra-oral digital impressions have never been employed during a clinical trial as a method for measuring the wear of resin composite restorations. Although the accuracy and precision of such devices are not as good as their tabletop counterparts, they show promise for clinical wear investigations because they measure the teeth directly. Intra-oral scanners are not affected by the same distortion errors generated during impression making and model pouring. However, intra-oral impressions are affected by another type of digital process referred to as stitching. Because the field of view of their camera is much smaller than that of a dental arch, multiple smaller images must be captured and “stitched” together. Alignment errors occur during stitching and the total accuracy of the impression decreases with increasing distance from the scanning start point. Indeed, one clinical trial comparing the accuracy of intra-oral impressions to extra-oral impressions of gypsum models of the same patient found that intra-oral impressions were well suited for the acquisition of single teeth but accuracy dropped when multiple teeth were compared as a whole.[55] Thankfully, many clinical trials examining wear of restorations focus on wear of single teeth, and therefore scans (i.e. intra-oral digital impressions) could be suitable for measuring wear in such investigations.
1.8. Accuracy of digital impression devices

1.8.1. Single tooth accuracy of intra-oral impressions

A large in vitro investigation by Rudolf et al. compared 10 extra-oral and four intra-oral scanners for their accuracy in digitizing single ceramic master-dies of an incisor and a molar tooth.[52] To make it clinically relevant, the extra-oral scanners digitized gypsum replicas of the ceramic dies while the intra-oral scanners digitized the die itself. This study found that all four intra-oral scanners had no statistically significant difference in accuracy when compared to the four best extra-oral scanners. The positive mean deviations of the three best extra-oral scanners ranged between 6.0±1.1 and 8.6±2.1 µm, while it ranged from 6.4±1.1 and 8.0±1.9 µm for the two best intra-oral scanners. Although the CEREC Bluecam and iTero (10.7±5.4 – 14.5±2.9 µm) performed slightly worse than the 3M Lava C.O.S. and TRIOS (6.4±1.1 – 8.0±1.9 µm), the difference was not statistically significant.

Similarly, Hack et al. tested the accuracy of six intra-oral scanners for digitizing a molar preparation on a dentoform tooth. They found that the accuracy of four of the better intra-oral scanners tested (TRIOS, CS 3500, 3M True Definition and iTero) ranged between 6.9±0.9 and 10.3±0.9 µm.[53] However, there was a significant difference in accuracy between those four scanners, when compared to the PlanScan (30.9±0.9) and Omnicam (45.2±17.1)

1.8.2. Multiple-unit accuracy of intra-oral digital impressions

Several studies have reported on the accuracy of intra-oral digital impressions.[49, 54, 56, 57] Because of their study design, these studies should be compared based on the number of teeth included in the impression.
Four-unit digital impressions

Güth et al. [49] reported on the accuracy of direct versus indirect digitization of a titanium model representing a premolar and a molar with a chamfer preparation for a 4-unit fixed partial denture. The model was digitized directly with a Lava C.O.S. intra-oral scanner and indirectly by digitizing polyether impressions with a reference micro-CT scanner and by digitizing the corresponding gypsum models with a 3M Lava ST laboratory scanner. A total of 12 impressions were made per group. After comparing the impressions of the three groups with the direct reference impression made with an industrial micro-CT, they found statistically significant differences. The direct impressions made with the 3M Lava C.O.S. had the smallest mean absolute distances from the reference impression (15±6 μm) compared to the digitized polyether impression (23±9 μm) and the laboratory impression of the gypsum models made with Lava ST (36±7 μm). Although the authors concluded that intraoral digital impressions had higher accuracy than gypsum models for four-unit impressions, it is interesting to note that the accuracy of four-unit impressions in this study (~16 μm) was two times worse than that of single-unit restorations reported by Hack et al. and Rudolf et al. (~8 μm). [52, 53]

Single quadrant digital impressions

Quass et al. compared the in vivo deviation between quadrant intraoral digital impressions and extraoral digitization of models obtained with conventional polyether impressions in 10 subjects. Deviation was measured as the difference in distance between the extraoral digitization and intraoral impression made with CEREC 3D. They found mean positive deviations of 38±18 μm and mean maximum positive deviations of 200±117 μm per quadrant. Deviation increased proportionally to the distance away from the center of alignment of the
impressions. The authors concluded that intraoral digital impressions were well suited for single-tooth restorative procedures, but not multiple-unit restorations.

*Full arch digital impressions*

Patzel *et al.* [54] investigated the *in vitro* accuracy of full-arch scans of 14-unit prepared abutments using intra-oral scanners. They found that the iTero and Lava C.O.S. had mean accuracy values of 38±14 and 50±14 µm, respectively, while CEREC AC Bluecam had mean accuracy values of 333±65 µm when compared to the reference scan. They attributed this large difference in accuracy to the technological limitations of the Bluecam scanner, specifically the active triangulation system which it uses to obtain distance information. Furthermore, the heavy powdering used with the Bluecam scanner also played a detrimental role. The authors report that these technological limitations led to an increased “horizontal expansion” of the impression.

However, when the CEREC Bluecam was tested in a clinical trial with six other intra-oral digital impression systems, it performed similarly. [58] Ender *et al.* reported on the precision of conventional and digital impression methods for obtaining complete arch impressions. [56] They found that intra-oral digital impression devices had a precision ranging from 43-83 µm, while gypsum casts poured from conventional vinylsiloxanether impressions had mean precision of 17.7±5.1 µm, which was statistically significantly better. They also reported that newer versions of intra-oral digital impression devices such as the CEREC Omnicam and the 3M True Definition scanners performed better than their predecessors (i.e. the CEREC Bluecam and 3M Lava C.O.S. scanners). Unfortunately, because this was a clinical study, only precision could be evaluated, and accuracy was unknown. Furthermore, it was found that the clinical precision of the intra-oral devices tested clinically was not as optimal as that found during an *in vitro* research study conducted by the same authors. [56]
1.9. Wear of resin composite restorations

1.9.1. Historical perspective on the clinical wear of posterior resin composites

Wear was a concern for early resin composite materials. Phillips et al. published one of the first multi-year clinical studies on posterior resin composites in 1973.[1] This research study used USPHS criteria to assess and compare the clinical performance of Velvalloy amalgams (S.S. White Dental Mfg. Co., Philadelphia, PA) versus Adaptic resin composites (Johnson & Johnson, East Windsor, NJ), a two-paste Bis-GMA system. They reported a decrease in Alfa scores for the anatomic form in the resin composite group from 100% at baseline to 13% at 3 years due to excessive wear, and concluded that the use of resin composite in Class II restorations was contraindicated except where esthetics is the primary consideration.

Bayne et al. proposed that the wear behavior of these conventional resin composites (macrofill and midfill) can be explained by the “protection hypothesis” for wear.[59] This theory suggests that the high CFA wear predominantly seen in conventional resin composites is due to the greater filler interparticle spacing of their larger filler particles. Indeed, CFA wear is caused by three-body abrasive wear of the resin matrix by the abrasive particles in the food bolus. A larger filler size and, therefore, interparticle spacing would result in a greater area of exposed resin matrix available to be abraded away. It has been shown that microfill resin composites, because of their smaller filler size, have a smaller interparticle spacing, which is narrow enough to shelter the matrix and prevent wear during contact with the food bolus. This phenomenon is sometimes referred to as microprotection[18] and its effects can be seen in clinical trials by Heymann et al., which show significantly less wear of microfill resin composite versus conventional resin composite.[60, 61] Indeed, the microfill resin composites showed 111-113
µm of wear (estimates according to Leinfelder method) compared to 150-199 µm of wear for the conventional resin composites after 2 years.

There is also a process called macroprotection, which occurs when the resin composite restoration is sheltered by the narrow tooth preparation.[18] Indeed, if the restoration width is small, it minimizes food bolus contact. This is one reason why larger restorations, such as those found in molars, are more susceptible to CFA wear. Furthermore, macroprotection also explains why the wear of posterior resin composites decreases with time. As wear occurs on the resin composite, the pressure exerted by the food bolus decreases. This was described by Wilder et al. in their study on the clinical wear of conservative-width posterior UV light-cured microfill and midfill resin composites over a 17-year period using the Leinfelder cast evaluation method.[62] They reported that out of the average wear of 264 µm at 17 years, 75% of the total wear occurred between baseline and 5 years, 14% of the total wear occurred between 5-10 years and only 11% of the total wear occurred between 10-17 years.

However, wear behavior of newer resin composites do not necessarily follow this same progression over time. Indeed, in a 10-year study on the clinical performance of a packable posterior resin composite, Wilder et al. reported that SureFil (Dentsply) showed a strong linear regression with time ($r^2=0.98$) and that the wear had not leveled off at 10 years.[21, 63] The microprotection from the smaller interparticle spacing of this newer resin composite seems to be the reason of the slower and more linear wear rate. Wear, as measured by the Leinfelder technique, was reported as 52±30 µm at 4 years and 142±71 µm at 10 years. Because the wear was linear, the authors estimated the yearly wear rate at ~14 µm/yr.

Although these results attest to the clinical wear resistance of the SureFil resin composite, the numerical values must be interpreted with caution. Indeed, using the Leinfelder technique to
quantify the wear of “low wear” materials is questionable because the inter-examiner error for this method is about 50 μm.[64] Furthermore, calibrated cast-based methods (Leinfelder) systematically underestimated wear when compared to a 3D laser digitizer.[44] As mentioned previously, a digital mapping technique is the preferred method of examining newer materials.

Nonetheless, the pooled values of total wear of nine different conventional resin composites from the results of several clinical trials at the University of North Carolina as reported by Bayne et al.[21] show a similar progression over time. Using the Leinfelder technique, wear of Class II restorations ranged from 160-250 μm at 5 years and 200-330 μm at 10 years.

1.9.2. Clinical wear of resin composites measured with 3D digital mapping

Comparing clinical trials quantitatively examining the wear of posterior resin composite is challenging because very few studies employ the same methodology, digitizing device, or software.[2, 5, 6, 44, 65-72] Furthermore, wear has been reported using different variables and units of measurement. Also, some authors do not always provide numerical values and data must be extrapolated from their charts.[72] Nonetheless, interesting trends can be discovered when reviewing this literature.

In 1984, Lutz et al. measured the wear of posterior resin composite restorations and amalgam restorations after 6 months and 1 year with a modified profilometer.[72] They found that resin composite wear in OCAs as significantly greater than the CFA wear. Indeed ~47 μm of vertical wear was found in the OCAs versus ~ 20 μm in the CFA, a 2.5X increase. Furthermore, they reported vertical wear at 1 year in OCAs of ~25 μm for both amalgam and resin composite groups in Class I occlusal cavities. However, OCA wear in large MOD cavities was significantly different, with ~60 μm of vertical wear for amalgam and ~135 μm for resin composites. They
concluded that none of the types of resin composite tested could act as a replacement for amalgam in stress-bearing posterior restorations.

In 1997, Ferracane et al. reported on the wear of an experimental hybrid resin composite with various cure times placed in cylindrical holes of first and second molars of complete dentures in 50 patients.[73] Measurements of clinical wear were made with a profilometer. At 2 years, they found an average wear depth of 144 µm for the 9 s cure time group, 112 µm for the 12 s group, 69 µm for the 25 s group, 50 µm for the 40 s group and 36 µm for the 40 s group which light-cured followed by heat application. Heliomolar was also tested and had an average wear depth at 2 years of 16 µm with 40 s cure time and 12 µm with 40 s light-curing followed by heat application. Because the authors found that the degree of conversion of the resin composites increased with curing time, they concluded that the abrasive wear of resin composites could be improved by increasing their degree of convergence.

In 2001, Söderholm et al. reported on the clinical wear of 128 experimental resin composites after 3 years using two different digitizing methods.[70] The resin composites varied in matrix type, filler type and silane treatment method. They found that both the 3D laser digitizer and measuring microscope revealed similar average wear values. However, the maximum wear detected by the laser was higher than the microscopic measurements, most likely due to the increased resolution of the laser system. Also, they reported average wear at three years of ~330 µm for the BisGMA/TEGGMA resin composites versus ~240 µm for the UEDMA/TEGDMA resin composites. Based on their findings, they concluded that the matrix composition was the most significant factor affecting the wear rate. In evaluations conducted in their laboratory, they found that BisGMA/TEGDMA had a conversion rate of 55% while UEDMA/TEGDMA had a conversion rate of 70%. These results are in accordance with
Ferracane et al.[73], who also found that reduced conversion rate was associated with increased wear.

In 2011, Palaniappan reported on the 5-year clinical wear of two types of resin composites placed in Class I and Class II preparations in 37 teeth.[2] The study population consisted of volunteer dental students with a strict exclusion criterion of those with evidence of parafunctional habits. The authors reported a non-statistically significant difference between the Z100 microhybrid resin composite and the Filtek Supreme nanocomposite for both vertical wear (77±25 and 84±21 µm, respectively) and volume loss (0.82±0.2 and 1.04±0.9 mm³, respectively) after 5 years. Furthermore, the authors reported that the amount of vertical wear over time did not progress in a linear fashion. Indeed, most of the vertical wear occurred between baseline and 6 months: 32±9 µm for Z100 and 37±10 µm for Filtek Supreme. Contrary to vertical wear, volume wear increased with time, with the highest amount of volume loss occurring after 36-48 months. The authors reported only 0.049±0.03 and 0.073±0.1 mm³ of volume loss in the first 6 months for Filtek Supreme and Z100, respectively.[69] For these reasons, the authors separated the amount of wear based on running-in wear (0-6 months), early stage wear (6-36 months), and the steady state wear (36-60 months). Additionally, they found significant differences between the wear of Class I and Class II restorations and between different operators.

In 2012, Cetin et al. reported on the clinical wear after 6 and 12 months of three nanocomposites and two indirect hybrid resin composites in Class I and Class II restorations on molar teeth in 54 patients.[67] They measured wear using a 3D laser scan system and, unlike previous studies, calculated volume as the mean vertical wear multiplied by the contact area. Regarding the direct resin composite group, they reported significantly different mean volumetric wear at 6 months between Aelite Aesthetic (0.058 ± 0.01 mm³) versus Filtek
Supreme XT and Tetric EvoCeram (0.087 ± 0.02 µm and 0.085 ± 0.01 mm³, respectively). However, the difference in wear was no longer statistically significant at 12 months, with ~0.090 mm³ for Aelite Aesthetic and ~ 0.112 mm³ for both Filtek Supreme XT and Tetric EvoCeram. Interestingly, the standard deviation in this study is much smaller than all other quantitative clinical studies.

In 2012, Palaniappan reported on another 5-year clinical.[6] Their aim was to compare the clinical wear performance of nanohybrid, microfill, and conventional hybrid resin composites placed in Class I and II cavities, in a population of 15 predominantly female dental students.[6] At 6 months, vertical wear was reported as 36±16 µm for enamel (heavy occlusion), 17 ± 4 µm for enamel (light occlusion), 46±13 µm for Tetric Ceram (conventional hybrid), 43±14 µm for Tetric EvoCeram (nanohybrid), and 49±16 µm for Gradia Direct Posterior (microfilled hybrid). Similar to other studies, the 6-month running-in period was responsible for the highest rate of vertical wear when compared to the following steady-state period. However, contrary to the 2011 study by the same authors[2], the rate of volume loss was higher during the running-in period and decreased thereafter. At 5 years, there was no significant difference in vertical wear rate between the materials, with vertical wear ranging from 111-139 ± 32 µm. However, there was a significant difference in volume loss at 5 years between Tetric EvoCeram and the other two materials, with a volume loss of 0.97±0.3 mm³ versus 1.40-1.41±0.6 mm³, respectively.

In 2012, DeLong et al. reported on the correlation of wear between an in vitro artificial mouth simulator and in vivo results from a 5-year UNC clinical trial that assessed wear of SureFil resin composite.[66] Remarkably, they initially found at 6 months a slight increase in height (~5 ± 12 µm) and slight increase in volume (0.060 ± 0.149 mm³) for the restorations with only CFA wear. They attributed this to hygroscopic volume expansion of SureFill. One study
found a 0.5% expansion of SureFil after storage in artificial saliva.[74] However, DeLong et al. reported 35 ± 18 µm of OCA wear at the same 6-month time period. At 5 years, they reported 27 ± 24 µm of total mean wear depth and 0.532 ± 0.372 mm³ of volume loss for all SureFil restorations. Furthermore, contact wear rate was significantly greater than contact-free wear rates. Mean wear depth for OCAs at 5 years was 88 ± 26 µm.

This is in accordance with the findings of Krämer et al., who reported in 2015 on the clinical wear and marginal adaptation of 68 resin composite restorations over 8 years.[65] They reported that the most severe changes of the resin composite over time primarily occurred at OCAs. Furthermore, mean wear at 8 years was 108 ± 88 µm for Grandio and 98 ± 53 µm for Tetric Ceram. OCA wear for those materials during the same period was 135 ± 104 µm and 110 ± 58 µm respectively. There was no statistically significant difference between the materials at any time point.

In 2015, Lawson et al. reported on the 2-year performance of conventional and flowable resin composites in Class I restorations.[5] Wear was measured with a three-dimensional light profilometer (Proscan 2000, Scantron). They reported no statistically significant difference in the volume loss between the conventional resin composite (Filtek Supreme Ultra Universal) and the flowable resin composite (Filtek Supreme Ultra Flowable), with 3.43 ± 2.50 mm³ versus 3.16 ± 2.38 mm³ of volume loss, respectively. They attributed the much higher amount of wear reported in their study compared to previous studies to several methodological differences. Firstly, unlike other studies, they considered all types of wear. Indeed, Palaniappan et al. manually deleted the wear and beveled margins[2, 6, 68, 69], and DeLong et al. excluded marginal fractures.[66] The exclusion of these areas of wear was particularly problematic because the greatest amount of wear was often observed at the cavosurface margin in the study. Furthermore, variation in
reported volume between studies can also be related to the difference in sizes of the resin composite restorations, impression and cast making techniques, accuracy of scanning devices, precision of the superimposition software, and patient related factors such as biting forces, number of remaining teeth, and tooth position.[5]

1.10. Wear of enamel

The classic study on the quantitative in vivo wear of human enamel was reported by Lambrechts et al. in 1989.[75] A computerized three-dimensional measuring microscope was used to measure the absolute maximum loss of substance in the center of the enamel OCA from baseline to 48 months in young adults who had received direct restorations. They reported an average steady-state wear of those areas of about 29 µm per year for molars and 50 µm per year for premolars. Running in wear for enamel was reported as 38 µm per year and 29 µm per year following restorations involving the occlusal surface.

These findings are similar to those of Palaniappan et al.[68], who reported 56 ± 12 µm of vertical wear for enamel wear facets with light occlusion and 107 ± 25 µm of vertical wear for those with heavy occlusion at 3 years. Consolidation of these observations leads to the conclusion that enamel wear proceeds at approximately 36 µm/year (heavy occlusion forces) and 19 µm/year, (light occlusal forces).

A noteworthy research study by Tantbirojn et al.[76] compared the volume loss of enamel between patients with gastroesophageal reflux disease (GERD) and a control group of healthy subjects after 6 months. They reported a threefold increase in wear in patients with GERD compared to the control (0.18 ± 0.12 mm³ versus 0.06 ± 0.03 mm³, respectively). This is even more thought-provoking considering that GERD patients were actively being treated and taking medication and that health patients may have had GERD that was undiagnosed.
1.11. **Bulk-fill resin composites**

A new trend in dentistry has been to simplify operative procedures so as to reduce technique sensitivity. This is particularly true with dentin bonding systems, which are being designed to require fewer clinical steps and are being marketed accordingly. More recently, a new category of resin composite materials called “bulk-fill” resin composite has been gaining in popularity. The marketing strategy for these materials is to claim that they save time by allowing placement in bulk increments of 4-6 mm thick. To do so, modifications in the composition of the resin composite have been made so as to overcome the detrimental effects of polymerization shrinkage stress.

This reformulation of resin composite materials has enabled lower polymerization shrinkage and, thereby, lower associated stress on the bonding interface. However, there may be unintended or unexpected consequences. Leprince *et al.*[77] reported that large and significant differences were observed for all considered physico-mechanical properties of most currently available bulk-fill resin composites. Barkmeier *et al.*[78] reported that SonicFill (Kerr), a bulk-fill material, exhibited significantly greater wear than that of all the other materials evaluated in their *in vitro* study.

There is very little information in the current literature regarding the clinical performance of bulk-fill resin composites, especially with regards to the high-viscosity bulk-fills, which are intended to be used for the entire restoration, and do not require to be covered with a conventional resin composite.[79] This knowledge gap is even greater for one such material, Filtek Bulk Fill Posterior Restorative material (3M ESPE), for which no clinical or *in vitro* information is yet available.
CHAPTER 2: MANUSCRIPT

2.1. Introduction

Wear of posterior resin composite materials was once considered a major concern. [1] However, changes in formulation and reduction in filler size have led to a substantial reduction in wear. [80] Indeed, recent microhybrid and nanofilled resin composites wear at a rate similar to that of enamel. [2] While it is true that wear is no longer a major concern in small-to-moderate-sized restorations, it remains problematic for large restorations and in patients with parafunctional habits. [4, 7, 70] Furthermore, little is known about the clinical wear performance of recently introduced bulk-fill resin composites, which have flooded the market in recent years. This is worrying considering that they show a large range of physical properties and perform differently as compared with conventional, incremental-fill resin composites in vitro. [81] Nonetheless, approximately 261 million direct resin composite resin restorations are placed worldwide every year. [8] A meta-analysis on posterior restoration has shown that about 12% of RBCs will show noticeable wear within an observation period of 10 years.

Using a laboratory scanner to digitize stone replicas made from conventional impressions of dental restorations is currently the recommended method for measuring quantitative wear in clinical trials. [23] However, this method is unpleasant for the patient, time-consuming for the evaluator, and requires expensive equipment. [23, 41, 82] Some authors have suggested the use of intraoral scanning techniques to replace conventional impressions because it eliminates potential
distortions from dimensional changes in the impression materials and dental stone.[76, 83] However, such a method has never been evaluated in a clinical trial thus far.

In this light, the objective of this prospective, randomized, split-mouth clinical trial was to comparatively assess the vertical and volume wear of an incremental-fill and a novel bulk-fill nanocomposite using an indirect (3D analysis of gypsum replicas) and a novel direct (intraoral 3D analysis) method, in parallel.

2.2. Material and methods

Two materials were compared: a “conventional”, incremental-fill nanofilled resin composite (Filtek Supreme Ultra Universal Restorative, 3M ESPE) and a novel bulk-fill nanofilled resin composite (Filtek Bulk Fill Posterior Restorative, 3M ESPE). Their characteristics are listed in Table 1.[84, 85]

2.2.1. Research Study population

Research study subjects were recruited within the UNC School of Dentistry clinics. The study is currently ongoing and subjects are still being screened. The aim is to include up to 50 adult subjects (18 years of age and older) to provide at least 50 sets of matched or unmatched paired teeth in need of study restorations. Subjects will be in need of two or four medium-sized Class II restorations in molar and/or premolar teeth. Although desirable, the pairs are not required to be precisely matched in tooth type or size. Twenty patients were included in the trial thus far, but only 13 patients were due for the 6-month recall at the time of redaction of this manuscript.
2.2.2. **Inclusion criteria**

- Subject must:
  - Be $\leq$ 18 years of age.
  - Be capable of giving written informed consent.
  - Have a pair of similar lesions or failed restorations in vital permanent molar or premolar teeth requiring Class II restorations of moderate size.
- Test teeth must be free of cracks, defects or other lesions necessitating operative intervention other than the restoration to be undertaken as part of the study.
- Opposing teeth must not be crowned or restored with a ceramic material
- Restoration must have a proximal portion with at least one margin that obviously extends into an interproximal embrasure.
- Rubber dam isolation must be possible

2.2.3. **Exclusion criteria**

- Subjects:
  - Have a history of any adverse reaction to clinical materials of the types to be evaluated.
  - Have a medical or dental history that could possibly complicate the provision of the proposed restorations and/or influence the behavior and performance of the restorations in clinical service.
  - Have advanced periodontitis affecting the mobility of the teeth.
  - Have xerostomia caused by medications, Sjögren’s syndrome, etc.
  - Are individuals with special needs.
- Test restorations of either material in occlusal or proximal contact with each other.
• Test teeth out of occlusion
• Base or liner is indicated

2.2.4. Restoration placement

The restorative material to be used was allocated by means of a randomization scheme based on computer-generated random numbers. Because the insertion procedure is different for each material, the operator could not be blinded. All teeth were prepared, finished and polished using the same electric slow-speed and high-speed handpieces by 3 different full-time Operative Dentistry faculty at the UNC School of Dentistry Go-Health Clinic.

No bevels were placed on any of the cavosurface margins. Sectional matrices were used. Enamel margins were selectively etched (Scotchbond Universal Etchant, 3M ESPE; 32% H3PO4) for 15s, rinsed for 15s, and air dried until dentin was moist, with no pooling of water. A single coat of adhesive (Scotchbond Universal L-Pop blisters single dose) was applied to the entire preparation, rubbed in for 20s, air thinned for 5s, and cured for 10s, as per manufacturer instructions.

For the bulk-fill group, a single increment up to 5mm in thickness was placed, adapted and cured for 10s (occlusal), and then 10s (buccal) and 10s (lingual) after matrix removal. If preparations were deeper than 5mm, a second increment was used, with an additional 10s (occlusal) curing time before matrix removal. For the incremental-fill group, the material was inserted in increments no greater than 2mm and cured with the same curing light for 10s per increment. The curing light (Elipar S10 LED Curing light, 3M ESPE) was tested every month with a radiometer (Bluephase Meter II, Ivoclar Vivadent), which reported a consistent light intensity output of 1400 mW/cm².
Restorations were left in occlusion when possible. Finishing and polishing materials and technique were determined by operator preference. Finishing diamonds, finishing carbides, silicone polishers, flexible polishing disks, and finishing strips were available for use.

2.2.5. Data collection and recall

Two conventional vinyl polysiloxane (VPS) impressions (Imprint 3 Heavy/Light Body Regular Set, 3M ESPE) and one digital impression was made for each restoration by the single evaluator. Conventional impressions were made using stock plastic trays (Master Tray #8 Partial UR/LL, Water Pik Inc.) and a single-step putty-wash technique. The impressions were removed after 4 minutes of intra-oral setting time.

Digital intraoral impressions (3M True Definition Scanner, 3M ESPE) were made with light-powdering (3M High-Resolution Scanning Spray, 3M ESPE; titanium dioxide) using the manufacturer recommended scan paths. Dri-Angle (Dental Health Products, Inc.) and OptraGate (Ivoclar Vivadent) were used for isolation and retraction. Open STL files of the scans were downloaded for analysis from the 3M Connection Center website. At 6-month recall, the above-described procedures were repeated. Restorations were photographed at baseline and recall periods. Additional photographs were captured of the occlusion marks left by single thickness 40 µm Arti-Check (Bausch) blue articulating paper on the restorations when the patient occluded in maximum intercuspal, excursive and protrusive movements. Occlusion loading of the restoration was categorized on the basis of the intensity of the occlusal contacts as either 1-none, 2-light, 3-heavy.

2.2.6. Wear analysis

Wear analysis was performed at Minnesota Dental Research Center for Biomaterials and Biomechanics by the same evaluator who made all the impressions.
Conventional impressions were treated with Smoothex Debubbling Solution (Whip Mix) and cast with Silky-Rock (Whip Mix) type IV low expansion die stone. Proper water/powder ratio was ensured by using an automatic water dispenser (Aquaspense, Whip Mix). Gypsum was vacuum mixed (VPM2, Whip Mix), and cast in the impressions using a vibrator (Heavy Duty Vibrator, Whip Mix). Models were separated from the impressions and the best replica model of each pair was mounted for digitization. They were digitized using an optical dental laboratory scanner (Lava Scan ST, 3M ESPE) a minimum of 24 hours after casting, to allow for water to evaporate from the models.

The baseline and six-month recall digitized models of the conventional impressions and the digital models from the intra-oral impressions were cropped to remove gingival tissue and to limit the impression to a maximum of 1 adjacent tooth on each side. Cumulus software (Regents of the University of Minnesota) was used to align the models by minimizing the root-mean-square (RMS) differences between tooth surfaces at baseline and six months.[76, 86, 87] The region of the restoration was selected in the software by including the occlusal surface of the restoration within the occlusal line angles and up to the proximal aspect of the marginal ridge. Marginal wear and minor marginal fractures were included. Wear was computed automatically for the selected restoration region by the software.

2.2.7. Statistical analysis

Outcomes measured for each restoration and with each measuring device were: volume loss, maximum depth loss, mean depth loss and area of restoration. Statistical analysis was performed with IBM SPSS Statistics v24.0.0.0 software. Mean volumetric loss, maximum height loss, and mean height loss between materials and between tooth type were compared with the Independent Samples Mann-Whitney U test ($\alpha = 0.05$). Due to the small sample size in the molar
group (n=3 per material), the Mann-Whitney test was also performed separately on the premolar group.

Mean volumetric loss, maximum height loss, mean height loss and restoration area between measuring methods were compared with the Related-Samples Wilcoxon Signed Rank Test (α = 0.05) and with Intraclass Correlation Coefficient (ICC) using a two-way mixed model, absolute agreement and single measures.

The Kruskal-Wallis H Test was used to measure differences between each outcome measured and categorical independent variables (occlusion, operator, weekly alcohol consumption and race/ethnicity). Dunn's nonparametric comparison for post hoc testing was performed to determine which specific groups of the independent variable were statistically significantly different.

Kendall’s Tau-b Correlation Coefficient Test was used to measure possible strength and direction of association between measured outcomes and continuous independent variables (age, weight, height, number of medications taken).

Spearman Rank-Order Correlation Coefficient Test was used to measure possible strength and direction of association between the area of restoration and the 3 wear outcomes: volume loss, maximum height and mean height loss.

Linear regression analysis of the volume loss and maximum height in relationship to the restoration area were also calculated.

2.3. Results

The recall rate was 92% at the 6-month recall period, with one patient lost to follow-up. Table 2 summarize the measured outcomes of the Class II restorations at the 6-month recall. Twenty-four out of 28 restorations were available for analysis. Two were lost due to a patient
dropout, 1 failed due to sensitivity and 1 was excluded due to obvious distortion in both VPS impressions for that restoration.

Regarding both the Lava Scan ST and 3M True Definition measurements, there were no statistically significant differences (see Table 1 for $p$-values) between materials for either volume loss, maximum height loss, mean height loss, or area of restoration.

However, when the data for the premolar group was compared separately from the molar group, statistically significant differences for mean depth loss were found for both Lava Scan ST ($p=0.043$) and 3M True Definition groups ($p=0.034$). Table 3 summarizes the measured outcomes for the premolar group. No statistically significant differences ($p>0.05$) were detected within the molar group for any of the materials.

Furthermore, there were statistically significant differences ($p<0.05$) for volume loss and area of restoration between the premolar and molar groups. Indeed, the mean volume loss measurements with the Lava Scan ST of the molar group measuring $0.182 \pm 0.087$ mm$^3$ were significantly different ($p=0.033$) than the premolar group measuring $0.080 \pm 0.099$ mm$^3$. Furthermore, the mean area of restoration measurements with the Lava Scan ST of the molar group measuring $28.894 \pm 18.574$ mm$^2$ were significantly different ($p=0.027$) than the premolar group measuring $10.147 \pm 6.569$ mm$^2$.

When comparing between measurements taken with the Lava Scan ST and 3M True Definition scanners, there was no statistically significant difference ($p>0.05$) for volume loss, maximum height loss, and mean height loss. However, there was a statistically significant difference ($p<0.001$) between the restoration area from the Lava Scan ST measurements ($14.834 \pm 13.253$ mm$^2$) and from the 3M True Definition measurements ($14.174 \pm 13.067$ mm$^2$). On average, restoration area measured with the 3M True Definition scanner was $0.660$ mm$^2$ smaller.
than that measured with the Lava Scan ST scanner. Nonetheless, intraclass correlation coefficient (ICC) between measurements from each scanner ranged from good to excellent for volume loss (0.944), maximum height (0.792), mean height (0.734) and area (0.997).

There were no significant differences ($p>0.05$) between the measured outcomes and the independent variables operator, weekly alcohol consumption, or race/ethnicity. Furthermore, there was no statistically significant ($p>0.05$) correlation between any of the measured outcomes and the independent variables age, height, weight, or number of medications taken.

However, there was a statistically significant difference in maximum depth ($p=0.011$) and mean depth loss ($p=0.047$) between the different occlusion groups when wear was measured with Lava Scan ST. Table 4 summarizes the measured outcomes according to varying intensities of occlusal contact. A significant difference in maximum depth loss ($p=0.004$) was also found between different occlusion groups when measured with 3M True Definition, but not for mean depth ($p=0.058$). The “none” group and the “light occlusal contact” group differed significantly from the “heavy occlusal contact” group for both scanners ($p<0.04$). However, no difference was found between the “none” group and the “light occlusal contact” group for maximum depth loss ($p=1.000$). Regarding the significant difference in mean depth loss for different occlusal groups, only the “light occlusal contact” group was significantly different than the “heavy occlusal contact” ($p=0.046$).

Furthermore, a statistically significant correlation was found between volume loss and area of restoration ($r_s=0.786; p<0.0005$) and between maximum depth and area of restoration ($r_s=0.688; p<0.0005$) for the Lava Scan ST group. The results were similar for the 3M True Definition group between volume loss and area of restoration ($r_s= 0.739; p<0.0005$) and between maximum depth and area of restoration ($r_s= 0.612; p<0.0005$).
A linear regression allowed analysis of the relationship between volume loss and the area of restoration as well as between maximum height loss and the area of restoration. Regarding the Lava Scan ST group, a statistically significant \((p=0.001)\) increase of 1 mm\(^2\) of the area of restorations was associated with an increase in volume loss of 0.005 ± 0.001 mm\(^3\) \((R^2= 0.402)\) and with an increase in maximum height of 3±1 µm \((R^2= 0.230)\). However, for the 3M True Definition group, an increase of 1 mm\(^2\) of the area of restorations was significantly \((p= 0.018)\) associated with an increase in volume loss of 0.003 ± 0.001 \((R^2= 0.394)\), but not significantly \((p=0.135)\) associated with an increase in maximum depth.

2.4. Discussion

Indirect quantitative methods for measuring clinical wear of resin composites have been common practice in dentistry over the last 20 years.[2, 5, 6, 44, 65-72] An accuracy of 10-20 µm has been reported by various authors, stemming from the limitations of the replication procedure and the 3D scanning method.[2, 67, 71] The Lava Scan ST laboratory scanner (3M ESPE) was chosen as the reference group in the present study, as it has been previously validated for measuring wear over a similarly short period of 6 months.[76] Its in vitro single-tooth accuracy is reported to be ~ 10 µm, which is similar to that of the intraoral scanner used in the present study (3M True Definition, 3M ESPE).[52, 53] The average root-mean-square fit for the laboratory scanner (11.7±4.7 µm) was significantly smaller \((p=0.001)\) to that of the intraoral scanner (16.0 ±2.3 µm). This smaller RMS indicates a more accurate fit for the conventional impressions than for the digital impressions, but the higher standard deviation indications a higher variation of the values, which may be associated to the use to stock impression trays or distortion during the impression making or model casting. Also, it may be due to the difference in resolution of scanners.[88] Digital model files (STL files) from the laboratory scanner had an
XYZ resolution of 50 µm, 40 µm, and 30 µm compared to the intraoral scanner, which had an XYZ resolution of 70 µm, 70 µm, and 80 µm, respectively.

Nonetheless, there was good to excellent correlation between wear measurements of the intraoral scanner and the laboratory scanner (ICC 0.734 – 0.997) and no significant differences between volume loss, maximum height loss and mean height loss measurements ($p>0.05$). A noteworthy trend, for the intraoral scanner, although not statistically significant, was to slightly underestimate the maximum height loss of wear occurring at restoration margins and underestimate the restoration area. This was most certainly due to the limited resolution. With a few exceptions, the intraoral scanner was able to detect the same statistically significant differences detected by the laboratory scanner. To our knowledge, this is the first such report of an intraoral scanner being used for quantitative clinical wear measurements. Considering the small sample size of the present study, its short-term nature and the micrometer scale of measurements, the intraoral scanner proved capable of providing clinically relevant wear data about the materials tested.

The clinical wear performance between the incremental-fill and bulk-fill nanocomposites in our study was not statistically significant if both molars and premolars were considered. This is most likely due to the large variation of wear among patients in our study, to the small sample size, and to the short recall period. Significant differences are harder to detect in small sample size groups with high variability. Therefore, data from the premolar group was analyzed separately, as it was the subgroup with the largest sample size and smallest variability.

The premolars restored with the bulk-fill resin composite had a statistically significant greater mean depth loss (17±8 µm) compared to the incremental-fill group (11±5 µm). No difference was found for volume loss or maximum height loss. This could indicate that the Filtek
Bulk Fill Posterior Restorative resin composites may be more susceptible to three-body abrasive wear, which is generally associated with mean height loss. Although mechanical properties of resin composite materials rarely correlate with clinical success,[89] it is noteworthy that internal 3M data shows a significant difference in *in vitro* three-body wear between Filtek Bulk Fill Posterior Restorative and Filtek Supreme Ultra.[90] Since both nanocomposites contain very similar filler content, perhaps this increased three-body wear is due to the properties of the significantly different resin matrix.

Regardless of the material used, significant differences were found between the total volume loss of restorations in premolars (0.080± 0.099 mm³) and molars (0.182± 0.087 mm³). This is most likely due to the larger area of restorations placed in molars. Indeed, between the area and volume loss was found in the present study. This is in agreement with the findings of Lutz, Söderholm *et al.* and Palaniappan *et al.*,[6, 70, 72]

The intensity of occlusal contacts played an important role in the maximum depth loss of the nanocomposites. Indeed, restorations with heavy occlusal contacts had significantly more wear (194±69 µm) versus light (91±55 µm) or no occlusal contacts (74± 29 µm). This is in accordance with the findings of Palaniappan *et al.*, who found significantly more fatigue wear in restorations with heavy occlusal contacts.[6] Furthermore, Lutz *et al.* found 2.5 times more wear in occlusal contact areas than in contact-free areas.[72]

Comparing the numerical quantitative wear values between different clinical trials is questionable because different outcomes are measured. For example, Palaniappan calculates mean vertical wear as the average wear along the restoration margin, whereas we considered the mean vertical wear across whole surface of the restoration.[68] Furthermore, the same authors excluded marginal wear from their volume loss calculations, whereas we included it. DeLong *et
al. excluded small marginal fractures from their measurements, whereas we considered it as fatigue wear, and included it.\textsuperscript{[66]} Cetin et al. calculated volume wear by multiplying the mean vertical wear by the restoration area whereas our software calculated it automatically with two different algorithms.\textsuperscript{[67]} Furthermore, study populations were different, with the largest clinical trials mostly recruiting young female dental students with strict exclusion criteria for parafunctional habits, whereas we had a heterogeneous population without such exclusion criteria.\textsuperscript{[2]}

2.4.1. Limitations

The two main limitations of the present study are the small sample size and its short-term nature. Fifty restorations available at baseline and 40 at the 18-month follow-up visit are the minimum number recommended in the 2001 ADA guidelines for clinical trials on resin composite for posterior restorations.\textsuperscript{[91]} Therefore, the present study should be regarded as presenting preliminary data, instead of offering definitive conclusions. Although efforts were made to match the shape and size of restorations in our split-mouth design, variability was inevitable. This resulted in a skewed premolar/molar distribution (3:1) and area of restorations ranging from 3-52 mm\textsuperscript{2}.

Another potential limitation is the technical sensitivity of the fitting process for aligning baseline and recall digital models. If distortions are present on any of those two models, it can result in alignments that are clinically impossible, such as enamel cusps increasing in height with time. For this reason, alignments were verified by their RMS values but also using clinical judgment. Furthermore, a single examiner analyzed all the models using the same protocol in order to avoid inter-evaluator error. Inter-examiner and intra-examiner reliability has never been measured in clinical trials using quantitative wear analysis methods. Authors have argued that
because the estimated total measurement error (20 µm) is distributed randomly across the study population, it does not affect the true mean.[2]

On several occasions, unusual changes were detected on the enamel surface of the teeth, such as occlusal grooves appearing over time, or buccal enamel increasing in volume. In one case, it was attributed to residual adhesive flash present in the baseline impression but not at recall. In another case, dental plaque on the gingival surfaces failed to be removed at the recall impression. Unusual discrepancies such as these were excluded from the fit region when digital models were aligned and had little impact on the final measurements. However, this process was time consuming and technique sensitive. Smaller discrepancies may have gone undetected. Air-thinning of the adhesive could be problematic for wear measurements and additional care should be taken to verify that all adhesive excess is removed before the impressions are taken. Furthermore, patients should be asked to brush their teeth at the recall appointment to avoid any plaque or debris interfering with the impressions.

The lower resolution of the 3M True Definition scanner made selecting the outline of the restorations more difficult. This was especially true in restorations with good marginal integrity at the recall appointment, because there outline could not be detected as easily on the monochromatic digital models. Photographs and anatomical landmarks were used to guide the examiner in cases where the restoration outline was uncertain. Future advances in intraoral scanner technology, such as color scans or higher resolution, will certainly help with this issue. Overall, there was excellent agreement (ICC = 0.997) between the restoration area of the 3M True Definition scanner and the Lava Scan ST, indicating that the outlines were similar. In any case, restoration outlines selected with the software usually went beyond the clinical restoration outline in order to ensure all marginal wear was captured. Because the enamel margins wear
much slower than the resin composite, their inclusion as part of the restoration outline should have little impact on the measurements. However, if examiners left marginal excess, this could lead to wear being overestimated.

Enamel wear was not measured in the current study due to the short follow up time. Tantbirojn et al. used the same Lava Scan ST scanner to measure enamel wear after 6 months in patients with gastroesophageal reflux disease (GERD) compared to healthy controls.[76] They reported that 80 out of 120 anterior or posterior teeth in the control group had less than 20 µm vertical enamel wear, which they considered to be below the measuring threshold in their study. Palaniappan et al. found an average vertical wear at occlusal area of posterior teeth to be approximately 19±4 µm/year for light contacts and 36±8 µm/year for heavy contacts.[68] For comparison, the present study found that restorations with at least one heavy contact had 22±13 µm of mean vertical wear and 194±69 µm of maximum vertical wear at 6 months.

Wear of restorations is much higher during the first 6 months than any other period thereafter. For this reason, wear of resin composites is usually categorized as running-in wear and steady-state wear. Consequently, values presented in the current research study should not be extrapolated over a longer period of time, as the rate of wear is not initially linear.

2.5. Conclusion

Within the limitations of this preliminary research study:

1. Intra-oral scanners may be suitable for clinical assessment of wear, but a higher resolution would be preferable for research use.

2. The three-body abrasive wear of Filtek Bulk Fill was greater than that of Filtek Supreme Ultra in the premolar group (p=0.043)
3. Larger restorations are correlated with a significant increase in volume loss and maximum vertical wear ($p<0.0005$)

4. Heavy occlusal contacts are significantly associated with high maximum vertical wear in the conventional and bulk-fil nanocomposites evaluated in this clinical trial ($p=0.011$).
# TABLES

## Table 1: Resin composite systems used

<table>
<thead>
<tr>
<th>Material</th>
<th>Type</th>
<th>Polymer</th>
<th>Nanoparticle fillers</th>
<th>Nanocluster size</th>
<th>Filler content (% by volume)</th>
<th>Filler content (by weight)</th>
<th>Depth of cure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtek Supreme Ultra Universal Restorative</td>
<td>Nano</td>
<td>bis-GMA, UDMA, TEGDMA, PEGDMA, bis-EMA</td>
<td>20 nm silica nanoparticles, 4 to 11 nm zirconia nanoparticles</td>
<td>0.6-10 µm aggregated zirconia/silica nanoclusters (comprised of silica and zirconia nanoparticles)</td>
<td>63.3%</td>
<td>78.5%</td>
<td>2 mm</td>
</tr>
<tr>
<td>Filtek Bulk Fill Posterior Restorative</td>
<td>Nano</td>
<td>Proprietary AUDMA and AFM, UDMA, DDDMA</td>
<td>20 nm silica nanoparticles, 4 to 11 nm zirconia nanoparticles, 100nm ytterbium trifluoride nanoparticles</td>
<td>0.6-10 µm aggregated zirconia/silica nanoclusters (comprised of silica and zirconia nanoparticles)</td>
<td>58.4%</td>
<td>76.5%</td>
<td>5 mm (Class II)</td>
</tr>
</tbody>
</table>
Table 2: Measured outcomes of Class II restorations after 6-month recall

<table>
<thead>
<tr>
<th></th>
<th>Volume Loss (mm³) - Lava Scan ST</th>
<th>Volume Loss (mm³) - 3M True Definition</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (n=24)</td>
<td>0.106 (0.104)</td>
<td>0.116 (0.119)</td>
<td>0.376</td>
</tr>
<tr>
<td>Bulk Fill (n=11)</td>
<td>0.121 (0.136)</td>
<td>0.136 (0.153)</td>
<td></td>
</tr>
<tr>
<td>Supreme Ultra (n=13)</td>
<td>0.093 (0.071)</td>
<td>0.099 (0.083)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Mean (SD)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total (n=24)</td>
<td>0.113 (0.071)</td>
<td>0.104 (0.058)</td>
</tr>
<tr>
<td></td>
<td>Bulk Fill (n=11)</td>
<td>0.106 (0.044)</td>
<td>0.109 (0.055)</td>
</tr>
<tr>
<td></td>
<td>Supreme Ultra (n=13)</td>
<td>0.120 (0.090)</td>
<td>0.099 (0.061)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Mean (SD)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total (n=24)</td>
<td>0.014 (0.009)</td>
<td>0.015 (0.007)</td>
</tr>
<tr>
<td></td>
<td>Bulk Fill (n=11)</td>
<td>0.014 (0.008)</td>
<td>0.016 (0.008)</td>
</tr>
<tr>
<td></td>
<td>Supreme Ultra (n=13)</td>
<td>0.015 (0.011)</td>
<td>0.014 (0.005)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Mean (SD)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total (n=24)</td>
<td>14.834 (13.253)</td>
<td>14.174 (13.067)</td>
</tr>
<tr>
<td></td>
<td>Bulk Fill (n=11)</td>
<td>14.708 (16.002)</td>
<td>14.187 (15.864)</td>
</tr>
<tr>
<td></td>
<td>Supreme Ultra (n=13)</td>
<td>14.940 (11.102)</td>
<td>14.163 (10.841)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Mean (SD)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total (n=24)</td>
<td>10.147 (6.569)</td>
<td>9.532 (6.299)</td>
</tr>
<tr>
<td></td>
<td>Bulk Fill (n=11)</td>
<td>28.894 (18.574)</td>
<td>28.100 (18.446)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Mean (SD)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total (n=24)</td>
<td>14.834 (13.253)</td>
<td>14.174 (13.067)</td>
</tr>
<tr>
<td></td>
<td>Bulk Fill (n=11)</td>
<td>14.708 (16.002)</td>
<td>14.187 (15.864)</td>
</tr>
<tr>
<td></td>
<td>Supreme Ultra (n=13)</td>
<td>14.940 (11.102)</td>
<td>14.163 (10.841)</td>
</tr>
</tbody>
</table>
Table 3: Measured outcomes of Class II restorations in premolars after 6-month recall

<table>
<thead>
<tr>
<th></th>
<th>Volume Loss (mm³) - Lava Scan ST</th>
<th>Volume Loss (mm³) - 3M True Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Bulk Fill (n=8)</td>
<td>0.103</td>
<td>(0.141)</td>
</tr>
<tr>
<td>Supreme Ultra (n=10)</td>
<td>0.062</td>
<td>(0.046)</td>
</tr>
</tbody>
</table>

**p value** 1.000 0.633

<table>
<thead>
<tr>
<th></th>
<th>Maximum Depth Loss (mm) - Lava Scan ST</th>
<th>Maximum Depth Loss (mm) - 3M True Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Bulk Fill (n=8)</td>
<td>0.101</td>
<td>(0.040)</td>
</tr>
<tr>
<td>Supreme Ultra (n=10)</td>
<td>0.092</td>
<td>(0.074)</td>
</tr>
</tbody>
</table>

**p value** 0.237 0.146

<table>
<thead>
<tr>
<th></th>
<th>Mean Depth Loss (mm) - Lava Scan ST</th>
<th>Mean Depth Loss (mm) - 3M True Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Bulk Fill (n=8)</td>
<td>0.017</td>
<td>(0.008)</td>
</tr>
<tr>
<td>Supreme Ultra (n=10)</td>
<td>0.011</td>
<td>(0.005)</td>
</tr>
</tbody>
</table>

**p value** 0.043 0.034

<table>
<thead>
<tr>
<th></th>
<th>Area (mm²) - Lava Scan ST</th>
<th>Area (mm²) - 3M True Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Bulk Fill (n=8)</td>
<td>8.256</td>
<td>(4.448)</td>
</tr>
<tr>
<td>Supreme Ultra (n=10)</td>
<td>11.660</td>
<td>(7.771)</td>
</tr>
</tbody>
</table>

**p value** 0.515 0.573

Table 4: Measured outcomes of Class II restorations with varying intensity of occlusal contacts after 6-month recall

<table>
<thead>
<tr>
<th>Occlusal Contact</th>
<th>Volume Loss (mm³) - Lava Scan ST</th>
<th>Maximum Height Loss (mm) - Lava Scan ST</th>
<th>Mean Height Loss (mm) - Lava Scan ST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>None</td>
<td>0.076</td>
<td>(0.077)</td>
<td>0.074</td>
</tr>
<tr>
<td>Light</td>
<td>0.093</td>
<td>(0.095)</td>
<td>0.091</td>
</tr>
<tr>
<td>Heavy</td>
<td>0.159</td>
<td>(0.137)</td>
<td>0.194</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Occlusion Contact</th>
<th>Volume Loss (mm³) - 3M True Definition</th>
<th>Maximum Height Loss (mm) - 3M True Definition</th>
<th>Mean Height Loss (mm) - 3M True Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>None</td>
<td>0.066</td>
<td>(0.058)</td>
<td>0.079</td>
</tr>
<tr>
<td>Light</td>
<td>0.119</td>
<td>(0.108)</td>
<td>0.081</td>
</tr>
<tr>
<td>Heavy</td>
<td>0.174</td>
<td>(0.172)</td>
<td>0.177</td>
</tr>
</tbody>
</table>

Within a given row of three, values with different letters are significantly different ($p < 0.05$)
FIGURES

Figure 1: Various types of wear on a posterior tooth and restoration

Figure 2: Leinfelder standards for cast evaluation
REFERENCES


