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3D Surface Analysis as a Method to Evaluate Progress of Students' Restorative Skills Over Time

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ABSTRACT

Introduction: Digital scanning technology in dental education is on the rise offering precise feedback for indirect restorations. This technology could have similar applications for direct restorations worth exploring. To this end, this study used 3D surface analysis to measure students' ability to restore teeth's occlusal and proximal contours over time.

Method: 169 teeth restored with composite were scanned with a desktop scanner (E3, 3Shape, Copenhagen) at the end of an academic year. Compound composite restorations were performed in three iterations by 2nd year students enrolled in their first preclinical course. Standard Tessellation Language (STL) files of all restored teeth were analysed for fit with a digital reference using a surface matching software (Geomagic Control 2021; 3D systems). The 3D digital surface analysis output was compared at the different iterations. Additionally, the association between the 3D surface analysis output and scores awarded by tutors was assessed to evaluate this technology's potential to enhance students' independent learning.

Results: Assessment of restored surfaces using 3D surface analyses showed statistically significant differences between second and third iterations ($p < 0.001$). There was a positive association between tutors' scores and the 3D surface analysis data.

Conclusion: The results suggest that digital scanning and 3D surface analysis technology could enhance feedback and promote students' independent learning.

1 | Introduction

Composite restorations require dental operators to have fine psychomotor skills gained and maintained through years of practice. Practice alone is not sufficient to improve skills. Immediate error correction feedback is necessary to prevent incorrectly learnt skills and patients' harm [1]. Deficient composite restorations can have detrimental effects on mastication, periodontal health and increased risk of secondary decay [2–4]. Dental students receive immediate error correction feedback from their educators. Starting with simulation typodont teeth, students complete restorations and tutors assess restorations' quality against pre-established standards [5]. These formative assessments generate feedback information. Students apply this feedback to improve their future performance and teachers use it to adapt their teaching to students' needs [6].

To promote students' understanding of their tutors' feedback, formative assessments incorporate strategies such as self-assessment, rubrics and assessment of exemplars [7]. In addition, these activities engage students to actively assess their own work and others, promoting self-regulation and making students more resourceful, adaptable and able to maintain competency [8]. Therefore, tutors need to provide immediate error feedback [1] and, at the same time, empower students to be part of the assessment process, giving them opportunities to act on the feedback provided [9]. Currently, the quality of occlusal and interproximal contours of restored teeth is assessed with visual and tactile methods using checklists or rubrics to ensure the reliability and validity of the evaluation [10, 11]. Although strategies are in place to reduce assessor bias, subjectivity inherent to human judgement cannot be eliminated completely from the assessments [12].

Consistency of tutors' feedback is challenged by diversity of teachers' philosophy, background and experience [13]. This often results in tutors' having different views on what constitutes acceptable restorative work [14]. The quality of tutors' feedback and teaching abilities is further undermined by the casualisation of tertiary education [15] and difficulties in recruiting, training and retaining full-time teaching staff [16] due to inadequate pay and limited pay progression within clinical teaching positions [17]. Inconsistency of feedback not only concerns students [18] but it also distorts evidence about the effectiveness of teaching strategies utilised in a course.

Consequently, digital approaches are increasingly being used in preclinical settings to assess students' preparations for indirect restorations providing objective and accurate information about students' technical abilities [19–21]. 3D surface analysis has been used for indirect restorations, such as generating feedback on crown preparations and full crown wax ups [22, 23]. Digital assessment tools evaluating and reporting on the quality of students' crown preparations have been reported to be particularly useful for students with poor performance [24]. In addition, 3D surface analysis has been used to investigate the morphology of proximal areas created by different matrix systems with composite [25]. These uses demonstrate the potential of 3D surface analysis to objectively assess dental composite restorations' contours and to quantify the effect teaching strategies have on students' restorative abilities. Digital scanning and 3D surface analysis technology are reported to be useful to measure students' preparations skills [26]. However, it remains unknown if direct restorative skills progress can be monitored with this technology. To this end, this study used a 3D surface analysis to measure students' ability to restore occlusal and proximal contours of teeth over time. In addition, the association between the 3D surface analysis output and scores awarded to students' work by tutors was assessed to evaluate if the technology could be used to enhance independent learning.

2 | Materials and Methods

This study was approved by the institution's ethics' committee Ref no 2019/455.

At the end of the academic term, 169 teeth restored with composite were scanned with a benchtop scanner (E3, 3Shape). The teeth were used for one of many preclinic activities performed by students in their preclinical course. Restorations were performed in three iterations by 2nd year students enrolled in the second trimester of their preclinical course. In their first trimester, students prepared and restored teeth with amalgam. Didactic materials, lectures and demonstrations were accessed by students online before their first attempt restoring the premolar with composite.

The first iteration was students' first attempt at restoring a compound preparation with composite resin. They restored a standard mesio-occlusal preparation in a #25 (Nissin Catalogue code UL 54B). Three days later (second iteration), students restored a fresh second left premolar with a standard mesio-occlusal preparation (Nissin Catalogue code UL 54B). Students did not have preclinical activities between the first and second iterations. Between the second and third iterations, students had six sessions of practice, two sessions weekly, where students cut and restored compound preparations with composite resins in posterior teeth. During these three-hour sessions, students self- and peer-assessed their work and then received feedback from a tutor. In a third iteration, students restored a #16 with a standard mesio-occlusal preparation (Nissin Catalogue code UR 64).

2.1 | Restorative Activity During Iterations

Students were required to restore standard prepared teeth in each of the iterations to ensure all preparations were equally challenging. Students had 1 h to restore the tooth under exam conditions without help from tutors or peers and without consulting teaching resources. All teeth were restored using an adhesive system (Prime&Bond active, Dentsply, Germany), Composite resin (Spectra ST, Dentsply, Germany) (A2), sectional matrix system (Triodent, Dentsply, New Zealand) and under dental dam isolation. No interproximal polishing strips were used.

2.2 | Data Collection and Analysis

2.2.1 | Three-Dimensional Surface Analysis of Restored Teeth

2.2.1.1 | Digital References. A total of ten unprepared premolars and molars (#25 Nissin, #16 Nissin) were digitally scanned using a benchtop 3D scanner (E3, 3Shape) to generate and validate an STL file for use as a digital reference model. The first scan was designated as the reference model, while the subsequent nine scans were utilised to evaluate the precision and inter-scan variability of the scanner across the 10 teeth. A three-dimensional deviation analysis was performed to assess the reproducibility and accuracy of the scans. Statistical analysis revealed no significant differences in precision between the first scan and the remaining nine scans. Consequently, the first scanned tooth was selected as the reference for conducting deviation analysis on the student restorations [27].

2.2.1.2 | Restored Teeth. All teeth included in the study were mounted in a putty jig to ensure consistency of scanning, then scanned individually with a desktop scanner (E3, 3Shape, Copenhagen). A Standard Tesselation File (STL) was generated and exported. The STL of the restored tooth was imported into a metrology software (Geomagic Control 2021; 3D systems). A superimposition was performed with an initial alignment, best fit algorithm and 3D comparison of the files was then performed. Measurements were separated into two areas: Figure 1 shows the regions analysed: occlusal (up to mesial pit) and proximal (including marginal ridge).

2.2.1.3 | Comparing Digital References With Restored Teeth. The output of the metrology software was used to compare to what extent each restored tooth matched the digital

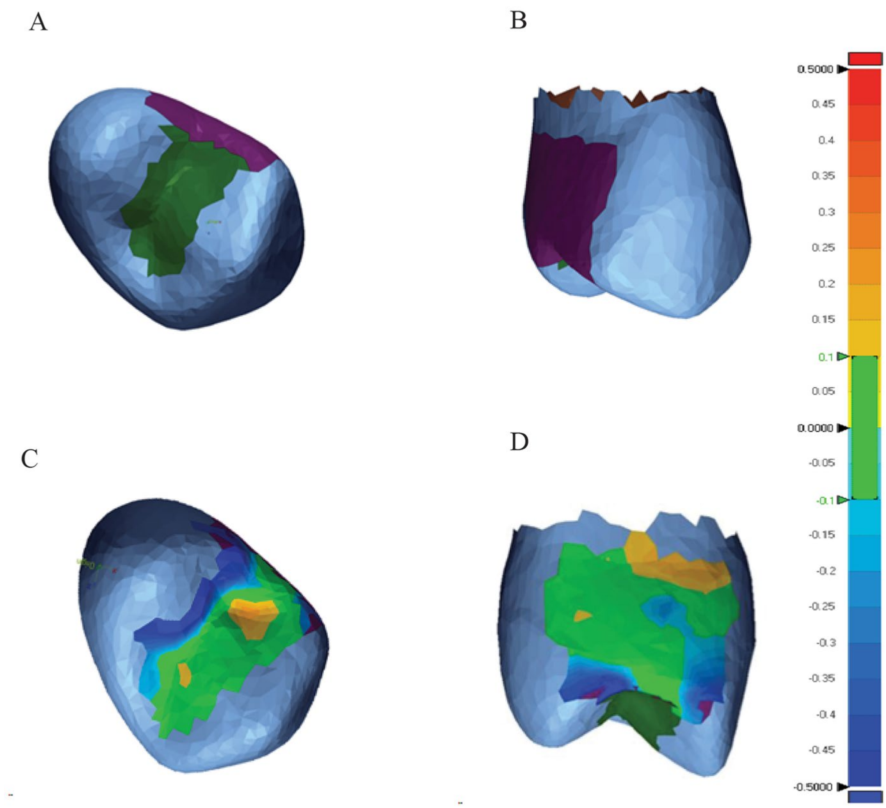

FIGURE 1 | STL images of scanned premolars. (A) Occlusal (Green) and (B) Proximal (Purple) areas. Colour map indicating areas of fitness with unprepared tooth. (C) Occlusal (D) Proximal.

reference with 0.1 mm tolerance. The level of agreement between the reference and restored tooth is expressed in percentage (%). The higher the percentage, the closer the shape of the restoration to the original tooth, indicating student ability to restore the tooth to its original form. A 0.1 mm tolerance was selected as an indication of clinically acceptable range as the unaided human eye resolution is known to be 0.2 mm [28]. In addition, areas of contact or near contact (ACNC) for molars and premolars are between $< 50\,\mu m$ and $350\,\mu m$ [29]. In the colour map produced by the program, green indicates agreement between 0.1 and -0.1 mm (Figure 1).

All data on the level of agreement between digital reference and restored teeth were exported and collated in Excel spreadsheets and assessed for normality using Kolmogorov–Smirnov. Repeated measures of ANOVA of the 3D surface analysis data determined mean differences between iterations. One-way ANOVA was used to determine the association of 3D surface output with tutors' scores.

2.3 | Tutors' Grading

2.3.1 | Calibration

Seven tutors assessed the same composite restorations individually. Interrater agreement between tutors was calculated using the agreement test Somer's D and Spearman correlation analysis. All pairs show strong agreement (Mean 0.81 Correlation), with the lowest correlation at 0.69 and the highest at 1.00, suggesting an acceptable to a high level of interrater agreement [30].

2.3.2 | Tutors' Assessment

Tutors assessed students' restorations individually using the provided rubrics. The rubrics were modified and simplified from the Rye/USPHS Clinical Criteria [10]. Table 1. Scores were entered in Microsoft Forms (Office MS, USA); the link to Forms was hosted in MS OneNote (Web version MS, USA). Data from MS Forms was then collected and collated in one MS Excel spreadsheet.

Only Anatomy and Point of Contact criteria were included in this study.

3 | Results

3.1 | 3D Surface Analysis

A repeated measures analysis of variance (ANOVA) was performed to examine the differences in surface areas of restorations at both the occlusal and proximal aspects across three iterations. The results revealed significant differences in both regions. Scans of the occlusal surface showed statistically significant differences between the three iterations. Specifically, the third iteration exhibited a significantly larger percentage of restoration surface areas more closely resembling the intact tooth surfaces, in comparison to both the first and second iterations. Additionally, there was a significant difference between the first and second iterations, with the first iteration showing a higher percentage of restoration surface areas more like those of the intact tooth. Similarly, the proximal surfaces of the restorations showed significant differences across the iterations. The third iteration demonstrated a significantly larger percentage of restoration surface areas closer to the intact tooth surfaces compared to the first and second iterations. Notably, three participants were absent during the third iteration due to illness. These findings indicate that surface characteristics of restorations improve over successive iterations, particularly with respect to achieving a closer resemblance to the original tooth morphology (Table 2).

The 3D surface data distribution shows an improvement of restorations in the proximal and occlusal surface areas between the first and third iterations. In the third iteration, proximal surface areas were all above 50% of the middle quartile. Although occlusal contours improved, some restorations in the middle quartile remained less than in the first iteration and below 40% Figure 2.

3.2 | Tutors' Scores Analysis: Association Between 3D Surface Analysis and Tutors' Scores

There was an association between tutors' scores and the 3D surface analysis data. The association was statistically significant in the first iteration, occlusal surface area and in the third iteration occlusal and proximal surface areas. Tutors' scores increased from standards not met to an acceptable level; the 3D surface analysis data output also increased (Table 3). This is notable in all iterations in the occlusal surface area and in the second and third iterations in the proximal surface area.

4 | Discussion

Analysis of 3D surface data and tutors' scores identified improvements on students' compound restorations over time. As expected, restorations' surface areas, occlusal and proximal, were significantly better after six sessions of practice. But digitalisation allowed analysis of restorations in sections providing detailed information on students' restorative skills progress by sections. For instance, the proximal aspect of the restoration was the most accurate of the surfaces restored since matrices provide a scaffolding that reproduces the curvatures of the tooth's proximal aspect [31]. And yet, occlusal was the aspect of the tooth's contour students improved the most. This demonstrates clear improvement in students' dexterity as occlusal aspects are restored 'free hand' without any scaffolding. In addition, the third iteration was done in an upper molar. A tooth with a more intricate occlusal morphology, challenging access and visibility. It can be argued that some improvements between the first two

TABLE 1 | Marking criteria for two surfaces composite restorations.

Criteria	Ideal	Acceptable	Standards not met
Anatomy	Accurate reproduction of tooth anatomy features cusp, pits, and grooves.	Vague reproduction of tooth anatomy features.	Incorrect/lack anatomy features and or change in anatomy due overuse of polishing burs.
Margins	Continuity between composite and tooth	Margins slightly over-/under-filled.	Gross under-/over-extension.
Point of Contact	Accurate reproduction of B[a], L, O and G embrasures. Resistance to flossing.	One embrasure not present. Slight resistance to flossing.	More than one embrasure not present and/or no resistance to flossing.
Finishing	Smooth and glossy surface. There are no scratches or voids.	Smooth surface but with some scratches and small voids.	Rough surface and/all multiple scratches and voids.

[a]Buccal (B), Lingual (L), Occlusal (O), Gingival (G).

TABLE 2 | Mean (%) differences of restorations' occlusal and proximal surface areas within 0.1 mm of intact tooth between iterations.

Areas	First iteration ($n=57$)	Second iteration ($n=57$)	Third iteration ($n=54$)	F	Post hoc
Occlusal	43.00 (15.63)	38.11 (15.56)	50.06 (12.91)	8.349	First > Second ($F=3.757$, $p=0.058$) Third > First ($F=7.929$, $p=0.007$) Third > Second ($F=19.496$, $p<0.001$)
Proximal	52.32 (13.08)	50.32 (11.68)	59.30 (12.07)	10.874	Third > First ($F=8.767$, $p=0.005$) Third > Second ($F=13.394$, $p<0.001$)

Note: $p<0.05$ indicates statistical significance.

iterations and the third iteration could be explained by restoring different teeth. Although counterintuitive, an upper second premolar may be more difficult to restore than an upper first molar. This, however, would need to be investigated further.

Restorations' surface areas, occlusal and proximal, restored in the second iteration were worse than in the first iteration. The decrease in the percentage of restoration surface areas resembling the intact tooth surfaces between the first and second iterations can be attributed to the short observation period, which did not allow students to practice between iterations [32] and the repeated observations made on the same subject [12]. These results demonstrate that 3D scanning technology can analyse restoration contours and highlight the parts students may find

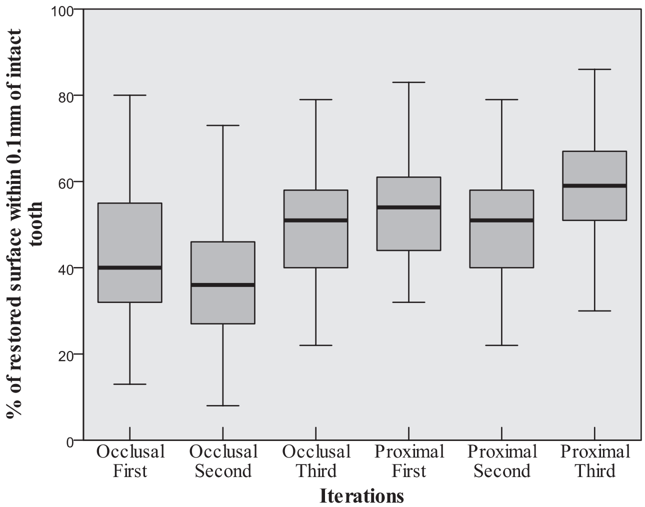

FIGURE 2 | Box plot showing surface area changes in three iterations.

challenging to restore. More importantly, it shows the potential to improve feedback by reporting on various aspects of the restoration's contours.

The act of evaluating students' work quality generates information and creates feedback for students and teachers [33]. 3D surface analysis technology generates objective information, adding a source of feedback with the potential to enable self-regulation. Students could monitor and reflect on their performance by scanning their restorations and generating colour deviation maps that illustrate how close the restoration is from the original tooth's shape. Information visually reported in sections and showing areas of congruence, excess or deficiency can be an eloquent message for students to focus their efforts and practice more independently. Students, particularly in their earlier stages of training, still require considerable guidance and support from their tutors [11], and a three-dimensional colour deviation map of a student's restoration could be used to illustrate and facilitate dialogue and feedback between tutor and student. Furthermore, 3D surface analysis data reported as a percentage or image can add objectivity to tutors' judgements, who often disagree on what constitutes acceptable restorative work [14].

The aggregation of 3D surface data of students' restorations can objectively inform course designers about the impact an educational intervention has on students' learning. As a result, instructors can use an evidence-based approach for their teaching and educational design. It would be of value to know, for instance, if significant improvements are possible by adding or subtracting sessions of practice or by modifying some other aspect of the learning intervention.

Although this study demonstrated a positive association between tutors' scores and digital output, the potential of 3D

TABLE 3 | Analysis of the relation between tutors' scores and 3D surface data.

	Occlusal surface area				Proximal surface area			
Tutors scores: anatomy	***n***	**Mean (SD)**	***F***	***p***	**Tutors scores: point of contact**	***n***	**Mean (SD)**	***F***	***p***
First iteration					**First iteration**				
Standard not met.	28	37.55 (14.52)	7.48	0.008**	Standard not met.	31	52.91 (11.99)	0.09	0.77
Acceptable.	29	48.28 (15.08)			Acceptable.	26	52.00 (11.51)		
Total	57	43.01 (15.64)			Total	57	52.49 (11.68)		
Second iteration					**Second iteration**				
Standard not met.	23	35.61 (14.96)	1	0.32	Standard not met.	17	47.39 (13.99)	1.23	0.27
Acceptable.	34	39.81 (15.96)			Acceptable.	40	51.58 (12.66)		
Total	57	38.11 (15.57)			Total	57	50.33 (13.09)		
Third iteration					**Third iteration**				
Standard not met.	12	38.80 (9.40)	14.8	< 0.001***	Standard not met.	19	55.04 (13.18)	3.86	0.05*
Acceptable.	42	53.29 (12.00)			Acceptable.	35	61.62 (10.93)		
Total	54	50.07 (12.92)			Total	54	59.31 (12.07)		

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$ is statistically significant.

surface data to create individualised feedback for students cannot be ignored. Many schools are already using such technology for digital impressions and, as dental digital technology becomes mainstream, access to hardware and software should become easier [34]. This means that real-time analysis of restorations via 3D metrology software is possible and could give immediate feedback to the learner.

There are limitations to 3D surface analysis technology to evaluate students' composite restorations. Currently, restoration margins and finishing cannot be assessed with the proposed method. However, 3D surface analysis could elucidate to what extent margins and finishing can alter restorations' contours. This could be particularly valuable for students learning to recontour and finish composite restorations. Scanners, software, data management and computer power are costly, and the logistics of scanning teeth can be cumbersome. Teeth scanned in this study were removed from the teeth model and placed in a gig. This is time consuming, and the benefits from this may not offset the time that could have been used in a more conventional teaching activity. This area is worth exploring as institutions face challenges recruiting, training and retaining teaching staff [15, 17].

This study showed a positive association between the 3D surface analysis data and tutors' scores. This association is clearly significant in the third iteration. This could be explained by tutors having more experience grading restorations by the third iteration. Suggesting that despite being calibrated tutors' assessment abilities improve with practice. Interestingly, there was a strong association between 3D surface data and tutors' scores in the first iteration, but only the occlusal aspect of the restoration. This finding needs to be explored further. Future studies could investigate the use of 3D surface analysis for tutor training and grading validation.

As technology improves and becomes more accessible, new workflows involving scanners and 3D data analysis can create a system for personalised and immediate feedback based on precise information about students' work quality. Recognising errors immediately would allow for correction and prevention of poorly learnt skills [1]. In the early stages of learning, tutors are the primary source of advice for correcting and preventing errors. Optimal advice depends on a shared understanding of quality digital technology that could help to create. There is abundant room for future research and development of 3D surface analysis for teaching direct restorations, starting with the development of 3D surface analysis protocols and workflows for students and tutors to facilitate feedback and independent learning.

4.1 | Study Limitations

This study is limited by having three students absent in the third iteration due to sickness. This could have distorted the results over time, but not the positive association between tutors' scores and the 3D surface analysis data.

5 | Conclusion

3D Surface analysis measured an improvement in restoration contours, and there was a positive association between tutors scores and digital output. The results suggest that digital scanning and 3D surface analysis technology could enhance tutors' feedback and promote students' independent learning.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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