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UNIVERSIDADE ESTADUAL PAULISTA "JÚLIO DE MESQUITA FILHO"
Instituto de Ciência e Tecnologia
Campus de São José dos Campos

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Volumetric measurement of sleep bruxism-like indentations on acrylic surface using intraoral scanner and inlay wax

Medição volumétrica de indentações semelhantes ao bruxismo do sono na superfície de acrílico usando scanner intraoral e cera para fundição

Thaviporn LIMRACHTAMORN[1], **Teekayu Plangkoon JORNS**[2], **Supanigar RUANGSRI**[2], **Rajda CHAICHIT**[3], **Jarin PAPHANGKORAKIT**[2]

1 - Thammasat University, Faculty of Dentistry, Pathumthani, Thailand.
2 - Khon Kaen University, Faculty of Dentistry, Department of Oral Biomedical Science, Khon Kaen, Thailand.
3 - Khon Kaen University, Faculty of Dentistry, Department of Preventive Dentistry, Khon Kaen, Thailand.

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ABSTRACT

Objective: This *in vitro* study introduced methods to measure the volume of sleep bruxism-like indentations to be used in the evaluation of bruxing intensity. **Material and Methods:** Indentations of different sizes and depths were created on seven clear heat-cured acrylic blocks. The volume of all indentations was first measured by a profilometer as the gold standard, then by scanning the negative replicate of the indentations obtained from polyvinyl siloxane impressions both with double impression technique (IOSD) and putty silicone only (IOSP), using an intraoral scanner, and lastly by weighing the blue inlay wax used to fill the indentation. Agreements between the intraoral scanning and blue inlay wax methods compared to the profilometer were tested using ICC. **Results:** ICCs between IOSD, IOSP, inlay wax and the profilometer were 0.963, 0.950, and 0.999 respectively. The average volumetric error tended to be greater with IOSD (30.51±8.34 %) and IOSP (35.68±10.29 %) compared to that of blue inlay wax (24.87±10.29 %). Blue inlay wax was apparently superior to IOSD and IOSP in quantifying small and deep indentations. **Conclusion:** Both intraoral scanner and blue inlay wax had high agreement in volumetric measurement of acrylic indentations while the wax method performed the best. These methods could be used to measure the amount of wear on occlusal splints.

KEYWORDS

Intraoral scanner; Occlusal wear; Occlusal splints; Polyvinyl siloxane; Sleep bruxism.

RESUMO

Objetivo: Este estudo *in vitro* introduziu métodos para medir o volume de indentações semelhantes às do bruxismo do sono para serem usadas na avaliação da intensidade do bruxismo. **Material e Métodos:** Foram criadas indentações de diferentes tamanhos e profundidades em sete blocos de acrílico transparente curado pelo calor. O volume de todas as indentações foi medido primeiro com um perfilômetro como padrão de ouro, depois através da digitalização da réplica negativa das indentações obtidas a partir de impressões de polivinil siloxano, tanto com a técnica do silicone de impressão dupla (DS) como apenas com silicone pesado (SP), utilizando um escanêr intra-oral e, por último, pesando a cera para fundição azul utilizada para preencher a indentação. As concordâncias entre os métodos de digitalização intra-oral e de cera para fundição azul, em comparação com o perfilômetro, foram testadas utilizando o Coeficiente de Correlação Intraclasse (ICC). **Resultados:** Os resultados mostraram que os ICCs entre o DS, o SP, a cera para fundição azul e o perfilômetro foram 0.963, 0.950, e 0.999 respetivamente. O erro volumétrico médio tendeu a ser maior com o DS (30.51±8.34%) e o SP (35.68±10.29%) comparado com o da cera para fundição azul (24.87±10.29%). A cera para fundição azul foi aparentemente superior ao DS e ao SP na quantificação de indentações pequenas e profundas. **Conclusão:** Tanto o scanner intra-oral como a cera para fundição azul apresentaram uma elevada concordância na medição volumétrica das indentações acrílicas, enquanto o método da cera teve o melhor desempenho. Estes métodos podem ser utilizados para medir a quantidade de desgaste em placas oclusais.

PALAVRAS-CHAVE

Escâner intra-oral; Desgaste oclusal; Placas oclusais; Polivinilsiloxano; Bruxismo do sono.

INTRODUCTION

Sleep bruxism is defined as the repetitive contraction of jaw muscles characterized by clenching or grinding of teeth and/ or by bracing or thrusting of the mandible [1]. This can result in masticatory muscle hypertrophy, cracked teeth, failed restorative materials, tooth sensitivity, toothache, loss of periodontal support [2]. In addition, sleep bruxism might be related to temporomandibular disorders (TMD) [3,4].

One of the most common treatments for sleep bruxism is the prescription of flat plane stabilization occlusal splint [5]. The main goal of the splint is to protect the teeth from damage caused by clenching or grinding [2,6,7]. It is generally recommended that occlusal splint patients should be scheduled to be returned for evaluation within 2-7 days after the delivery visit. During the follow-up visit, the bruxing wear on the occlusal splint should be examined so the sleep bruxism activity could be monitored. Routinely, dentists are only able to examine the positions and approximate changes of the wear but not its magnitude. This makes it difficult to accurately monitor the efficacy of occlusal splint treatment.

A profilometer has been used as the gold standard in quantifying the amount of worn surface [8] and surface roughness [9] but it is impractical for clinical use. Digital impression using intraoral scanners has gained increased popularity and tended to be preferred by both practitioners and patients in terms of comfort, total working time [10] and accuracy [11]. The accuracy of intraoral scanning was found to be not significantly different from that of conventional impression when the marginal gap of the fabricated crown was examined [12]. When different types of intraoral scanners were tested against various conventional impression materials in real patients, the precision of the dental arch obtained from the intraoral scanners fell between vinysiloxanether (highest precision) and alginate (lowest precision), the older scanning systems (*e.g.* Lava COS®, Cadent iTero®) being less accurate than the modern ones (*e.g.* 3Shape TRIOS®) [13]. The authors suggested using intraoral scanners for single-unit restorations up to 4-unit fixed partial dentures rather than whole arch rehabilitation. Among seven digital impression systems tested, TRIOS 3® was shown to have the best balance of speed and accuracy due to its good trueness and precision for complete arch scanning [14]. Recently, intraoral scanner has been introduced to quantify wear volume on tooth surfaces in both laboratory and clinical studies. For example, Kumar *et al* [15]. measured the amount of tooth loss from enamel samples by scanning their surface before and after immersion in citric acid and found that the intraoral scanner was able to detect early tooth wear but the accuracy was low. O'toole *et al.* compared the volumetric loss of tooth surface over 3 years on dental stone duplicated with conventional silicone impression between the intraoral scanner and profilometer, analyzed with the gold-standard software, and demonstrated that the values measured with both instruments were significantly different [16]. Mitrirattanakul *et al.* used an intraoral scanner (iTero Element® 2) to detect the loss of tooth surface in vitro and found that the overall sensitivity was 98% compared to micro-CT image with the accuracy of 97% [17]. In another study, intraoral scanning of an alveolar bone-defect model revealed acceptable precision compared to the gravimetric method based on the Archimedes' principle in which silicone impression was used to fill the defect and its volume was derived by dividing its mass by the density [18]. Regarding the above findings, the present study aimed to introduce practical methods to quantify the volume of indentations on acrylic surface using the intraoral scanner and blue inlay wax and compare the accuracy between these methods and the profilometer. The findings could help clinicians to more accurately monitor the level of sleep bruxism in splint-wearing patients.

MATERIAL AND METHODS

Preparation of indentations

Circular and linear indentations of different sizes and depth were created on clear heat-cured acrylic blocks (labelled A to G) (Meliodent®, Kulzer, Germany), ten of each. Blocks A and B represented shallow (approximately 0.5 mm deep) and deep (approximately 1 mm deep) circular indentations whereas blocks F and G represented shallow (approximately 0.5 mm deep) and deep (approximately 1 mm deep) linear indentations. Blocks C, D and E represented shallow linear indentations with different lengths (approximately 2, 3, and 4 mm long) (Figure 1). All indentations were created using a round steel bur No.014 with a micromotor vertically stabilized on a fixed stand. Although the drilling method was standardized, it was not possible to create all indentations with exactly same dimensions. However, the sizes of final indentations in the same group were similar and could be grouped in each of the above categories. The average actual dimensions of all indentations in each acrylic block determined by the profilometer were shown in Table I.

Volumetric assessment

Profilometer

Each indentation was scanned with a profilometer (Optical Surface Profiler Contour GT, Bruker, MA, USA). The x and y axes of the profilometer was gradually titled to ensure that the whole top surface of the acrylic block showed brightest fringes. The measurement type was set as VSI, the back scan was set between 5-10 μm and the threshold was set at 5%. If the indentation was larger than the scanning field, being 1.3 x 1.5 mm^2 (width x length), more than one scan was performed and all scanned photos were connected via reference points so that the first part of the indentation was not re-measured. Finally, the surface area and depth of the indentation were obtained using Vision 64 Map software (Bruker, MA, USA) and the indentation's volume was calculated.

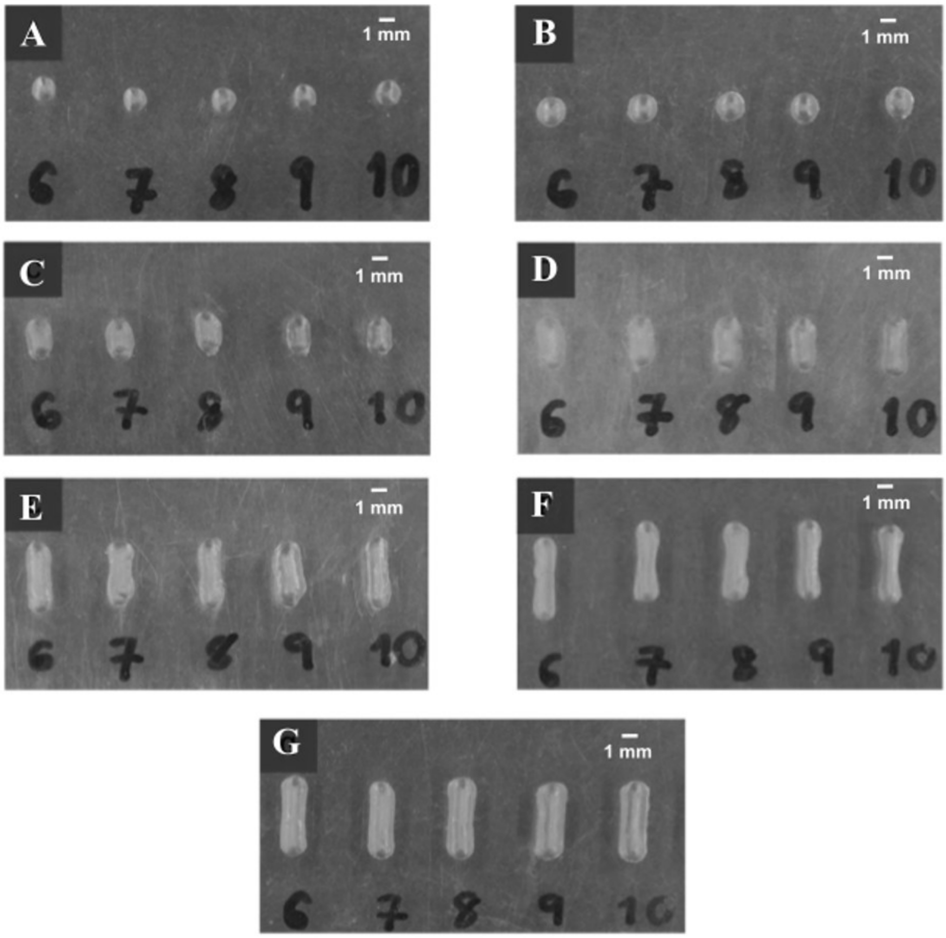

Figure 1 - Examples of the indentations in blocks A to G used in the present study sized to the same scale.

Table I - The average actual dimensions (± SD) of all indentations in each acrylic block measured by the profilometer

Block	Average diameter (mm)	Average width (mm)	Average length (mm)	Average depth (mm)
A	1.3748 ± 0.0688	-	-	0.2937 ± 0.0403
B	1.6581 ± 0.0518	-	-	0.8030 ± 0.0461
C	-	1.4315 ± 0.0656	2.4437 ± 0.1076	0.2875 ± 0.0242
D	-	1.4537 ± 0.0811	3.2073 ± 0.1278	0.2378 ± 0.0264
E	-	1.4554 ± 0.2054	4.2393 ± 0.2791	0.2214 ± 0.0359
F	-	1.3214 ± 0.1487	5.1117 ± 0.2557	0.2235 ± 0.0503
G	-	2.0286 ± 0.4933	5.0440 ± 0.0702	0.5055 ± 0.0914

Intraoral scanner method

In the beginning, the indentation was directly scanned using an intraoral scanner (TRIOS 4®, 3Shape Global, Denmark) but the resulting quality was not acceptable due to the transparency of the acrylic. Hence, the indirect method was used. The indentation was first duplicated with double impression technique using polyvinyl siloxane light body (Provil® Novo Light, Kulzer, Japan) and putty-type polyvinyl siloxane (Provil® Novo Putty Soft, Kulzer, Japan) and then scanned with the intraoral scanner (IOSD). Secondly, the same indentation was duplicated using putty-type polyvinyl siloxane alone and scanned (IOSP). Small amount of the impression material was first injected into the indentation and the remaining material was then loaded onto a flat acrylic plate and pressed against the indentations with a force of approximately 40-50 N. The scanner's probe was kept within 5-mm distance from the surface of the impression and moved slowly. A click sound must be heard before proceeding to the next area. The 3-D scanned image was subsequently converted to a steriolithograph file (stl) and imported to a 3-D mesh modelling software (Meshmixer®, Autodesk, CA, USA) to calculate the volume of the indentation (Figure 2).

Blue inlay wax method

The original acrylic block was first weighed as the baseline value using a 4-digit digital scale (ALT 100-5AM, Kern, Germany). The indentation was then filled with blue inlay wax (Blue inlay casting wax: regular- type II, class I, Kerr, Switzerland) and the excess wax was scraped off at the surface level with a dental roach carver. The acrylic block was re-weighed after the wax was added. The difference of the weight of the acrylic block before and after filling with the inlay wax was calculated and the volume of the indentation was determined by dividing its weight by the density. The density of the blue inlay wax was separately derived by weighing a wax cube sized 5 x 5 x 5 mm^3 (volume of 125 mm^3) made inside a stainless steel crucible. After completing the first indentation, the wax was thoroughly rinsed off using 50 °C water using a micro brush applicator. The acrylic block was then cleaned with a piece of paper towel and air-dried before repeating the whole procedure for the next indentation.

Tests for intra-examiner and inter-examiner reliability

Reliability tests were performed for the intraoral scanner and blue inlay wax methods within the same examiner and between two examiners, both being dentists. Six out of 10 indentations in each acrylic block were randomly selected for re-measurements, representing 60% of the total indentations.

Statistical analysis

The average volume and standard deviation (SD) of each indentation measured by all methods as well as the corresponding volumetric error compared to the profilometer were described. The agreement of the volumetric values between IOSD, IOSP, blue inlay wax methods and the profilometer was determined by intraclass correlation coefficients (ICC). In addition, any difference in the overall volumetric error between IOSD, IOSP and blue inlay wax methods was analyzed using Friedman test and post-hoc pairwise comparisons. Intra- and inter-examiner reliability of the intraoral scanner and blue inlay wax techniques were also determined by ICC.

RESULTS

The average volume of the indentations in each acrylic block measured by the profilometer,

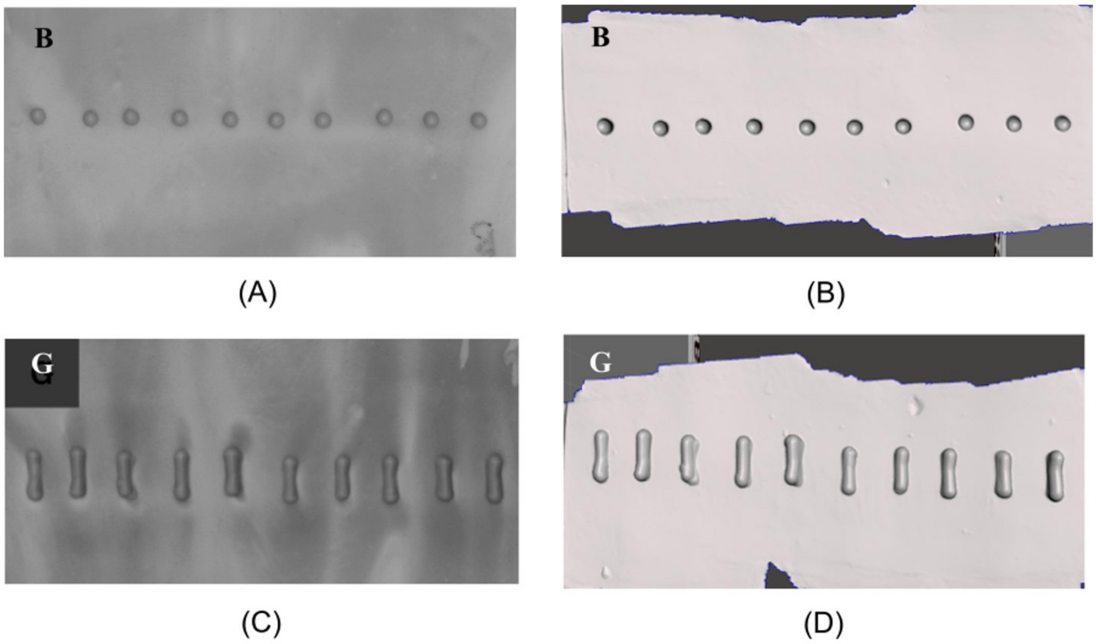

Figure 2 - Examples of silicone impression obtained from double-impression technique (A, C) and corresponding scanned images using Meshmixer® (B, D). (The label of the acrylic block was shown in each picture).

IOSD, IOSP, and blue inlay wax methods, along with corresponding ICCs and volumetric errors compared to those obtained from the profilometer were shown in Table II. The intra-examiner reliability of IOSP (ICC = 0.999) was smaller than that of ISOD and the inlay wax (ICC = 1.000). The inter-examiner reliability of all methods was excellent (ICCs = 0.999).

ICCs ranged from 0.878 (block A) - 0.983 (block F) with IOSD, 0.850 (block A) - 0.976 (block F) with IOSP, and 0.965 (block C) - 1.000 (block G) with blue inlay wax (Figure 3). When all data were pooled, blue inlay wax had higher ICC (0.999) than IOSD and IOSP (0.963 and 0.950 respectively).

All volumetric values obtained from IOSD, IOSP, and blue inlay wax were smaller than those from the profilometer. The average volumetric error of IOSD ranged from 24.88 ± 13.31% (block G) to 41.23 ± 6.62% (block A) with the pooled error of 30.51 ± 8.34%. The average volumetric error of IOSP ranged from 29.12 ± 11.87% (block G) to 47.71 ± 4.88% (block A) with the pooled error of 35.68 ± 10.29%. The average volumetric error of blue inlay wax ranged from 9.71 ± 3.24% (block G) to 37.98 ± 4.54% (block C) with the pooled error of 24.87 ± 10.29%. Overall, the volumetric error of the three measuring methods was significantly different ($p < 0.001$), the error of the blue inlay being the least whereas that of IOSD was smaller than IOSP (Table II).

DISCUSSION

The present study has demonstrated that using profilometer as the gold standard, blue inlay wax could be used in quantifying the indented surface of the clear acrylic with high accuracy, regardless of the size, shape, and depth of indentations. In addition, the indirect intraoral scanning methods, could also be used with less, but still acceptable accuracy (ICCs greater than 0.8).

An optical profilometer was used as our standard since it can measure surface irregularities with high precision. Silicone impression material was used to duplicate the indentations since it is commonly used in fixed prosthodontic works for its good duplicability and stability. Putty type silicone impression alone was tested and explored in the present study because the impression technique was simple. Blue inlay wax was used in the present study because it is commonly used in dental laboratories due to its good thermoplastic properties, being solid at room temperature but uniformly softened without decomposition to form mobile liquid when warmed to 40-50 °C. It exhibits excellent adaptability to model or die surfaces and can be removed from the prepared tooth with minimal distortion. Blue inlay wax also has good contrast in color with clear acrylic resin, and is easily carved after softening.

Table II - Average volume (± SD) of indentations in acrylic blocks A to G measured by the profilometer, intraoral scanner with double impression technique (IOSD), intraoral scanner with putty silicone only (IOSP) and blue inlay wax methods and their ICCs and volumetric errors compared to those of the profilometer

Block	Average volume (mm^3)				ICCs*			Volumetric error** (%)			p-value
	Profilometer	IOSD	IOSP	Wax	IOSD	IOSP	Wax	IOSD	IOSP	Wax	
A	0.4279 ± 0.1073	0.2448 ± 0.0647	0.2215 ± 0.0505	0.2855 ± 0.0760	0.878	0.850	0.967	41.23 ± 6.62	47.71 ± 4.88	33.44 ± 2.33	<0.001***
B	1.7250 ± 0.1596	1.2023 ± 0.1406	0.9706 ± 0.1536	1.4861 ± 0.1699	0.954	0.926	0.987	30.40 ± 3.29	43.95 ± 5.30	13.99 ± 2.83	
C	0.8551 ± 0.1154	0.5610 ± 0.0741	0.5205 ± 0.0929	0.5328 ± 0.0985	0.918	0.886	0.965	34.27 ± 3.32	39.17 ± 6.05	37.98 ± 4.54	
D	1.0014 ± 0.1480	0.7141 ± 0.1482	0.7142 ± 0.1791	0.7322 ± 0.1175	0.956	0.923	0.967	29.03 ± 5.74	29.25 ± 8.39	26.91 ± 3.12	
E	1.2987 ± 0.2102	0.9534 ± 0.1970	0.9190 ± 0.2247	0.9642 ± 0.1954	0.979	0.958	0.984	27.01 ± 5.01	29.97 ± 8.59	26.15 ± 4.43	
F	1.3414 ± 0.3470	0.9880 ± 0.2948	0.9548 ± 0.2951	1.0383 ± 0.3088	0.983	0.976	0.993	26.75 ± 4.68	29.27 ± 5.92	23.42 ± 4.21	
G	5.0829 ± 2.0036	3.7036 ± 1.4141	3.4801 ± 1.1907	4.6413 ± 1.9735	0.900	0.875	1.000	24.88 ± 13.31	29.12 ± 11.87	9.71 ± 3.24	
Pooled					0.963	0.950	0.999	30.51 ± 8.34	35.68 ± 10.29	24.87 ± 10.29	

*ICCs were determined with respect to values from the profilometer. ** Although the values measured by the profilometer were always larger than those measured by other methods, the minus signs were omitted for simplicity.*** Significant difference in volumetric errors between three measuring methods (Friedman test) in which the blue inlay wax method was different from both IOSD and IOSP whereas IOSD was different from IOSP (pairwise comparisons).

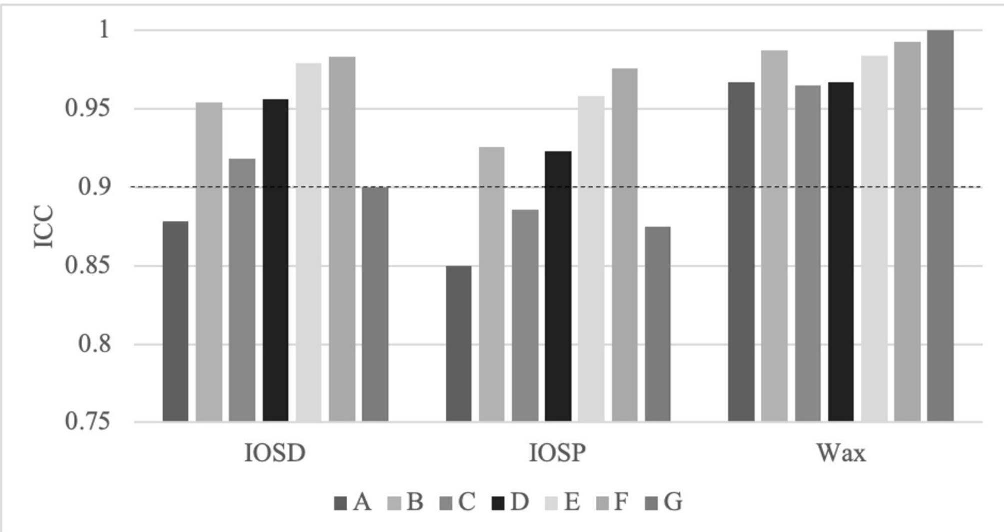

Figure 3 - Bar graphs showing interclass correlation coefficients (ICCs) between volumetric measurement obtained from IOSD, IOSP, blue inlay wax methods and the profilometer. A horizontal line was drawn at ICC of 0.9 to indicate the cut-off for the excellent agreement.

The volumetric values obtained from the profilometer were always greater than those obtained from the indirect intraoral scanning and blue inlay wax methods. This could be due to the high sensitivity of the profilometer in detecting the edges of the indentation, resulting in increased boundaries and the subsequent volume. Hsu et al. [8] studied the conformity between the profilometer and a laser scanner in measuring the volume of surface indentations on a ceramic disk and found that the volume obtained from the profilometer could be both larger and smaller than those obtained from a laser scanner, depending on the type of material being scanned.

On a ceramic disk, the profilometer provided larger values with the overall volume difference of 25.32%, whereas on the silicone impression replicate, the profilometer gave smaller values with the means difference of 77.5%.

ICC was used to test the agreement between our measurement methods since it took into account both magnitude and correlation of two data sets. ICCs were mostly in accordance with percentage volumetric errors. The blue inlay wax method tended to have highest ICCs. Duplicating the indentation with polyvinyl siloxane impression material could produce some error. Hsu et al. [8] showed a volumetric difference of 6.1% between the original indentation and its replicated impression. The error could be further increased by the scanning procedure. Hsu *et al.* also demonstrated decreased accuracy of a laser scanner when impression replicates of the indentations (approximate depths of 70-260 μ) were scanned (average volumetric error of 77.5%), compared with the original indented surface (average volumetric error of 23.5%). The average volumetric errors in the present study using the intraoral scanner were smaller (30.51% with IOSD, 35.68% with IOSP). However, the high ICCs with respect to gold standard indicated that all three methods could be used in assessing relatively small changes in the volume of surface indentations.

IOSD and IOSP produced similar ICCs and volumetric errors although IOSD seemed to be slightly more accurate than IOSP. This was expected since the double impression technique has been conventionally used in duplicating the fine details of tooth crown prepared in fixed prosthodontic work. Considering the small percentage error between both methods, it was proposed that IOSP could also be used to quantify the amount of wear, with fewer steps.

Types of indentation apparently affected the accuracy of the intraoral scanning methods whereas less effect was seen with blue inlay wax. Intraoral scanners especially IOSP had ICCs lower than 0.9 (the cut-off for excellent agreement) in small circular (block A), small linear (block C) and deep linear (block G) indentations, whereas the blue inlay wax method seemed to be superior to IOSD and IOSP for these indentations. Smaller volumetric errors and higher ICCs were also noted with blue inlay wax for deep circular indentations (block B) although all methods showed ICCs greater than 0.9. The effect of indentations' length could be roughly determined by comparing ICCs between blocks C, D, and E in which the size and depth of the indentations were similar, but the length was different. The ICCs were gradually increased from block C to block E, suggesting that the volume of longer linear indentations tended to be more accurately measured than that of the shorter ones.

The present study had some limitations. First, the study was conducted in vitro. Although the dimension of the indentations (especially blocks A-D) mimicked those seen in sleep bruxing patients in our orofacial pain clinic and those previously described [19], the results might not be accurately applied to the indentations with sharp-angled base as well as other types of wear which could be observed in real bruxers. Secondly, the smallest indentation in the present study was approximately 1.3 mm wide and 0.2 mm deep whilst the actual brux indentations could be even smaller. For such indentations, the accuracy was likely to be reduced with indirect intraoral scanning methods.

Under the above limitations, we have demonstrated that both indirect intraoral scanning and blue inlay wax methods could be used to quantify the volume of indentations on clear acrylic surface with acceptable agreement compared to the profilometer, suggesting that they could be used to accurately study the relative change in the volumes. The blue inlay wax method, on the other hand, seemed to have both higher agreement and accuracy. However, in clinical practice, waxing might require more chair time and could be difficult to be applied in shallow and irregular indentations. It was presumed that intraoral scanning of silicone impressions might be more practical but only when the analyzing method was further simplified.

CONCLUSION

Within the limitation of this *in vitro* experimental design, there was generally excellent agreement in the volumetric measurement of indentations on the acrylic surface using indirect intraoral scanning methods, either with putty silicone impression alone or the double-impression technique, and the blue inlay wax method compared to the profilometer. The techniques could be used to quantify volumetric changes in bruxing wear on an occlusal splint so its efficacy could be evaluated. Blue inlay wax had the highest agreement for all types of indentations. Further study is needed in order to verify the clinical application of the techniques.

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Author's Contributions

TL: Conceptualization, Methodology, Data Curation, Formal Analysis, Writing- Original Draft Preparation. TPJ: Methodology, Formal Analysis, Writing - Review & Editing. SR: Methodology, Formal Analysis, Writing - Review & Editing. RC: Methodology, Formal Analysis, Writing - Review & Editing. JP: Conceptualization, Methodology, Formal Analysis, Supervision, Writing - Review & Editing.

Conflict of Interest

The authors have no conflicts of interest to declare.

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The study has no external funding.

Regulatory Statement

This study did not utilize hazardous substances, animal or human subjects. As a result, adherence to specific regulatory laws or guidelines concerning occupational health, safety, or environmental protection was not required. All appropriate steps were taken to uphold ethical research standards and ensure laboratory safety.

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Jarin Paphangkorakit
(Corresponding address)
Khon Kaen University, Faculty of Dentistry, Department of Oral Biomedical Science, Khon Kaen, Thailand.
Email: jarin@kku.ac.th

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