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The Effect of Using an Auxiliary Splint on the Accuracy of Intraoral Scanners: An *In Vitro* Study

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ABSTRACT

Objective
This study examines how using an auxiliary splint affects the accuracy of digital dental scans while creating a prosthesis for a multi-unit (4 missing continuous teeth) in a single segment.

Material and Methods
In this *in-vitro* study**,** upper and lower dental models were created using CAD/CAM technology. Three scanning techniques were applied to acquire the data from the models: a new modified intraoral scanning technique, a traditional intraoral scanning technique, and a traditional clinical method. The data collected from these techniques were compared to a Gold Standard Method, considered the most accurate reference to measure how precise each technique was in capturing 3D positions of implants, soft tissues, and neighboring teeth. Statistical tools such as ANOVA (Analysis of Variance) and the SNK-q test were used to analyze the results. ANOVA was applied to compare the deviations (differences from the Gold Standard) within each group for implant accuracy, neighboring tooth accuracy, and the soft tissue scanning. The SNK-q test was applied to identify the specific differences within these groups. Further comparisons were made using t-tests: An independent t-test was used to compare the accuracy between the upper and lower models and two implant distribution methods. A paired t-test was used to compare the results of two intraoral scanners applied within the same group. The statistical analysis determined whether the deviations were significant or not, indicating the p- value ≤ 0.05 indicating meaningful differences. This approach systemically assessed which scanning method and tool provide the most precise data for dental implant procedures.

Results
Results showed that the modified scanning technique and the traditional clinical method were more accurate in capturing implant positions (A, B, and C) than the traditional intraoral scanning technique with a statistical significance of (P>0.05). However, the differences in accuracy of upper and lower models and between two intraoral scanners were not statistically significant (P<0.05). Additionally, the two implant distribution methods showed no statistical significance in implant accuracy. For soft tissue scanning, the modified technique and clinical method performed better compared to the traditional scanning method, with RMS values indicating small deviations (P<0.05). Meanwhile, the neighboring tooth accuracy showed minimal differences among the techniques (P<0.05). These findings suggest that

the modified intraoral scanning technique is a reliable and accurate alternative to the traditional methods for multi-unit implant prosthesis.

Conclusion
This study compared three different scanning techniques, such as the modified scanning technique, the traditional intraoral scanning technique, and the traditional clinical method, to capture the impressions of dental implants for a case of four continuous missing teeth. The new modified scanning method demonstrated high accuracy in capturing both the positions of implants and the surrounding soft tissue.

Keywords: Digital impressions; CAD/CAM technology; Implant position accuracy; 3D deviation analysis; Auxiliary splint; Modified intraoral scanning; Traditional intraoral scanning; Traditional clinical method; Soft tissue scanning; RMS deviations.

Introduction

Dental implants are now a vital part of restorative dentistry, providing patients with both a functional and aesthetically pleasing option for lost teeth. With the increasing demand for implant-supported prosthesis, clinical research has been focused on developing ways to ensure long term success. Implant treatment usually consists of two stages; first, analyzing the bone quality and placing implants inside the bone, followed by the healing phase [1] in which osseointegration occurs. After the healing is completed, an impression is taken to create a fixed prosthesis, such as crown or bridge. [2] For long-term implant-supported prostheses success, one of the most crucial factors is the passive fit. Nonpassive fit may lead to many mechanical and biological complications that could affect treatment success. [3] Mechanical complications include tension, compression, and flexion forces, caused by poor passive fit, which can result in screw loosening or fractures, unfavorable movements, prosthesis breakage, and even implant fractures. Biological complications may also arise from poor passive fit due to gaps between the prosthesis and implant, which host an accumulation of microorganisms causing biological problems in supporting tissues. [4] To achieve the required passive fit, dental impression must be accurate. [5]

Dental impressions are imprints of teeth, implants, and the surrounding anatomical structures in oral cavity. [6] These impressions can be obtained with both conventional and digital techniques to produce implant-supported prosthesis. In either case, impression-making is the first step before the subsequent fabrication of a dental prosthesis. [7] Conventional methods uses closed or open tray techniques, [8] with silicone-based materials. These impressions are poured with gypsum to create model casts. Although reliable, these traditional techniques have notable limitations: [9] such as the potential deformation of the impression materials, [10] polymerization shrinkage, issues with material type, and variations caused by pouring techniques, [11] or implant angulation. [12] Additionally, patients may experience discomfort or gag reflexes, especially during multiple implant impressions, which can lead to retakes and increased clinical time. [13] According to some clinical researchers, Traditional impressions are frequently one of the most uncomfortable aspects of the appointment for the creation of fixed prosthesis. The impression material taste, smell, and texture are frequently problematic for patients, creating an unpleasant experience with the patients.[B]

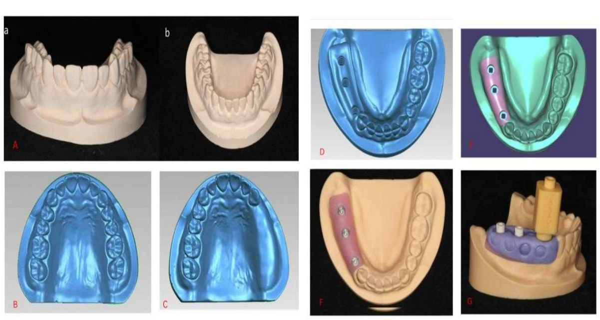
To address these issues, digital intraoral scanning (IOS) was introduced, offering a faster, comfortable, and more precise alternative that eliminates the need for physical materials, [14] reduces infection risk, [15] and simplifies workflows by providing detailed 3D images of soft and hard tissues. [16] Patients have preferred digital scans, especially in single-tooth restorations, due to reduced clinical time and comparable accuracy to conventional methods. [17]

Even with the advancements in CAD/CAM technology, digital impressions face limitations in complex cases, such as full-arch or multi-unit implant rehabilitation. The accuracy of IOS tends to decline with an increasing number of missing teeth, as scanners rely on surface features to create cohesive images. In edentulous areas, where distinct features are absent, digital impressions may show higher deviations compared to traditional methods. [18] Research indicates that while digital impressions can reliably capture single-unit implants (short-span scanning), they become less accurate in multi-unit or full-arch cases (long-span scanning) [19]. For instance, an in vitro study found that deviation values increased slightly but were not statistically significant when intraoral scanners were used to capture impressions of 1, 2, or 3-unit implants, with trueness measurements of 40.5±18.9 μm, 43.4±13.4 μm, and 44.7±14.9 μm, respectively. [20] Light conditions also have a considerable impact on the accuracy of intraloral scanners (IOS). Scans carried out under room lighting produced the least absolute error values, suggesting greater precision. Furthermore, the size of the digital scan appeared as a significant factor influencing scanning accuracy. [A]

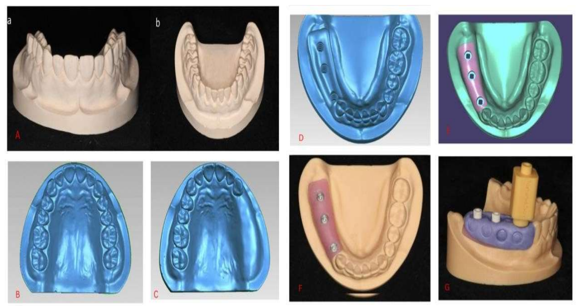
Several techniques, such as scan bodies with arcuate (curve) extensions, [21] splints, [22] auxiliary devices to cover the edentulous ridge, [23] extensional structures with occlusal geometry, [24] and 3D-printed modular chains, have been developed to address these challenges. These modifications improve scanning precision by providing additional reference points, especially in edentulous regions. [25] Despite advancements in techniques and materials, Oral scans do have certain limitations, including movable soft tissues, difficulties caused by excessive salivation, reflective dental restorations, and differences in scanning protocols. [26] To address issues with digital impressions, This study explores the effectiveness of a new modified intraoral scanning technique that includes an auxiliary splint to improve the accuracy of digital impressions in long-span edentulous areas. This technique has the potential to offer a simpler and more patient-friendly alternative to conventional impressions, enabling clinicians to use digital impressions with confidence in multi-unit implant cases.

Methodology

In this study, experimental dental models for partial edentulous free-end saddle cases were fabricated using maxillary and mandibular impressions from a 39-year-old patient (having all teeth intact and a good bone quality) at the Xuzhou affiliated hospital. Dental stone casts were prepared using type IV dental stones, (Fig.1 A) and scanned with a laboratory scanner to collect optical data.. (Fig.1 B) Virtual tooth extraction was performed on the scanned data



using CAD software, (Fig.1 C) and digital models of soft tissue, and implant analogs spaces were designed. (Fig.1 D,E) The models were 3D printed using specialized resins, and assembled with implant analogs placed subgingivally and



soft tissue models attached using adhesive. (Fig.1 F) Additionally, a textured seal was designed and 3D printed to enhance the scanning accuracy of flat edentulous areas. This auxiliary component connects impression scan bodies and creates distinguishable surface marks for precise scanning. (Fig.1 G).

Figure 1: Creation of experimental dental models from stone casts and digital scans to 3D-printed models with implant analogs and soft tissue simulations

The study employed four distinct groups to compare different implant impression techniques and scan body types: a modified intraoral scanning method, traditional intraoral scanning, conventional opentray silicone impressions, and a reference group using gold-standard laboratory scanning. In the modified intraoral scanning group, an auxiliary splint was used along with digital scan bodies, and data was collected using two intraoral scanners (3-Shape Trios 3 and CS 3600).This method was designed to improve scanning accuracy by following an organized way to capture the soft tissues and neighboring teeth more clearly. (Figure. 2).

Figure. 2: Modified Intraoral Scanning Group

In the traditional intraoral scanning group, models were scanned using the same intraoral devices without the auxiliary splint, following a conventional scanning technique. The traditional clinical method group utilized a conventional open-tray impression technique with silicone materials, followed by model pouring and laboratory scanning to collect data with and without scan bodies.

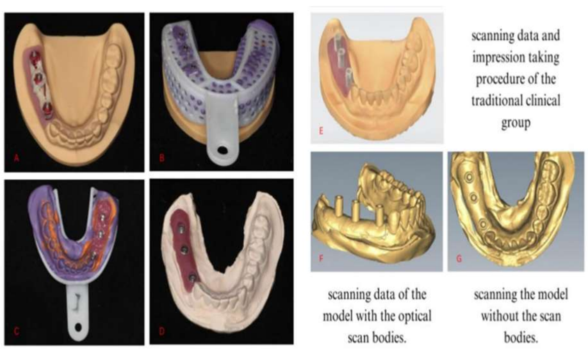


Figure. 3: Traditional Intraoral Scanning Group

Lastly, the gold-standard group used a laboratory scanner to capture high-precision data with and without scan bodies. Each process was repeated multiple times to ensure accuracy and consistency across different implant distributions and arch models, resulting in 120 scans. All the collected data was exported in STL format for further analysis. For soft tissue data, the auxiliary splint was scanned separately using a laboratory scanner. The accuracy of scanning implants, soft tissue, and nearby teeth was evaluated in all four groups: the modified intraoral scanning group, traditional intraoral scanning group, traditional clinical method group, and gold standard group. The data from experimental groups was compared to the gold standard using Geomagic Studio 2014 software to analyze 3D alignment and differences. Implant accuracy was checked by comparing the central axis and angle differences between the experimental models and the gold standard, and average values calculated from the repeated tests. For soft tissue accuracy in toothless areas, data from each group were compared to the gold standard, and color-coded maps were created to show the differences. Finally, the scan data of the neighboring tooth (adjacent to the edentulous area) was analyzed and compared to the gold standard group. All evaluations were conducted by a single technician to ensure consistency. This analysis assesses the precision of each scanning method and supports the overall objectives of the study.

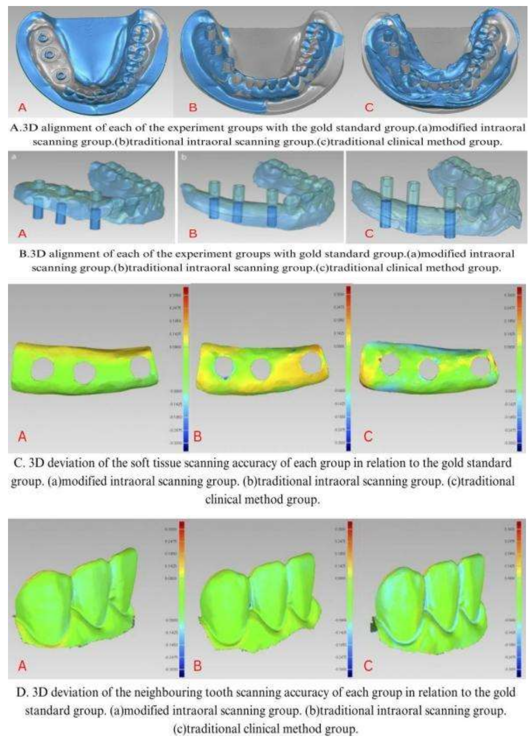


Figure. 4

Statistical analysis was conducted using SPSS 16.0 software to evaluate the deviations in 3D implant position accuracy, soft tissue scanning accuracy, and neighboring tooth scanning accuracy across various experimental groups. Normality and variance homogeneity of the data were verified using Shapiro-Wilk and Levene tests. Two-sample t-tests were applied to compare deviations between upper and lower arches, intraoral scanner types (3Shape Trios 3 and CS 3600), and implant distribution methods (positions 457 vs. 467) within each group. Variance analysis followed by SNK-q tests was used to assess deviations among experimental groups (modified scanning, traditional scanning, and traditional clinical methods) and individual implants within each group. A significant level of P< 0.05 was applied to ensure reliable and meaningful comparisons.

Results:

The modified scanning system and the traditional clinical method showed less deviation in implant position (A, B, C) compared to the traditional scanning method, with statistically significant differences of P<0.05.

Table 1: Implant 3D deviation of each of the scanning groups (μm)

		Modified intraoral scanning group	Traditional intraoral scanning group	Traditional clinical method group
Position A implant	a	46.50±19.4	57.83±22.1	52.17±21.0
	B	52.50±20.3	63.33±22.5	55.33±20.7
	θ	0.53±0.1	0.63±0.2	0.54±0.1
Position B implant	a	56.50±22.0	140.50±35.5	58.50±21.3
	B	61.67±22.2	147.50±35.9	62.83±22.7
	θ	0.59±0.1	0.94±0.2	0.61±0.1
Position C implant	a	59.67±23.4	256.00±28.6	64.33±23.3
	B	65.17±23.5	262.17±28.6	65.83±22.2
	θ	0.64±0.1	1.07±0.2	0.64±0.1

Table 2: Implant 3D deviation of each group between two different implant distribution methods (μm)

Modified intraoral scanning group	Position A implant	A	47.00±19.3	46.00±19.9
		B	52.33±22.3	52.67±18.5
		θ	0.54±0.1	0.53±0.1
	Position B implant	A	52.67±23.1	60.33±20.5
		B	58.67±23.0	63.67±21.5
		θ	0.58±0.1	0.59±0.1
	Position C implant	A	59.67±23.1	59.33±24.0
		B	66.33±25.6	64.00±21.5
		θ	0.63±0.1	0.65±0.2
Traditional intraoral scanning group	Position A implant	A	60.33±22.2	55.33±22.2
		B	66.67±23.5	60.00±21.3

		θ	0.61±0.2	0.65±0.2
	Position B implant	A	125.33±35.7	155.67±28.4
		B	132.67±34.1	162.33±31.8
		θ	0.84±0.2	1.05±0.2
	Position C implant	A	254.33±29.6	257.67±28.0
		B	259.67±31.0	264.67±26.3
		θ	1.06±0.2	1.09±0.2
Traditional clinical method group	Position A implant	A	53.00±21.0	51.33±21.2
		B	57.00±20.03	53.67±21.5
		θ	0.53±0.1	0.54±0.2
	Position B implant	A	55.33±20.1	61.67±22.4
		B	60.00±21.8	65.67±23.5
		θ	0.59±0.2	0.62±0.1
	Position C implant	A	64.00±24.7	64.67±22.5
		B	69.00±23.3	66.00±22.0
		θ	0.62±0.2	0.66±0.1

Table 3: Soft tissue deviation and neighboring tooth deviation of each group (μm)

	Modified intraoral scanning group	**Traditional intraoral scanning group**	**Traditional clinical method group**
Edentulous area soft tissue deviation	207.20±24.4	235.27±22.9	192.27±34.0
Scan body neighbouring tooth deviation	46.13±11.9	52.33±16.2	48.07±13.3

The deviation of A and C implant positions between the two implant distribution methods in all test groups was not statistically significant (P>0.05). However, in the traditional intraoral scanning group, the deviation of B5 implant position (second premolar) was smaller than that of the B6 implant position (first molar), with a statistical significance of (P<0.05). This indicates that implant distribution influenced B implant positions in this group, while no significant differences were found in the other groups. Additionally, in traditional intraoral scanning group, deviations in positions C and B6 were larger than those in positions A and B5, with statistical significance of (P<0.05). In the case of soft tissue scanning accuracy, modified scanning group and the traditional clinical method group showed smaller deviations compared to the traditional scanning group, with significant differences of (P<0.05). In the case of neighboring teeth accuracy, modified scanning group and traditional clinical method group had smaller deviations than the traditional scanning group; however, the differences were not statistically significant (P>0.05).

Disscussion:

The use of intraoral scanners (IOS) has revolutionized dental implant impression techniques, making them faster, easier, and far more accurate than traditional methods. In this research study, a modified scanning technique has been developed that uses an auxiliary splint to improve scan accuracy in long-span edentulous cases. This process generated better results than traditional scanning techniques and impressions. These findings are consistent with earlier research and offer novel approaches to the difficulty of scanning flat, edentulous surfaces. One major drawback of traditional intraoral scanning in long-span edentulous patients is the absence of identifying features on the gums' flat, smooth surfaces. Smooth surfaces provide a challenge for intraoral scanners, unlike textured surfaces that can help in exact image matching, resulting in higher accuracy. This study found that using the auxiliary splint resulted in higher accuracy and reliability across various implant positions, scanning devices, and arch locations. This study discovered that using the auxiliary splint improved accuracy and reliability across various types of implant positions, scanning devices, and arch locations. The modified scanning method, which started from the middle of the auxiliary splint and extended bilaterally, further reduced cumulative errors by shortening the scanning path. The deviation between the modified scanning group and the gold standard extraoral scanning group was minimal, highlighting the effectiveness of this approach. These findings are consistent with Pozzi et al., who showed that implant scan body splinting enhanced accuracy even in posterior positions, a critical area where traditional IOS accuracy declined. [25] [27]

Huang et al. also validated the use of auxiliary structures for improving scanning outcomes in edentulous areas. They demonstrated that the addition of extensional parts to scan bodies reduced mean linear deviation values from 119.53 μm to 68.89 μm. [28] Similarly, our study's auxiliary splint, which connected the scan bodies and provided textured surfaces, achieved improved trueness and precision. Notably, the trueness values in this study were measured as 8 ± 6 μm at the shortest reference distance and 35 ± 22 μm at the longest, which are comparable to the findings of Iturrate et al., who reported deviation values of 8 ± 6 μm at shorter distances using geometric parts. [29] When comparing digital and conventional impression techniques, it is evident that each has distinct advantages and limitations. While traditional silicone impressions are time-tested, they are associated with patient discomfort, a longer working time, and potential material distortion. [30] Digital impressions overcome these challenges by eliminating physical impression materials and transferring data directly to laboratories, significantly reducing time and human errors. [31] In line with other studies, participants in our study preferred digital scanning due to its efficiency and reduced discomfort. [32] However, it must be noted that for long-span edentulous cases, conventional methods, such as splinted open-tray techniques, still provide reliable results. Studies have shown that these conventional methods are comparable to advanced digital techniques in terms of accuracy. [33] Obtaining a correct impression that is not altered throughout the time between taking the impression and having it cast by the laboratory technician has always been crucial to producing a correct prosthesis. [34]

Despite its advantages, digital intraoral scanning remains limited in its application for full-arch implant-supported restorations. Complete arch scanning presents challenges due to errors accumulating over long spans. Stereo-photogrammetry has been shown to improve accuracy for complete arch implant cases, as it can estimate all coordinates algorithmically without relying solely on image linking. [35] However, studies like ours and others that utilize auxiliary parts demonstrate that introducing artificial landmarks can enhance IOS accuracy and extend their application to long-span cases. [36] It is important to note that this study was conducted in-vitro, and clinical application of the modified techniques is required to validate its effectiveness under real-world conditions, such as the presence of saliva, tongue movements, and varying oral temperatures. Although digital workflows have been demonstrated to be more efficient and patient-friendly, their clinical accuracy in multiple implant-supported restorations still requires further investigation [37]. The modified intraoral scanning technique with auxiliary splints greatly improves getting accurate impressions in longspan edentulous cases. By addressing the difficulties of smooth tissue surfaces and avoiding cumulative errors, this technology has shown comparable accuracy to traditional procedures while offering the advantages of digital processes. Future clinical investigations are required to validate these findings and explore the clinical accuracy of digital scans and digitally created interim or prototype prostheses before recommending digital implant scans for general clinical usage. [38]

Conclusion:

The modified intraoral scanning system showcased greater precision for multi-unit implant cases particularly in implant location and soft tissue scanning, indicating a possible improvement over conventional approaches.

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