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Effect of Scanning Pattern on the Accuracy of Intraoral Scans: A Narrative Review

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Abstract

Intraoral scanners (IOS) have emerged as a key component of digital dentistry, providing a reliable alternative to conventional impression techniques. The accuracy of intraoral scans is influenced by multiple factors. Scanning protocols are a relevant factor in achieving accurate results with these devices and supporting successful outcomes. This narrative review aims to investigate the effect of different scanning strategies on the trueness and precision of intraoral scans. This work is a narrative review of in vitro studies, clinical trials and comparative analyses focused on intraoral scanning patterns. Research was conducted through PubMed and Medline using Boolean operators with terms like "intraoral scanners", "digital impressions" and "scanning strategies." Only English language articles from the were included. Relevant literature addressing intraoral scanning strategies was identified and synthesized for qualitative analysis. Scanning strategy is a significant factor affecting the accuracy of intraoral scans, especially in complex cases. Optimization of scanning strategies can reduce scanning errors and improve final outcomes. However, variability among studies and scanner systems indicates the need for standardized guidelines and further research.

Keywords: Intraoral Scanner, Scanning Strategy, Scan Pattern, Trueness, Precision.

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1. Introduction

Intraoral scanning provides valuable digital data applicable to diagnosis, orthodontic evaluation, restorative dentistry and implant-supported prostheses [1-2]. IOS capture digital impressions directly from oral cavity using an integrated camera system, whereas extraoral scanners digitize physical casts derived from traditional impressions [3]. Despite existing challenges, ongoing technological advancements are expected to further improve performance and broaden integration of IOS into routine dental practice. These systems acquire multiple partial images of limited areas, which are subsequently processed and merged. The acquired data are converted into Standard Tessellation Language (STL) files, generating three-dimensional representations of the dental arches. The overall accuracy of these digital models is largely dependent on the efficiency of the image-stitching algorithms used [4]. Accuracy is the method used to evaluate the quality of digital impressions. The ISO 5725-1 standard divides accuracy into two components: trueness and precision (Figure 1). Trueness reflects the resemblance between the digital model and the actual scanned object, while precision denotes the similarity between digital models acquired through multiple scans of the same object [4]. The precision of different scanners for the same dentition at varying scan spans remains largely unexplored [5]. The accuracy of the impression is crucial for any enduring dental restoration, as it directly impacts the marginal fit and overall quality of the final restoration [5.

Accuracy is typically evaluated using three-dimensional superimposition techniques that allow calculation of deviations between test and reference datasets, often expressed as root mean square (RMS) error values (Figure 2). Trueness can be evaluated in vitro by scanning an experimental model with both the intraoral scanner and a reference scanner, followed by a comparison of the resulting virtual casts. This method has commonly been used to assess in vitro trueness; however, studies have reported that IOS trueness tends to decrease when scanning a full dental arch compared with shorter spans [6-7]. In vivo, trueness is often approximated by comparing an intraoral scan with a virtual reference model generated from a conventional impression. It is important to note that conventional impressions themselves can introduce inaccuracies, and alternative approaches have also been employed in other studies to evaluate trueness [8. Intraoral scanning accuracy is affected during image acquisition and reconstruction (Figure 3). Stitching error occurs during the sequential alignment and merging of multiple images to form a three-dimensional model. Small inaccuracies in this process can accumulate, particularly in full-arch scans [9]. Another important source of error is tracking loss, which occurs when the scanner is unable to maintain continuous recognition of previously captured anatomical landmarks. This may result from insufficient surface detail and rapid or inconsistent scanner movement which can lead to interruptions in data acquisition and have an effect of accuracy of intraoral scans [4-10].

A further limitation is cumulative distortion, which is progressive accumulation of small alignment errors across the scanned arch. Over extended scanning distances, these inaccuracies may increase [11-12]. Scanning strategy is widely recognized as one of the factors influencing the accuracy of intraoral digital scans**.** Scanning strategy refers to the path followed by the intraoral scanner during sequential data acquisition across dental surfaces, enabling accurate image stitching and three-dimensional reconstruction [10-13]. Previous studies reported that scan strategy and the scanner tip movement during scanning has an effect on the trueness and precision of the intraoral scan [14-15]. Scanning systems create three-dimensional (3D) model by stitching or merging sequential images taken under different viewpoints [11-12]. Scan protocol is closely related to the image stitching software. Therefore, if the scanner movement is interrupted or done with extreme changes in orientation this may led to data gaps and distortion [13-16]. The effect of scan pattern on the accuracy of intraoral scans is more significant in full-arch scans because possible error in image stitching increases when the span of scanned area increased [17]. Scan strategies in intraoral scanning have been widely investigated; however, the optimal scanning pattern remains a subject of discussion in literature. Therefore, this review aims to investigate effect of different scanning strategies on accuracy of intraoral scans.

2. Scanning patterns

The scanning pattern is the direction of movement of the scanner tip during the scanning procedure [18-19. The concept of scanning strategy in intraoral scanning has evolved alongside advancements in digital intraoral scanning technologies. Early systems primarily focused on image acquisition, with limited attention to operator movement. However, with the development of image stitching algorithms and continuous data acquisition, the influence of scan strategy on accuracy became more evident, particularly in full-arch scans [13-20]. Because intraoral scanners reconstruct three-dimensional models through the sequential alignment of multiple images, the path and sequence of scanner movement affect how reliably these images are captured and merged. This led to the introduction of manufacturer-recommended scanning protocols, which were later investigated in the literature as distinct scanning strategies [10]. Manufacturers of IOS usually recommend specific scanning strategies, particularly for procedures including single crowns, quadrants or complete arch scans [12-21]. Deviating from recommended strategies sometimes may affect the accuracy of intraoral scans [18]. The effect of scanning strategy on accuracy of intraoral scans varies among different type of the IOS. Thus, scanning strategy should be adapted to the characteristics of each device used [18].

A comprehensive understanding of these factors can support the development of the suitable scanning strategy for each clinical condition encountered. Several scanning strategies have been described in literature, varying in terms of movement strategy, sequence of surface acquisition and scan origin. For the scanning strategy, the scanner may follow different movement patterns including linear paths, zigzag motions or S-shaped as shown in fig. 4. The linear scanning strategy follows a relatively straight path along the dental arch, typically starting from the occlusal surfaces then the buccal and palatal/lingual surfaces [19-22]. This method is straightforward and relatively easy to learn but it provides less overlap between scan images compared to other scan strategies [11-19]. In contrast, the zig-zag scanning strategy involves back and forth, angular movement in which the scanner tip typically crosses the arch in a buccal and lingual direction repeatedly in short paths. The scan usually begins at the most posterior molar of dentate arch and then shifts across the arch in transverse strokes.

This strategy produces frequent overlap between adjacent scan images, which improves performance of stitching algorithms [11-19]. The S-shaped scanning pattern is characterized by a continuous, wave-like movement of the scanner tip along the dental arch with the scanner following a curved motion that alternates between buccal and lingual directions while progressing in a mesiodistal direction [17-19-23]. This pattern has the advantage of overlap between scan images but less localized than zig-zag strategy. Alternative motion strategies have been described in more recent studies such as circular or wiggling scanning strategies. These approaches aim to increase surface coverage and improve data capturing. The circular scanning strategy involves moving head of IOS in a semi-circular motion around tooth surfaces sequentially [17-19]. The wiggling strategy involves repeated side to side movement of head of IOS along dental arch. It was introduced in more recent studies to improve capturing fine details [17-24]. However, both strategies are technique sensitive and evidence regarding their accuracy remains insufficient. Variations also exist in how dental arch is scanned, with some approaches relying on continues data acquisition, while others use segmental scanning with subsequent merging of datasets.

Scanning distance is described as length of a continuous scan or linear distance covered an uninterrupted scanning motion, for example in a full-arch scan. As the scanning distance increases, more image stitching is required and can introduce greater errors [22-25-26]. Alternatively, segmental scanning involves dividing the dental arch into quadrants or short spans which are scanned separately and subsequently merged using software algorithms. Full-arch scanning can be performed as separate segments that are subsequently stitched together, which may offer clinical advantages by improving control over common intraoral challenges such as saliva accumulation, tongue movement and soft tissue interference. From a clinical perspective, this approach may also help mitigate error propagation by limiting length of continuous scanning paths, thereby reducing accumulation of stitching errors [10-27]. However, their success depends on accurate merging of datasets as errors may be introduced during alignment if overlap or reference features are insufficient [10-19]. These differences in scanning patterns reflect attempts to optimize accuracy and minimize errors during digital impression acquisition.

3. Factor Interactions in Scan Accuracy

Although scanning strategy is an important factor that can influence the intraoral scan accuracy, its effect is not independent, as multiple interacting factors may significantly affect the final outcome. Establishing the scanning origin requires the consideration of multiple factors, including teeth morphology and clinical conditions [18-21-25-28-29]. Initiating the scan on the occlusal surface of a posterior tooth is commonly recommended, as areas with more anatomical complexity enhance image stitching compared to smoother regions such as buccal surfaces [18-21-25]. Accordingly, the occlusal-first scanning pattern demonstrated higher precision than the S-shaped scanning pattern in some studies [29]. It is also recommended to start the scan at the terminal end of the remaining dental arch than from an isolated tooth extending toward a mucosal area [30]. Although some manufacturers recommend the scanning origin to be in the most posterior region, Increased distance from the scanning origin may lead to cumulative errors and it does not always guarantee optimal accuracy [31]. Different IOS systems and imaging technologies may interact differently with specific scanning strategies, ultimately influencing the accuracy of the resulting intraoral scans. This variation depends on the different data acquisition technologies, reconstruction algorithms and meshing procedures [11-27-32]. As a result, some scanners are more affected with different scanning sequences while other systems show no significant differences in trueness among the different scan patterns [32].

Uncontrolled movements of head of IOS can affect the stitching process and consequently affect trueness and precision of intraoral scan [18]. Therefore, a stable rotational and vertical position of IOS head should be maintained to achieve accurate results [33]. Operator experience can also have an effect intraoral scanning strategies, as accuracy of digital impressions is highly dependent on the consistency and control of scanner movement [11-34]. Less experienced operators tend to exhibit greater variability in scan paths and an increased risk of tracking loss, particularly with more complex scanning strategies [4-34]. This effect becomes more pronounced in full-arch or continuous scanning strategies, where cumulative errors are more likely to occur over longer scanning distances (19). In contrast, structured scanning protocols such as linear approaches, appear to reduce operator-dependent variability by providing a more controlled scanning path [11]. Therefore, the scanning strategy and operator experience are associated factors, with operator proficiency significantly influencing the accuracy outcomes of different scanning approaches [11-34-35]. The effect of scanning speed is closely related to scanning strategy used, as more complex scanning patterns require different levels of control and continuity during data acquisition [22].

If scanning speed is too fast, intraoral scanner may fail to capture sufficient overlapping data points within given scanning pattern. Conversely, excessively slow scanning may increase likelihood of patient movement, muscle fatigue or loss of tracking stability, which can also negatively affect scan accuracy, especially in continuous scanning patterns [22-29]. Maintaining an appropriate and consistent scanning speed, adapted to selected scanning strategy and in accordance with manufacturer recommendations is essential to optimize data acquisition and ensure reliable results. Scanning distance has been shown to significantly influence intraoral scan accuracy. Increasing scanning distance generally leads to decreased accuracy across various devices. The optimal range is between 2.5 and 5 mm [34]. However, optimal scanning distance can vary according to the intraoral scanner used. Structured scanning patterns tend to facilitate more stable control within the device's depth of field, whereas less organized movements may lead to greater fluctuations in distance, increasing the risk of stitching inaccuracies. This interaction becomes particularly relevant in full-arch scans [36].

4. Effect of Scanning Strategy on Accuracy of Intraoral Scans

The accuracy of intraoral scans varies according to the scanning strategy employed and depending on the clinical and procedural conditions. Scanning strategies that enhance the tracking stability and reduce cumulative errors tend to achieve higher trueness and precision of the digital intraoral scan. Linear scanning strategy is generally associated with lower accuracy in full-arch scans compared to other approaches [11-19-22] as linear scanning strategy exhibits less overlap between successive scan images compared to other approaches [11-19]. It is also associated with increased stitching errors and cumulative distortion, particularly in full-arch scans [11-19-22]. This is because unidirectional movement provides less reference points for image alignment. Therefore, linear scanning strategy provides high accuracy of intraoral scans more reliably in short-span scans due to presence of less cumulative errors. Zig-zag scanning strategy is linked to improved trueness and precision relative to simpler movement paths, especially in full-arch scans [17-19-37]. This improvement is largely attributed to more stable tracking during acquisition as alternating movement reduces risk of tracking loss. However, its effectiveness still depends on factors such as operator experience and type of IOS used.

In addition, when an S-shaped pattern is employed, the accuracy of intraoral scans appears to be highly dependent on operator experience, primarily due to less controlled overlap between successive scan images [19-27]. Therefore, it provides acceptable results in short-span cases but it may not always be optimal in full-arch cases that have a higher risk of cumulative errors. Continuous scanning strategies, generally provide high accuracy because of uninterrupted data acquisition. As the scanning distance increases, a greater amount of image stitching is required, which can introduce additional errors [22-25-26]. Therefore, accuracy tends to differ between short-arch and complete-arch scans, with complete-arch scans being more challenging, particularly in edentulous areas [26-38]. Segmental scanning approaches reduce length of individual scans and may enhance accuracy by limiting cumulative errors while improving tracking stability within each segment [6-19. Accordingly, segmental scanning methods have been shown to improve both trueness and precision in full-arch scans when combined with appropriate alignment protocols and proper operator control [10-11-19]. The relative accuracy of each scanning strategy depends on clinical situation and there is not an optimal strategy to use in every case.

5. Clinical implications

The scanning strategy selection plays an important role in optimizing intraoral scan accuracy [10-19]. Segmental scanning approaches may help reduce cumulative distortion by limiting the length of continuous data acquisition and improving control over intraoral conditions such as saliva and soft tissue movement, particularly in full-arch restorations [19].

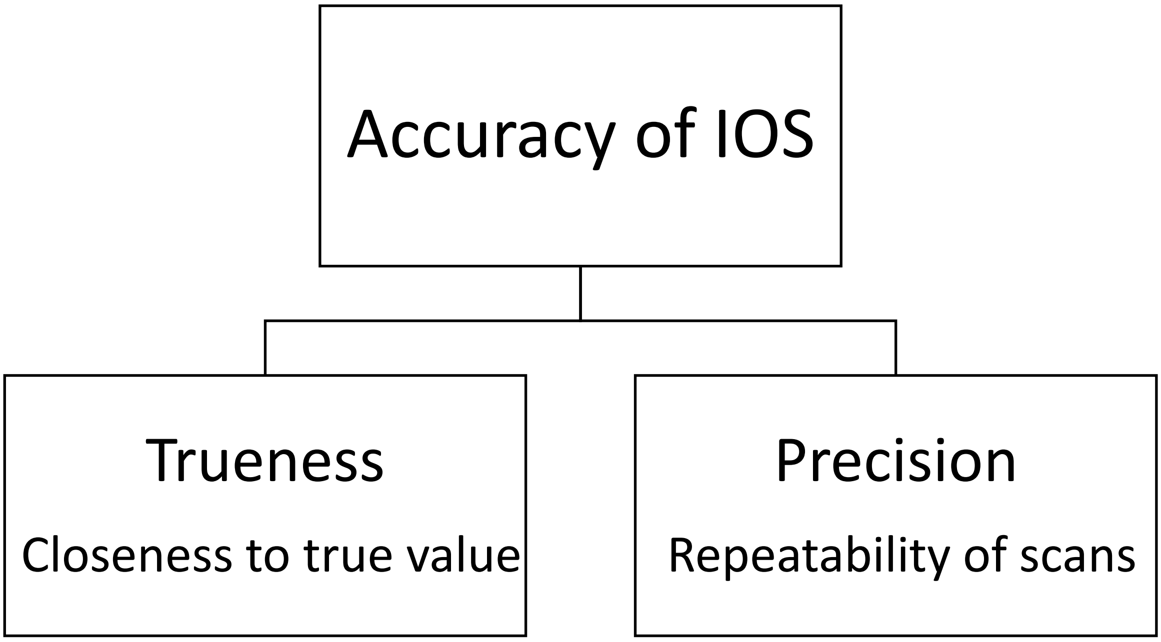


Figure 1. Conceptual Components of Accuracy in Intraoral scans.

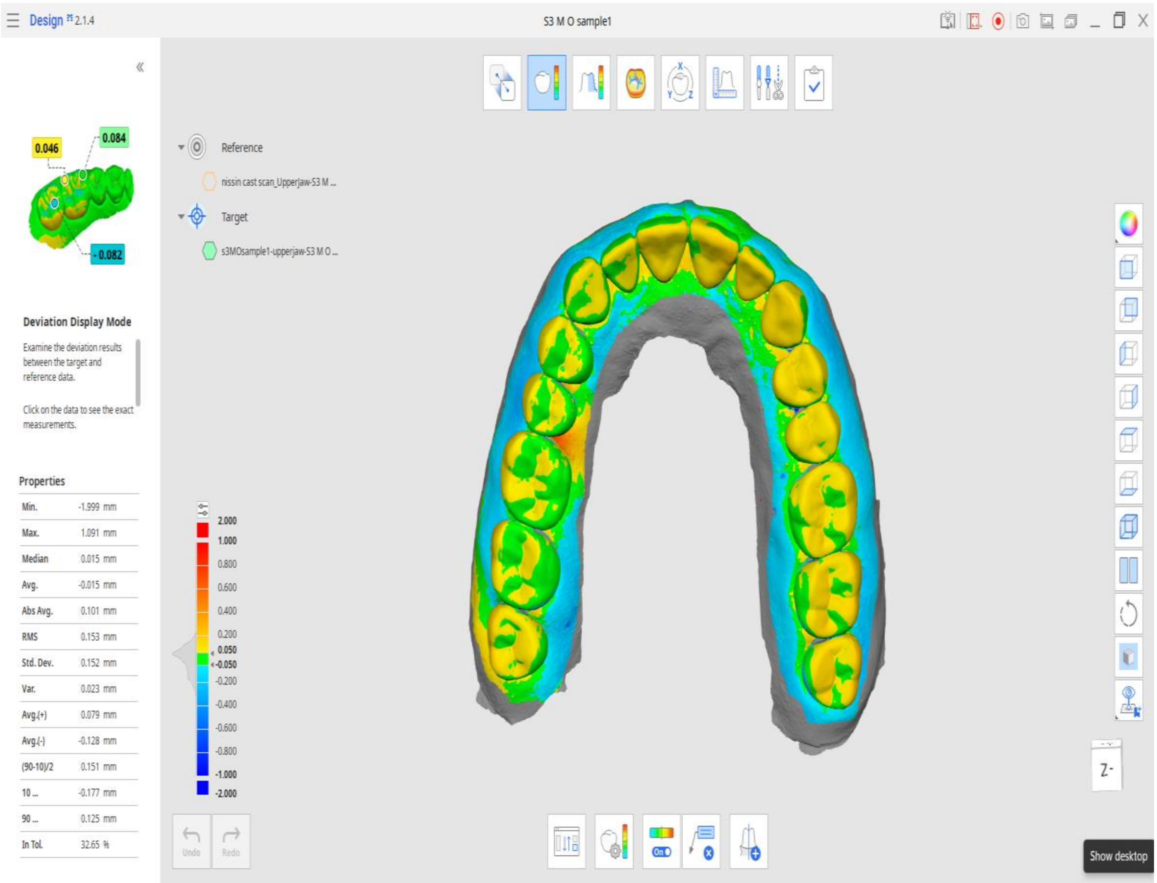


Figure 2. Best-Fit Alignment for Superimposition of Digital Models Using Medit Software.

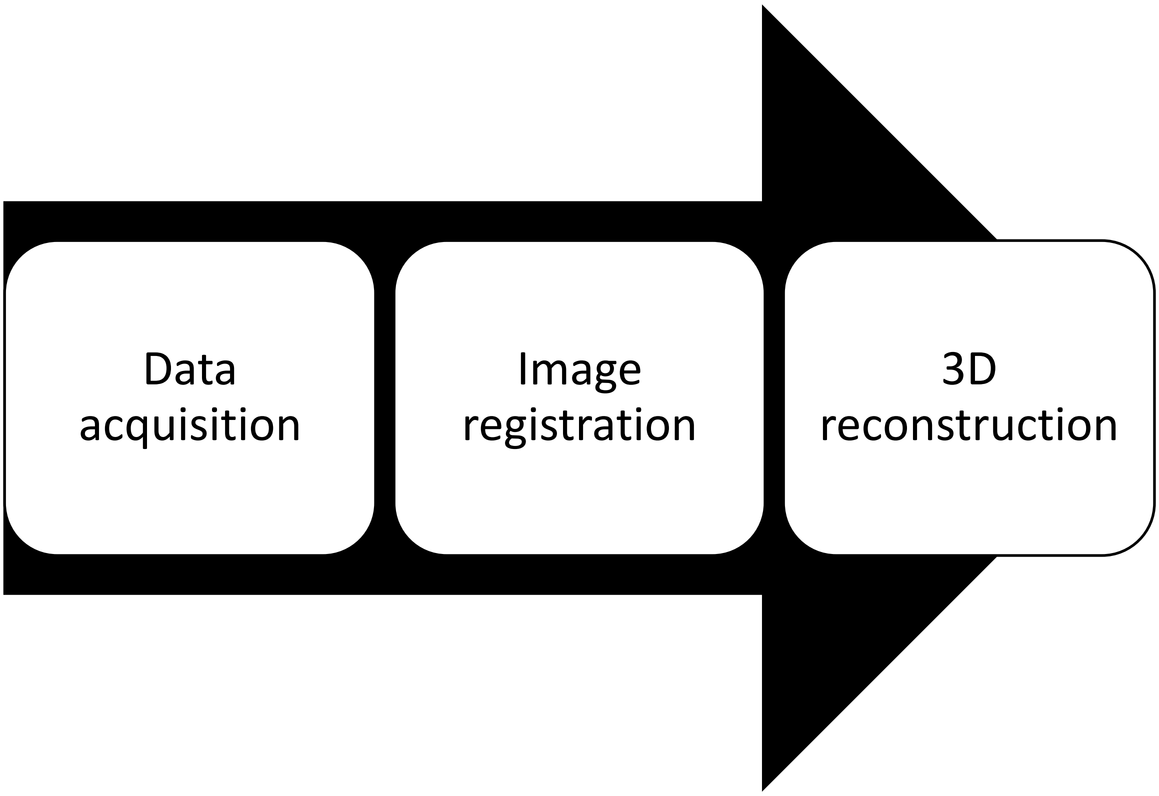
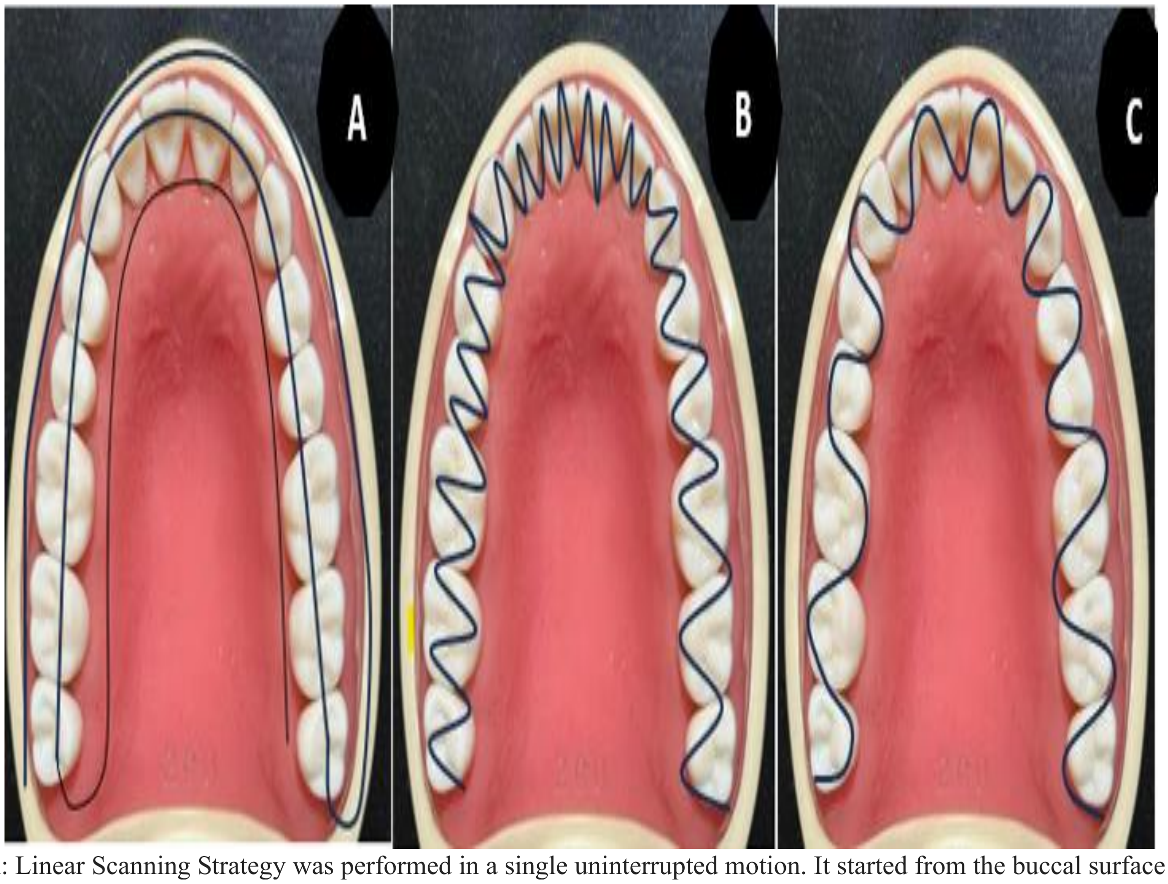


Figure 3. Schematic of the intraoral scanning workflow from image acquisition to 3D model reconstruction.



Strategy A: Linear Scanning Strategy was performed in a single uninterrupted motion. It started from the buccal surface left to the right, followed by the occlusal surface and then the palatal.
Strategy B: Zig-zag Scanning Strategy was done in a continuous buccal to palatal motion, from left to the right.
Strategy C: S- shaped Scanning Strategy performed in a continuous motion from the left side to the right side.

Figure 4. Illustration of scanning strategies described in the literature, highlighting variations in trajectory.

Continuous full-arch scanning may be suitable for less complex cases but is more susceptible to error accumulation due to extended stitching requirements [19-33]. In completely edentulous maxilla where the anatomical landmarks are reduced, bucco-palatal method has been reported as the most accurate approach [39]. This method begins at the crest of the edentulous ridge area, starting from left maxillary tuberosity, and continuing along the ridge to the right tuberosity, then continues on the buccal aspect and concludes on palatal vault [40]. In implant scanning, a two-step protocol where the crest is scanned first without scan bodies, followed by a second scan with scan bodies and then superimposition of the images has demonstrated significantly lower precision compared to direct scanning strategy with scan bodies in place [41]. Clinical performance is also influenced by scanner technology, operator experience and other patient-related factors [11-34]. These interacting variables emphasizes that scanning strategy is a part of a broad clinical decision-making process. Therefore, optimal scanning strategy should be selected according to each clinical situation for each case to achieve accurate digital impressions [12-34].

6. Conclusion

Available evidence indicates that scanning strategy is a key determinant of both trueness and precision in intraoral scanning, particularly in full-arch scans. Structured approaches, including linear, segmental or strategically sequenced scanning protocols, generally demonstrate improved accuracy compared with less organized or inconsistent scan paths. The effect of scanning strategy is also influenced by multiple interacting factors such as scanner technology, operator experience and other clinical conditions.

7. Limitations

This review is subject to several limitations that should be considered when interpreting the presented evidence. The available literature on scanning strategies is characterized by variations in intraoral scanner systems, scanning protocols and outcome assessment methods, which limits direct comparison between studies. In addition, a large proportion of the evidence is derived from in vitro investigations, which may not fully replicate the complexity of intraoral conditions such as saliva, soft tissue movement and limited mouth opening [20]. Differences in operator experience and the lack of standardized scanning procedures across studies further contribute to variability in reported outcomes. Moreover, the rapid evolution of intraoral scanning technologies means that findings from earlier studies may not fully reflect the performance of current generation devices [42]. Therefore, further well-designed clinical studies are needed to establish standardized, evidence-based scanning protocols.

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Declarations

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Not applicable.

Consent for publication

Not applicable

Data Availability

All data used in this study are available within the paper.

Competing interests

The authors declare that they have no competing interests.

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