Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

GUIDED VERSUS MANUAL MODE IN A SMARTPHONE APP USING A PHOTOGRAMMETRY ALGORITHM:

AN IN VITRO STUDY ON THE TIME EFFICIENCY OF EACH TECHNIQUE FOR COMPLETE-ARCH IMPLANT CAPTURE

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RESUMEN

Introducción: La fotogrametría se ha convertido en una tecnología clave para la toma de impresiones digitales en implantología. Su uso en la captura de arcadas completas sobre implantes ha mejorado la precisión de las impresiones digitales. La introducción de aplicaciones móviles basadas en fotogrametría ha generado interrogantes en relación con la eficiencia en el tiempo de adquisición.
Objetivos: El objetivo de este estudio fue evaluar y comparar in vitro la eficiencia temporal en la captura de una arcada completa sobre implantes utilizando los modos guiado y manual de una aplicación móvil basada en fotogrametría (PIC app®). **Materiales y métodos:** Se utilizó un modelo mandibular edéntulo fresado digitalmente con 6 análogos de pilares multiunit (MUA). Se realizaron un total de 120 registros de arcada completa por dos operadores empleando los modos guiado y manual de la PIC app®. **Resultados:** Para el Operador 1, el modo manual presentó tiempos de escaneado más cortos en comparación con el modo guiado (media ± DE: 45.6 ± 19.4 s frente a. 133.4 ± 68.5s). El Operador 2 mostró tiempos de escaneado más cortos con el modo guiado en comparación con el modo manual (media ± DE: 98.4 ± 40.1s frente a. 89.9 ± 73.4s). Debido a la distribución no normal de los datos, las comparaciones pareadas se realizaron mediante la prueba de Wilcoxon signed-rank test. Las diferencias en el tiempo de escaneado entre ambos modos fueron dependientes del operador. **Conclusiones:** Dentro de las limitaciones de este estudio in vitro, ninguno de los modos de adquisición para la captura de arcadas completas sobre implantes parece resultar más rápido entre los distintos operadores.

PALABRAS CLAVE

Odontología, Fotogrametría, Eficiencia temporal, Smartphone aplicación, Implantes, Arcada completa

ABSTRACT

Introduction: Photogrammetry has become a cornerstone technology for digital impression in implant dentistry. The use of photogrammetry for full arch implant capture has improved the accuracy of digital impression. The introduction of smartphone app based on photogrammetry has raised questions regarding time efficiency. **Objectives:** The purpose of this study was to assess and compare in-vitro the time efficiency for a complete-arch implant capture using both guided and manual mode in a smartphone app (PIC app®) using photogrammetry. **Materials and Methods:** A digitally milled cast of an edentulous mandibular arch with 6 multiunit abutment (MUA) analogs was used and 120 complete arch recordings were made by two operators using both guided and manual mode of the PIC app®. **Results:** For Operator 1 the manual mode showed a shorter scanning time compared to guided mode (mean ± SD: 45.6 ± 19.4s vs. 133.4 ± 68.5s). Operator 2 demonstrated shorter scanning times with the guided mode compared to the manual mode (mean ± SD: 98.4 ± 40.1s vs. 89.9 ± 73.4s). Due to the non-normal distribution of the data, paired comparison were performed using the Wilcoxon signed-rank test. The differences of scanning times between the two modes were dependent on the operator. **Conclusions:** Within the limitations of this in vitro study, neither acquisition modes for complete-arch implant appear to be more time efficient across operators.

KEYWORDS

Dentistry, Photogrammetry, Time efficiency, Smartphone app, Implants, Full arch

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1 INTRODUCTION

1.1 Overview of Impression Methods in Dentistry

1.1.1 Conventional impressions

Obtaining a high-quality impression has always represented a major challenge in prosthetic dentistry. The fundamental objective of an impression is to reproduce the patient's oral anatomy and arch configuration with the highest possible degree of accuracy in order to ensure an optimal fit of the final restoration. (1–5)

Conventional impressions have long been considered as the gold-standard method and are still the most commonly used technique in dentistry. (2,6–11)

Historically, hydrocolloid materials such as alginate were among the first elastic impression materials introduced in dental practice. Alginate, an irreversible hydrocolloid, became more widely used due to its simplicity of manipulation and low-cost. However, alginate has a limited dimensional stability and lower precision than elastomeric materials. The apparition and development of elastomeric impression materials marked a significant improvement regarding accuracy, dimensional stability, and elastic recovery. Among this section, polyvinyl-siloxane and polyether are currently the most used materials due to their superior tear resistance, fine detail reproduction, and stable dimensional properties over time. (4,11,12)

Despite their proven accuracy, conventional impressions require a meticulous and precise handling, skilled operator and patient compliance, while the clinical procedure itself can be time-consuming.

In addition, patient comfort is frequently reduced due to the invasive character and the potential extended setting time of elastomeric compounds. (4,8,10,11,13)

Several authors state that conventional impression techniques for capturing implant supported complete-arch prostheses are time consuming and prone to error. (4,8,14)

1.1.2 Digital impressions

Thanks to the continuous progress of scientific research and technological innovation, digital impressions have become widely adopted in contemporary dental practice. They are now considered as a valid alternative to conventional impression methods for recording intraoral anatomy and implant positions. (10) This technology enables clinicians to capture implant locations more easily while maintaining patient comfort, facilitates a faster and a more efficient access to digital data and eliminates the need for physical storage of impression materials or casts. (8)

With the continuous advancement of digital technologies and the widespread adoption of computer-aided design and computer-aided manufacturing (CAD/CAM) systems, digital impression techniques have progressively emerged as an alternative option and are gradually replacing conventional impression methods in contemporary dental practice. (4,8,15)

Digital impressions can be obtained through two alternative workflows. The partial digital workflow involves digitalizing a physical cast previously obtained from a conventional impression. In case of complete arch implant restorations, scan bodies are first positioned on the analogs of the master cast, which is digitalized using extraoral scanners either optical or contact based. Alternatively, the complete digital workflow enables a fully digital process where scan bodies are directly placed over the implants in the patient's mouth and the impression is captured using an intraoral scanner (IOS).

This approach eliminates the need for physical cast while allowing integration of information into the digital design process. (13,14)

Several studies considered digital impressions more efficient and a more comfortable alternative for the patient rather than traditional impression techniques. (8,13,14)

1.1.3 Limitations of Current Digital Workflows in Full-Arch Rehabilitation

Over time, new materials and innovative techniques have continuously emerged on the market, aiming to improve accuracy, efficiency, and clinical outcomes. (16)

Complete-arch implant restoration calls for a reliable and precise impression by a valid data-acquisition to achieve an optimal framework adaptation. (17–19) Indeed, several authors recommend that from a clinical standpoint, a passive fit with a maximum misfit of 150 μm is necessary to ensure the long-term prognosis and stability of the restoration. (1,3,4,6,12,18,19). The major challenge therefore lies in the ability and the techniques employed to obtain a high-quality impression, which is essential to guarantee a precise and reliable final prosthetic outcome.

Intraoral scanning (IOS) has become widely used in the field of implant dentistry and promising results have been reported. (10,14)

In situations of single-tooth restoration and short-span implant case, IOS accuracy meets its clinical requirements. In the other hand, for full arch implant restoration, IOS shows a more limited accuracy. Their reliability in full-arch digital implant impressions is still questionable in terms of accuracy and practicality particularly for the lower jaw. (6,8,20–22)

The accuracy of IOS can be influenced by several factors like ambient light, scanning pattern, scan body type or scanner brand. (21)

These limitations have encouraged the continuous search for alternative data acquisition methods capable of providing greater accuracy particularly in the context of complete-arch implant

rehabilitations. In response to these challenges, recent technological developments have introduced new systems designed to enhance precision while maintaining clinical efficiency and patient comfort. Among these innovations, photogrammetry stands-out as a promising technique for achieving higher degree of accuracy in implant localization and full-arch digital workflows. (5,10,15,16,18,19,21–25)

1.2 Principles and Technological Advances in Dental Photogrammetry

1.2.1 Begins of photogrammetry

Photogrammetry (PG) has been defined in the paper of International Society for Photogrammetry and Remote Sensing (ISPRS) in 2019 as the “determination of accurate measurements and three-dimensional data from photographs based on using images taken at different viewpoints to record the 3D geometry of a building or object.”

The origins of PG can be traced back to the French engineer Aimé Laussedat who is widely recognized as the founder of terrestrial photogrammetry for his pioneering work in using photographs for topographic measurement and mapping in 1851. (26) PG has been widely extensively applied across a wide range of disciplines including, cartography, anthropometry, archeology as well as in civil engineering. (24,27,28)

More than a century later, in 1994, photogrammetry made its first appearance in the landscape of dentistry. Lie and Jemt were the first researchers to integrate this technology for the precise measurement and localization of dental implant positions, marking a turning point in the digital recording of implant data. (29)

1.2.2 Photogrammetry and Stereophotogrammetry Principles

The name “photogrammetry" is derived from the three Greek words *phos* which means light, gramma which means draw, and *metrein*, the noun of measure. (28)

Stereophotogrammetry is a specific type of photogrammetry that determines the 3D implant positions by calculating the spatial intersection derived from 2-dimensional (2D) image captured simultaneously from different angles using a stereoscopic camera. (Figure 1) (2,6,18,21,30–32)

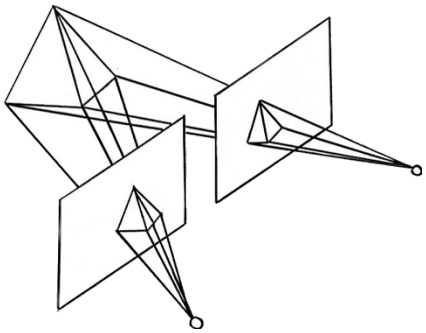


Figure 1. Principle of Stereoscopic camera

Through the analysis of series of images captured from different perspectives, this technique enables the precise reconstruction of 3D spatial coordinates, relying on high-resolution and geometrically calibrated cameras. (33)

Continuous advances in photogrammetry are reshaping the landscape of digital implant capture.

PG may offer a more reliable alternative than IOS for recording 3D position of dental implant. Indeed, unlike IOS, PG systems are generally less influenced by the different limitation factors IOS may have. However, a major limitation of PG lies in its inability of capturing soft tissue reference, maxillomandibular occlusal relationships or antagonist ach. More, PG does not work for single implants capture and require an additional IOS scan or conventional impression to design and create implant supported prothesis. To address this limitation, recent development have been made by incorporating PG technology into IOS devices such as Shining 3D (Aoralscan Elite). This integration seeks to associate the strengths of both technologies to potentially reduce workflow costs and unify the data acquisition process. (34,35)

Despite promising results, the accuracy of IPG for the fabrication of complete-arch implant rehabilitation, is still debated and need furthermore investigations. (1,8,31,36)

1.2.3 PIC dental (Precise Implant Capture)

When registering implant position, the use of photogrammetry enables an accurate and efficient recording. (37,38) In parallel, extraoral photogrammetry (EPG) systems have been specifically designed in pursuit of maximal precision and trueness of digital impressions. The extraoral camera design allows a considerable improvement in the use of dental photogrammetry as it avoid any potential disturbing factors and interferences in the operative field like saliva, blood or patient movement during the scanning. (21,33)

In 2010 the PIC system with the PIC camera is released.

Built upon photogrammetry, it localizes dental implants and capturing their geometrical relationship by analyzing extraoral images of intraoral optical markers (PIC transfers). Two infrared cameras record the position of PIC transfers and generate a 3D digital representation through photographic imaging. (5,18,33,37–39).

PIC transfers are the fiducial markers that are screwed directly onto the implants or at the abutment level. They are currently available in two formats; a larger version, known as PIC transfers standard which is better suited for posterior regions and PIC transfers Mini, that are 30% smaller thus more adapted for anterior regions or for impressions involving six implants or more. Each of the PIC transfers is individually manufactured and referenced by both engraved batch number and identification code on its surface. Structurally, they are made of a thermoplastic polymer that allow them having a higher longevity and resistance to sterilization cycles. Their flag shape design that facilitates intraoral placement and ensures that all transfers can be simultaneously captured within the camera's field of view**.** A pattern of white shiny dots is distributed across the surface. (9) (Figure 2.)

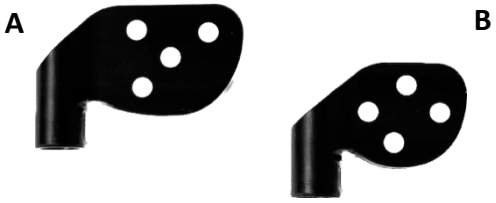


Figure 2. A. PIC transfers standard **B.** PIC transfers mini

These coded fiducial markers are detected by the infrared cameras of the PIC camera, enabling the system to recognize and reconstruct the precise spatial position of every implant along the three Cartesian axes (X, Y, Z). (31) Their geometry, surface diameter, and coating have been specifically engineered to optimize detection accuracy during image acquisition**.**

As of now, five dental EPG systems are commercialized on the market: the PIC System (PIC Dental), iCam4D (Imetric), MicronMapper (ClaroNav), OXO Fit (OXO) and 3Dots (Open Tech). (24,40)

The accuracy of implant scans obtained with these systems has been investigated in the dental literature. Several studies have reported trueness values for the PIC System ranging from 10µm to 49µm, with precision values between 5µm and 65µm. (18,31,41) For the iCam4D system, trueness ranged from 24 to 77µm and the precision value ranged from 2 to 203µm. The accuracy of the remaining systems has not been reported yet. (41)

1.3 Evolution of photogrammetry devices: From laboratory systems to Smartphone application

Traditionally, stationary systems have been the main configuration of devices using PG.

Over the years, PIC system introduced several versions of device including PIC Gravity, PIC System and PIC Station. However, these devices may present certain limitations related to their format such as a restricted portability and limited applicability if working in a small environment. The latest innovation, the PIC app, was developed to address these challenges. PIC app is a smartphone app incorporating PG technology.

Until recently, extraoral photogrammetry devices were based on the use of special stereoscopic cameras. Nevertheless, advances smartphone industry and significant improving of mobiles digital cameras have made possible obtaining reliable and highly precise measurements. The PIC app is currently compatible only with new generation of iPhone Pro models. This compatibility is linked to the fact that Pro versions include enhanced camera modules, larger sensors, optical stabilization and a triple camera system. (5)

The integration of smartphone technology for complete arch implant capture with a PG algorithm provide a more economical and accessible option for clinicians. (31) PIC app allows us to scan directly via mobile phone while employing the same physical components, accessories and follow the same principles as traditional extraoral PG scan.

An initial version of PIC app has already been released on the market while a new version remains under investigation. In complete arch implant capture, the necessity of precision and accuracy of impression is crucial.

In the manual mode, the operator enjoys a freedom of movements with no predefined scanning pattern or limited number of captures. In contrast, guided mode employs a predefined pattern of scan to assist the operator through the process. A limited number of photographs are captured in series (7–4–4). Operator's movement and captures are restricted accordingly.

After image acquisition, cases are upload to PIC cloud and exported to open STL format that generate a PIC file that provides a precise visual representation and measurement of the case.

As with PIC system, the PIC app still requires an additional scan either conventional or intraoral for recording soft tissues position.

Investigations of both versions are needed to evaluate their accuracy, ease of use, and time efficiency. This in vitro study aims to determinate time efficiency of manual and guided mode for a complete arch implant rehabilitation.

2 OBJECTIVE

The purpose of the present in-vitro study was to evaluate the time efficiency of a smartphone app using photogrammetry (PIC app®) by comparing a guided versus a manual mode.

The null hypothesis was that no significant time variation would exist between guided mode and manual mode for complete-arch implant capture.

3 MATERIAL AND METHODS

3.1 Study design

This in vitro experimental study has been approved by the Ethics Department of the Final Degree Project of the European University of Madrid (OD.034/2526) Annex 1.

This research was conduct at the PIC dental center of Torrelodones between October 2025 and March 2026. To analyze the time efficiency, two version of the PIC app were evaluated.

The current commercial version of PIC app (Figure 3.) includes a single operating mode, the manual mode, which allows full freedom of movement for the operator. PIC app developers have since innovated and create a more advanced version of the application. (Figure 4.)



Figure 3. PIC app® v.1.5.2; PIC dental



Figure 4. PIC app® new version

In this updated version, three distinct modes are introduced: an expert mode, a countdown mode and a guided mode. For the purpose of this study, the guided mode was the one selected for evaluation. The guided mode offers a predefined scanning strategy that directs the operator throughout the capture process.

PIC app is a smartphone app using photogrammetry that detects fiducial markers using specialized PG algorithm. (42) The application is restricted to Pro-series iPhones (14 Pro and newer) as these devices share technical features critical for photogrammetric accuracy, including high-resolution multi-camera module, sensor-shift stabilization, advanced image processing chain and uniform lens properties (43). These specifications ensure stable image quality and reliable conditions for 3D reconstruction that

older or non-Pro versions may not guarantee. To standardize all measurements, an iPhone 16 Pro was used for every recording in this study.

3.2 Experimental model

An edentulous mandibular titanium model featuring six multiunit abutment (MUA) implant analogs was designed using Computer-Aided Design (CAD) software, fabricated through a milling process and subsequently mounted in a phantom head. The multi-unit abutments were located at the sites of lateral incisors, second premolars and second molars. Fiducial markers supplied by the manufacturer's; PIC transfers (PIC Transfer, HC MUA Metal, Ø4.8 mm; PIC Dental) were secured on each implant abutment with a manual torque of 10 Ncm, in accordance with the manufacturer's instructions. (Figure 5.)



Figure 5. Experimental model with PIC transfers placed

To ensure optimal visibility of all optical markers during the scan, four regular-sized PIC transfers were placed on the molars and premolars analogs (526-MUA) while two small-sized PIC transfers (C94-MUA) were positioned on the lateral incisor analogs.

Throughout all recordings, same scan markers were used, maintaining identical position for each session to ensure consistency. The placement of optical markers followed a predefined orientation for optimal implant capture. At the molar sites, markers were oriented toward the lingual side, whereas at the premolar sites, they were positioned toward vestibular. For the incisors, the marker on the right lateral incisor was placed vestibularly while the marker on the left lateral incisor was oriented toward lingual.

3.3 Scanning procedure

3.3.1 Configuration of scanning sessions

A total of 120 recordings (n=120) were completed. 30 recordings per operator for the manual mode using the first app version and 30 recordings per operator for the guided mode on the updated app

version. The inclusion criteria were successfully completed arch scan. Sessions that generated an error message were excluded.

3.3.2 Manual mode

The manual mode operates without any predefined scanning pattern. Its interface is designed to be clear and intuitive, allowing an easy and operator-friendly experience. The app first displays an odontogram of the preliminary selected arch (maxilla or mandible). The operator selects the teeth involved in the scan, which then appear in a drop-down menu. Each selected tooth must be assigned its corresponding PIC transfers code (in this case, 536-MUA and C94-MUA) as well its positional number. The interface looks like a traditional camera interface but includes a central frame where the operator must position the optical markers during the image inquisition. This central frame is equipped with a focus-assist zoom feature, designed to help the operator maintain a proper distance and sharpness throughout the scan. At the top of the screen, a progression sketch provides a visual representation of the scan advancement through a color-coded arch and a completion percentage. Following the manufacturer guidelines, optimal scanning conditions were ensured by removing any phone accessories (protective cases or camera lens cover), cleaning the camera lenses with a lint-free microfiber cloth between each scan capture for ensuring that no smudges or debris are present and avoid too bright light exposure that could produce unwanted light reflections. In this mode, the operator has full freedom of movements and an unlimited number of possible shots. The number of captures required to complete each scan are presented in Figure 6.

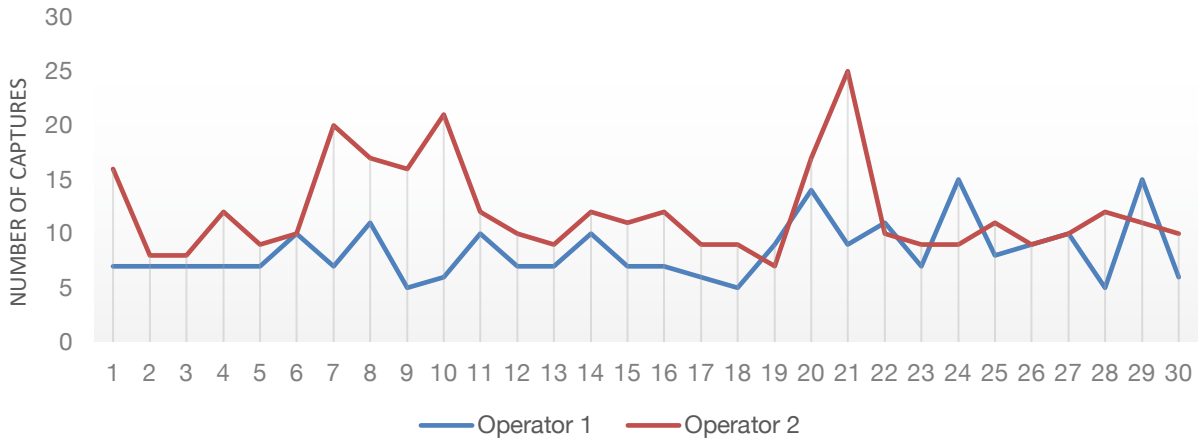


Figure 6. Number of captures required to generate a completed full-arch scan with Manual mode

3.3.3 Guided mode

Unlike the manual mode, the guided mode is, as its name suggest, fully guided. In this capture modality, the operator must follow a predefined scanning strategy imposed by the application.

Although the general layout of the interface remains similar to the one of the manual mode, the capture screen presents notable differences. As in the manual mode, a central frame window is displayed to assist the operator; however, in this version, the frame is surrounded by a darkened border to further emphasize the capture area and enhance the operator focus. A key innovation of this mode is the introduction of identification circles. Indeed, in addition to the focus-assist zoom feature also present in the manual mode, colored identification rings appear on the screen to help the user determined the comfort distance and positioning of the mobile phone. These rings change color from red to green providing intuitive feedback on whether the operator is correctly positioned.

Small alerts messages also indicate when the operator should move closer or further during the capture process. The guided mode is also equipped with an auto-scan function. It automatically triggers photo capture without requiring repeated manual activation of the shutter button. This feature relies on artificial intelligence to determine the ideal moment to capture each image and subsequently transmits it to the processing algorithm for analysis. Another recent addition is the integrate flash mode which allows the phone's flash to be activated during the scanning to compensate eventual insufficient ambient light. Because the guided mode follows a strictly predetermined path, the total number of images captured is also limited. The programmed trajectory consist of seven mandatory key-points captures as represented in Figure 7.



Figure 7. Key-points capture in Guided mode

The operator cannot proceed to the next point unless the system considers the current image sufficiently accurate. The point must be repeated until the system deems the capture adequate.

After seven required captures, if the algorithm is unable to generate the STL file due to insufficient information, the app prompts the operator to complete the scan with an additional series of four images. If needed, a second additional series of four images may also be required.

All guided-mode scans were performed under the same conditions as those used for manual mode. The number of captures required to complete each scan are presented in Figure 8.

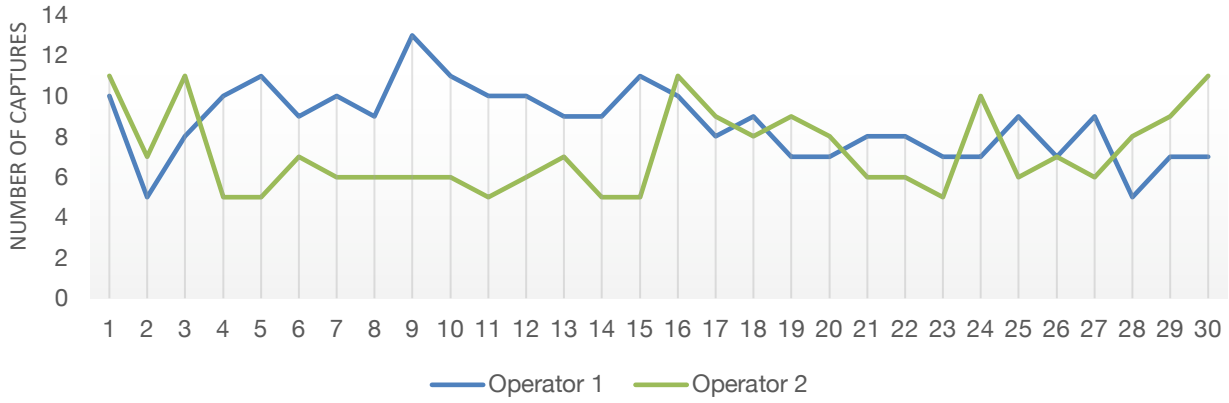


Figure 8. Number of captures required to generate a completed full-arch scan with Guided mode

3.4 Time recording method

All scans were manually timed using the stopwatch function of an iPhone 15 Pro. Although the stopwatch provides centisecond precision, we chose to record only minutes and seconds as the operator reaction time when starting and stopping the timer would make centisecond accuracy irrelevant. The timer was started as soon as the operator took the first photo and stopped when the application notified us that the capture had been successfully completed.

The recordings were performed by two operators who progressively improved their skills throughout the study, potentially becoming faster with each subsequent scan.

In cases where the app crashed, the timing was stopped and restarted from zero for the new attempt. All recording times were manually entered into a Word document table.

3.5 Operator parameters and environmental conditions

All recordings were performed under standardized environmental conditions to ensure reproducibility. The recordings were carried out by two independent operators, both of whom were calibrated before the start of the study. Their performances progressively improved over the time as they become more familiar with the scanning procedure, potentially influencing capture speed and handling fluidity. All scans were executed with the operators standing in order to replicate realistic clinical situation. The phantom head model was firmly stabilized throughout all procedures to prevent any displacement that could affect photogrammetric reconstruction. Similarly, operators have maintained a stable stance during scanning for minimizing body sway and excessive hand motion and ensure image sharpness.

The working scanning distance between the smartphone and the model was approximately between 30-45cm and with variable angulation estimated between 20° to 35° depending on the scans. Environmental lighting was kept constants for all sessions. No direct light source was oriented toward the optical markers to avoid glare or excessive reflections. The iPhone 16 Pro was configured on airplane mode to eliminate interruptions. A stable and high-quality internet connection was essential for the app to function properly and successful completion of scan generation.

4 RESULTS

4.1 Scanning time

A total of 120 scans were performed by two operators. The time required for each scan was recorded. Scanning time was measured manually using a stopwatch and only minutes and seconds were considered. For each scan, the time required for the manual and guided version was paired. As scanning times did not follow a normal distribution, comparison between the two versions were performed using a non-parametric paired test (Wilcoxon signed-rank test) presented in Table 1.

Table 1. Time required for manual and guided impressions performed by two operators.
Paired comparisons were performed using the Wilcoxon signed-rank test.

	App version	Mean ± SD (s)	Median (s)	Min-Max (s)	n	p
Operator 1	Manual	45.6 ± 19.4	37.0	26-110	30	<0.001
Operator 1	Guided	133.4 ± 68.5	117.0	56-365	30	
Operator 2	Manual	89.9 ± 73.4	58.5	33-308	30	0.152
Operator 2	Guided	98.4 ± 40.1	83.5	54-193	30	

4.2 Overall scanning time by acquisition mode

4.2.1 Manual mode

Figure 9 presents the distribution of scanning times obtained in manual mode for operators 1 and 2. The mean ± time for manual mode including both operators was 67.7 ± 57.7s (n=60).

Scanning times are represented using box plot, illustrating the median, interquartile range, overall data dispersion, maximum and minimum values. This graphical presentation allows the comparison of the variability of manual mode scanning times between both operators.

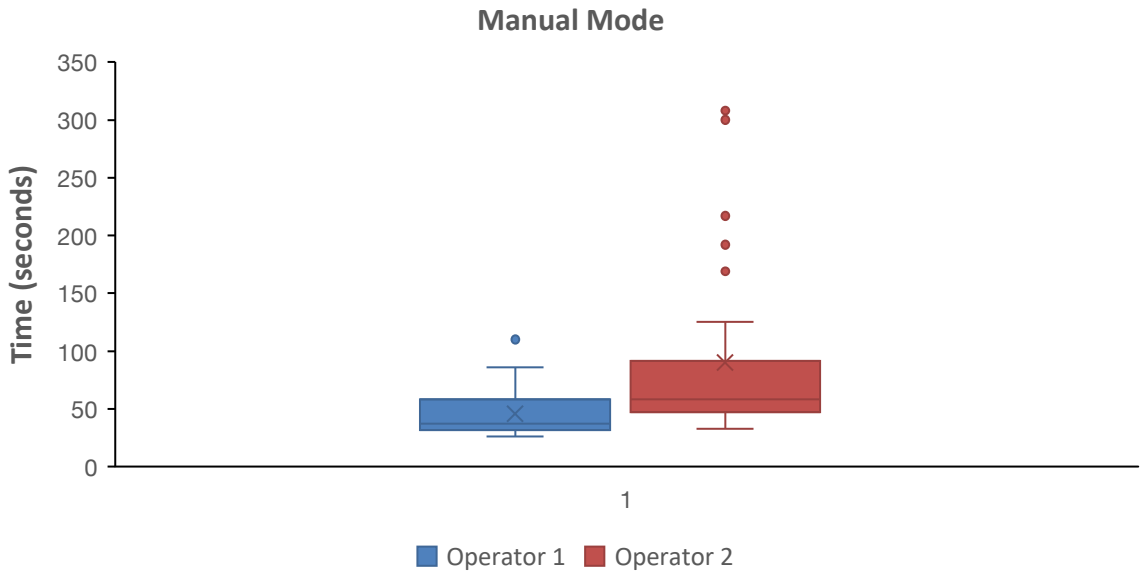


Figure 9. Distribution of manual mode scanning times for Operators 1 and 2

4.2.2 Guided mode

Figure 10 presents the distribution of scanning times obtained in manual mode for operators 1 and 2. The mean ± time for guided mode including both operators was 115.9 ± 58.4s (n=60). Scanning times are represented using box plot, illustrating the median, interquartile range, overall data dispersion, maximum and minimum values. This graphical presentation allows the comparison of the variability of guided mode scanning times between both operators.

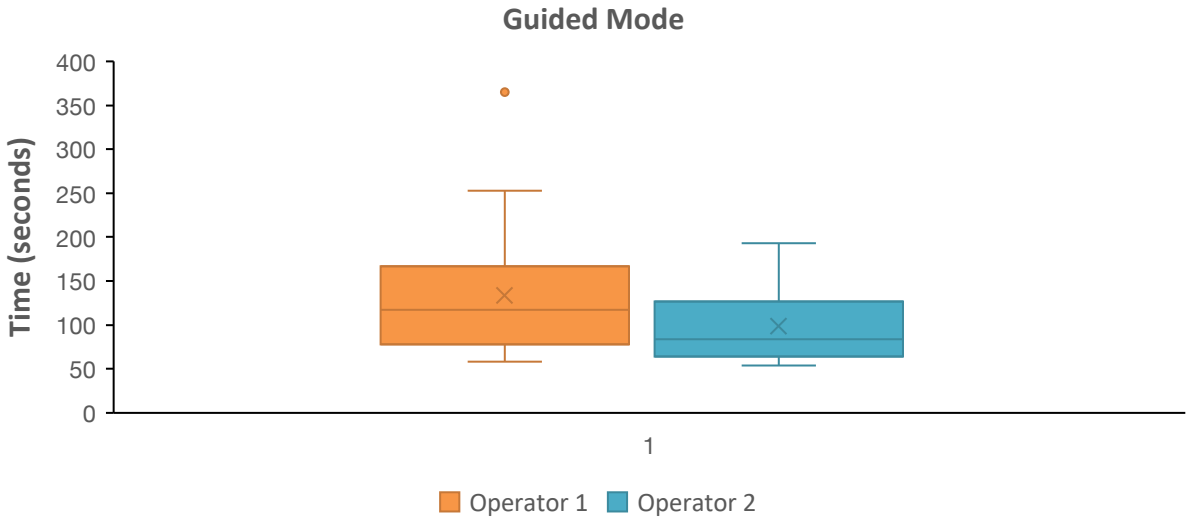


Figure 10. Distribution of guided mode scanning times for Operators 1 and 2

4.3 Scanning time according to operator

Scanning times differed between operators for both acquisition mode. Within the manual mode, operator 1 showed a lower median scanning time compared to operator 2. With guided mode, differences between scanning times distribution were also observed between both operators with a greater dispersion for operator 1.

In manual mode, scanning times for operator 1 tends to cluster more closely around the median. In the guided mode, a wider spread of the values is observed.

For operator 2, scanning times showed variability in both acquisition modes with a broader distribution of values in manual mode.

The mean scanning time was higher in the guided mode compared to the manual one. However, due to high variability and operator differences, statistical significance cannot be deducted from mean values alone.

For both acquisition modes, the shape and spread of the distributions differed between operators 1 and 2. Differences were observed in median values, interquartile ranges, and the presence of extreme values.

5 DISCUSSION

The null hypothesis stated that there are no differences in scanning time between guided and manual mode. Based on the results of this study, there is a significant difference between guided and manual modes regarding the scanning times for Operator 1.

Indeed, the guided mode acquisition time significantly increased for Operator 1 compared to the manual mode. This led to rejection of the null hypothesis for Operator 1.

In contrast, no significant differences between modes were observed for Operator 2 and the null hypothesis cannot be rejected. Regarding the pooled mean scanning time, even though the mean was higher for guided mode, the Wilcoxon signed-rank test did not demonstrate a consistent effect across operators suggesting that the difference observed is influenced by operator-dependent factors. These findings suggest that the impact of acquisition modes on scanning time is operator dependent. The results obtained highlight the influence of the operator over the time efficiency rather than a faster acquisition mode in itself.

Still, we are unaware of any previous studies that have used the same methodology and sample size to evaluate the time efficiency of manual and guided mode.

However, recent technologies such as intraoral photogrammetry systems (IPG) have also been studied regarding scanning time efficiency. In a recent investigation realized by Xiao-Jiao Fu, IPG demonstrated

shorter acquisition times (50.30 ± 6.77s) compared to conventional intraoral scanners (91.10 ± 20.31s) and intraoral scanners with prefabricated aids (IOSA) (125.00 ± 18.74s). (17) Differences in scanning protocols and technologies prevent a strict numerical comparison of the scanning time acquisition.

Therefore, we should consider carefully the interpretations of those results with this present study. IPG systems remains controversial and further investigations are required to clarify its time efficiency and clinical reliability.

The PIC system operates using a mechanism that differs from IPG currently available on the market. Unlike these systems, it does not rely on image stitching to generate digital files, nor does not need alignment of scan bodies through best-fit algorithms to reconstruct digital working model. Indeed, the PIC technology use specific dot coded markers scan bodies to determine mathematically the special position of each implant eliminating the need to capture geometric shape of and details of the scan bodies. (44)

It should be noted that the PIC system, as an extraoral scanning device, only records implant position and does not capture the surrounding soft tissue anatomy. (3,4,19,35,38)

However, recent integration with 3Shape Unite allows the combination of implant position data from PIC with soft tissue data obtained separately from intraoral scanner. Through the PIC cloud, both datasets can be linked and accessed in a single platform. This new featuring simplifies the digital workflow and improve the overall efficiency.

This study present inherent limitations related to its in-vitro design. Performing the scans in a controlled environment may differ from the deviations associated with the clinical learning curve of the scanning procedure. In-vitro conditions does not fully replicate the complexity of the intraoral environment. In clinical practice, several factors such as saliva, intraoral fogging, restricted mouth-opening and soft tissues movements may influence the scanning time efficiency.

Only two operators were included which limits the generalization of the findings to an absolute truth. Difference between operator familiarity with the different modes may have influenced the scanning times and may have contributed to the observed operator-dependent effect. More, the scanning times were measured with a manual stopwatch which can introduce a minor inaccuracy related to the operator's reaction time.

Despite its limitations, the present study brings relevant insights into the influence of acquisition mode and operator variability on scanning time efficiency of a complete-arch implant capture.

6 CONCLUSIONS

Within the limitations of this in vitro study, the scanning time efficiency of manual and guided mode acquisition for complete-arch implant capture appears to be operator-dependent. A significant

difference in scanning times between acquisition modes was observed for one operator, whereas no significant differences was found for the second operator. These findings indicate that scanning efficiency is influenced not only by the acquisition mode itself but also by individual operator performance. Although guided mode tended to require longer scanning times on average, the high variability observed, and the operator-dependent effect prevent the identification of a universally faster acquisition mode. Therefore, statistical significance cannot be inferred from mean values alone and difference in scanning time should be interpreted with caution. Moreover, the impact of these observed differences may not be clinically relevant.

Future studies including a larger number of operators are needed to further assess the scanning time efficiency of the guided and manual modes. The integration of emerging technologies such as artificial intelligence may also contribute to optimizing scanning time efficiency for complete-arch implant capture.

7 SUSTAINABILITY

The evaluation of scanning time efficiency with a smartphone application using photogrammetry for complete-arch implant capture contributes to the sustainability of dental practice from an economic and social point of view. Time efficiency is a cornerstone in clinical workflows as it reduces chairside time, productivity and improve patient comfort (8,45,46). The study highlights the operator-dependent factor of scanning time. It underlines the importance of an adequate user adaptation to digital systems. Improving operator performance may contribute to a more sustainable integration of digital dentistry in clinical practices. More, digital acquisition techniques may contribute to reduce the need of conventional impression materials contributing to a more responsible practice and reduced material waste. Time efficiency and digital clinical workflows are key elements for long term sustainability of modern dental practice (47).

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9 ANNEXES

Annex 1.

AUTORIZACIÓN Y CERTIFICACIÓN

PIC DENTAL S.L.
Con domicilio social en Calle Camino de Valladolid, 1, y CIF B86355609, en adelante "PIC dental", por medio del presente documento autoriza lo siguiente:

1. Autorización de uso de instalaciones

PIC dental autoriza expresamente al/la investigador/a Clemence Chailloux, con número de pasaporte 19FF15450 en adelante "el/la Investigador/a", a utilizar las instalaciones, los equipos y los recursos técnicos ubicados en su sede para la realización de actividades de investigación relacionadas con la presente tesis. Esta autorización incluye el acceso supervisado a los sistemas de captura, escaneo y registro fotogramétrico empleados habitualmente por PIC Dental, con el único fin de llevar a cabo las tareas necesarias para el estudio descrito en este documento.

2. Finalidad de la investigación

La finalidad específica del estudio es la obtención de impresiones y registros experimentales mediante técnicas de fotogrametría aplicadas a la captura de arcadas completas sobre implantes. Dichas impresiones permitirán la evaluación de los resultados experimentales y el análisis comparativo entre diferentes modalidades de captura, todo ello en el marco del proyecto de investigación aprobado.

3. Información sobre el trabajo de fin de grado

Número de trabajo de fin de grado de la Universidad Europea de Madrid curso 2025/2026: 75

Título original: "Guided versus Manual Mode in a Smartphone App Using a Photogrammetry Algorithm: An In Vitro Study on the Time Efficiency of Each Technique for Complete-Arch Implant Capture"

Título en español: "Modo guiado frente a modo manual en una aplicación para smartphone usando un algoritmo de fotogrametría: un estudio in vitro sobre la eficiencia temporal de cada técnica para la captura completa del implante del arco"

Tutor académico: Andrea Santamaria

4. Protección de Datos

PIC dental declara que todos los datos personales tratados durante la presente investigación serán gestionados de conformidad con lo dispuesto en el Reglamento (UE) 2016/679 del Parlamento Europeo y del Consejo (Reglamento General de Protección de Datos - RGPD) y con la Ley Orgánica 3/2018, de Protección de Datos Personales y garantía de los derechos digitales (LOPDGDD).

El/la Investigador/a manifiesta su conformidad con dichas normativas y se compromete a asegurar que cualquier información personal obtenida o generada en el marco del estudio será tratada de forma lícita, leal, transparente y exclusivamente para los fines científicos descritos, garantizando en todo momento la confidencialidad, integridad y seguridad de los datos.

5. Vigencia

La presente autorización es válida por el período estrictamente necesario para la realización del estudio y podrá ser revocada por PIC dental en cualquier momento por causas justificadas.

En Torrelodones, a 26 / 11 / 2025.

IDITEC NORTH WEST, S.L.
C.I.F. B-86355609

Firma y sello autorizados
PIC dental S.L.
Alejandro Moreno
CTO