Intra-oral photogrammetry: The next step in full-arch implant precision

Redefining digital accuracy in implant dentistry

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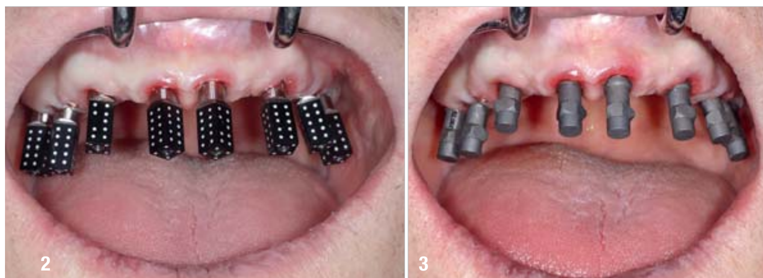
The dental industry is rapidly evolving, driven by technological innovations that are transforming patient care, diagnosis and treatment planning. The shift from film to digital radiographs has greatly enhanced the clinician's ability to interpret caries and pathology while improving patient communication. Over the past 20 years, these 2D images have been augmented with 3D images, made possible with CBCT, and interactive treatment planning software. Physical impressions for crown and bridge dentistry have been modernised with intra-oral scanning, creating the first digital workflows when combined with milling machines in the dental laboratory and then in the dental office. Dental implants can now be restored with information gained from specific scanning abutments designed to capture the intra-oral position of the implant and surrounding tissue with an intra-oral scanner and software that seamlessly transfers this data to the dental laboratory and clinician.

While intra-oral scanning has been widely adopted for single-tooth restorations, its application in capturing multiple implants—particularly in full-arch cases—presents unique challenges. Therefore, one area undergoing significant transformation is the accurate capture of multiple implants, especially full-arch implants, which is typically a complex process that demands a high level of precision. As intra-oral scanning falls short in accuracy, photogrammetry was developed to provide the exactness necessary to allow the dental laboratory technician to design superstructures that will fit passively on multiple implants without the need for a physical verification index. Innovative technology has been effective as a solution to intra-oral scanning to achieve this level of precision, yet a soft-tissue scan is still required to capture the soft tissue. Additionally, despite the positive aspects of photogrammetry, it is an expensive addition for a clinician because both devices are needed to capture all of the intra-oral data that is needed for the restorative process. This is where intra-oral photogrammetry (IPG), an emerging technology, comes into play, redefining accuracy and efficiency in full-arch implant procedures.

The digital transformation in dentistry

For decades, clinicians relied on physical impression techniques to create models of the oral cavity. These conventional methods involve using physical materials to capture the shapes and contours of teeth, soft tissue, tooth preparations and more recently implant positions. Physical impressions also often require retakes, leading to patient discomfort, contamination with blood and saliva, increased chair time and additional associated costs. Although these analogue materials can be effective, they are prone to deformation, patient movement and inaccuracies, making it difficult to achieve the precision required



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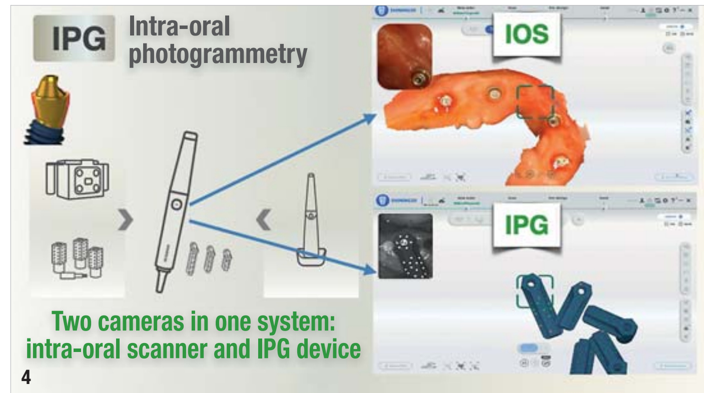
for complex implant cases. To overcome the issues of analogue impression materials and related laboratory protocols, intra-oral scanning was introduced, offering clinicians a digital solution that simplifies the impression process. Using a handheld device, clinicians and dental assistants can quickly capture a 3D digital image of the patient's oral cavity, and this image can then be used to create virtual models and prostheses designed with advanced CAD/CAM software.

However, intra-oral scanning has its own set of challenges for natural tooth preparations, and single and multiple implants, particularly the capture of full-arch implants. When scanning large areas, such as a full arch with multiple implants, errors can accumulate owing to the limitations related to the native topography of the oral cavity, the curve of the arch, necessary software stitching algorithms, image overlap and inherent distortions. The goal of implant and prosthetic treatment is to provide an aesthetic and functional treatment outcome that is dependent on a passive fit of the prosthesis to the implants. The limitations of intra-oral scanning can significantly affect the predictability of prostheses because even minor discrepancies can lead to major alignment errors and fitting problems, which if left undetected can lead to complications and implant failure. Therefore, despite their usefulness in allowing for digital workflows for many procedures, conventional intra-oral scanners often fall short in full-arch implant cases, making their treatment especially complex and prone to inaccuracies.

Understanding the limitations of intra-oral scanning for full-arch cases

Intra-oral scanners capture a series of images in rapid succession, and through the magic of software algorithms, these are then stitched together to form a virtual 3D model. While this technique is effective for single-tooth restorations, it is prone to errors when larger areas are scanned, especially when multiple implants are involved such as for full-arch reconstruction. The main issue arises from the need to align each captured image (scanning abutment) correctly with the next. When the scanner moves from one segment of the arch to another, even small alignment errors can lead to a loss of accuracy, creating cumulative errors that affect the passivity and final fit of the prosthesis, which may not seat correctly, resulting in poor fit and function. Moreover, intra-oral scanners often are unable to maintain a consistent line of sight over the entire arch, especially in areas where there are obstructions, such as the cheeks, the tongue or pre-existing restorations. This can lead to incomplete data capture, further compounding the problem. Another issue with conventional intra-oral scanning in full-arch cases is related to soft-tissue capture. Full-arch implant restorations often involve complex soft-tissue structures that need to be accurately represented in the digital model.



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Conventional intra-oral scanners can have difficulty capturing the subtle details of this soft tissue, leading to inaccuracies in the intaglio surface of the final prosthetic design. These limitations make it difficult to achieve a precise and predictable fit, particularly when implants are placed at different angles or depths.

The rise of photogrammetry in dental implantology

To address these drawbacks, the dental community turned to photogrammetry, a technique that uses multiple photographic images taken from different angles to calculate the precise 3D coordinates of fixed points. Photogrammetry has been widely used in industries such as metrology, engineering and aerospace for its high precision, and it has recently made its way into dentistry. In dental applications, photogrammetry involves using specialised scan markers attached to implants to serve

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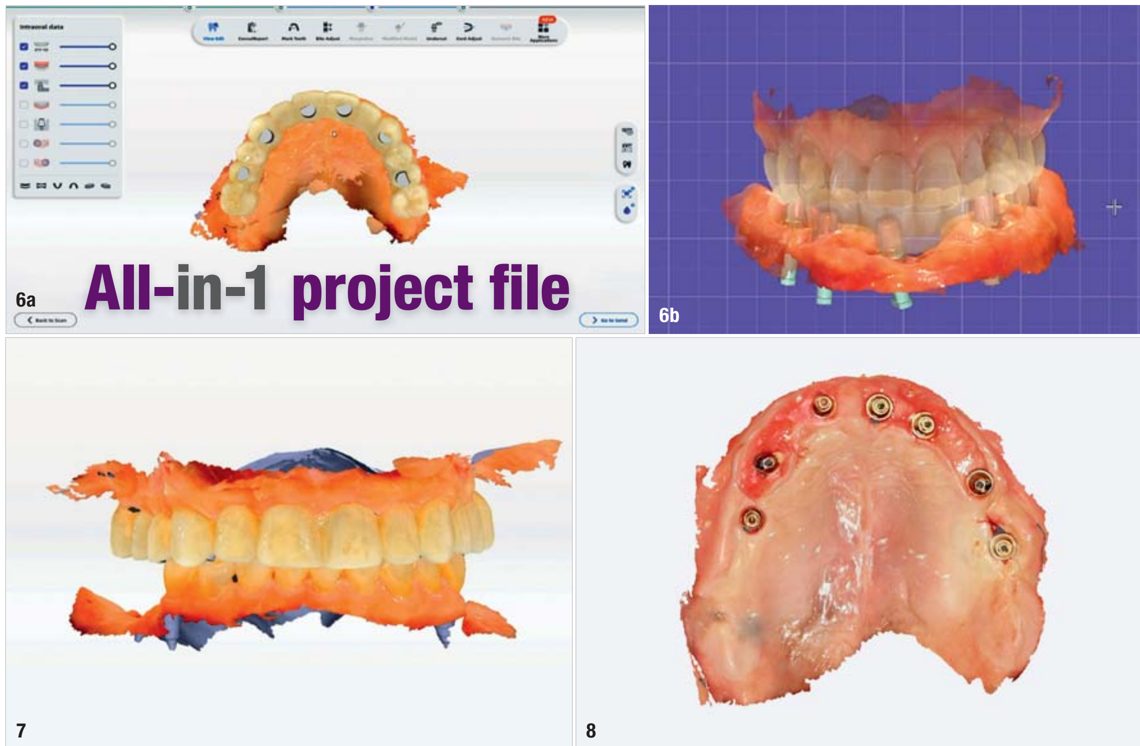


as reference points for the photogrammetric device. The device then calculates the exact positions of these markers, allowing for the precise capture of implant positions.

Extra-oral photogrammetry (EPG) devices, which are handheld and positioned outside the patient's mouth, capture multiple images of the markers from various angles (Fig. 1). The images are then processed and merged into a single 3D model using specialised software. EPG has been shown to achieve micrometre-level accuracy in capturing implant positions, making it a valuable tool for complex full-arch cases.

EPG systems do however have certain limitations. The extra-oral nature of the system requires a stable platform and consistent lighting conditions, making it less adaptable for intra-oral use. Additionally, EPG systems typically require separate scans for the implants (Fig. 2) and the surrounding soft tissue (Fig. 3). These separate data files are then exported and sent via the internet or cloud to the dental laboratory technician, who will manually merge the files utilising dental CAD software. This process is time-consuming and requires a high level of technical expertise, thus limiting its practicality for everyday clinical use. Additionally, there are only a handful of manufacturers of EPG devices, resulting in high purchase costs. Therefore, owing to its complexity and cost and the need for a separate intra-oral scanning device to capture the soft tissue, EPG is not widely used outside of specialised centres and advanced prosthodontics practices. These restrictive issues led to the development of a more streamlined approach: IPG.

Introducing intra-oral photogrammetry

IPG is a breakthrough technology that combines the precision of photogrammetry with the convenience of intra-oral scanning. Unlike EPG systems, IPG allows clinicians to capture both implant positions and the surrounding tissue in a single scan, without the need for separate images from two different capturing devices and thus the need for manual data merging. The IPG system uses a handheld intra-oral device equipped with two cameras, one for intra-oral scanning and one for IPG (Fig. 4). The system utilises specific

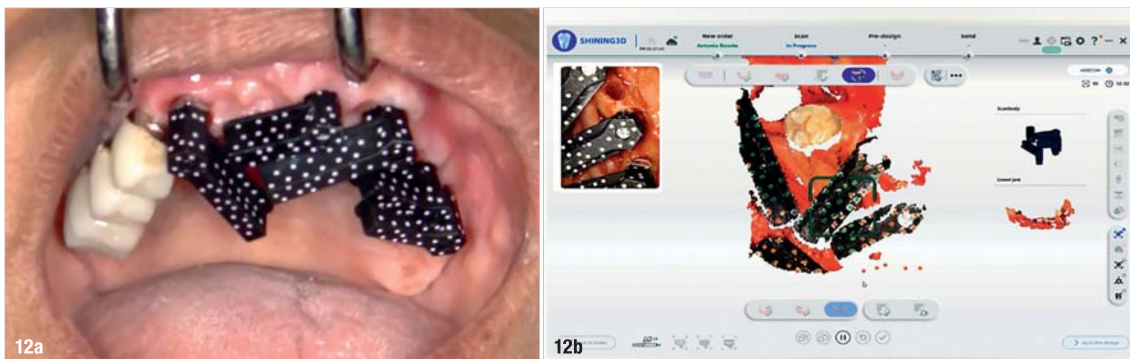
high-accuracy coded intra-oral markers to accurately capture the spatial relationships between implants (Fig. 5).

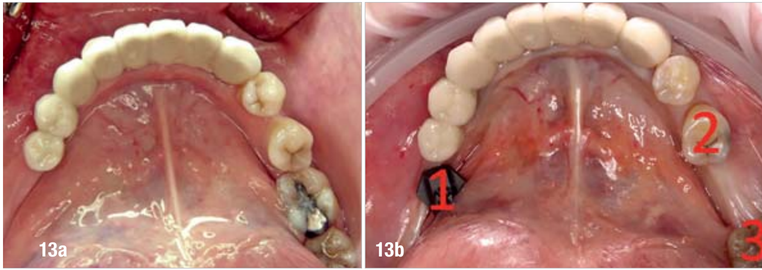
The utilisation of IPG for full-arch implant reconstruction begins once the implant surgery has been completed and multi-unit abutments have been secured to each implant. A conventional intra-oral scan of the tissue at the multi-unit level is acquired, followed by placement of the specially coded horizontal scan markers on to the multi-unit abutments connected to the implants. The markers, which are of three different lengths, are designed to be easily distinguishable by the scanner, ensuring that each one is captured accurately. The scanner's software identifies and tracks these markers in real time, allowing it to precisely measure their positions relative to each other. This real-time capture eliminates potential errors caused by patient movement or changes in lighting conditions, which are common pitfalls in conventional intra-oral scanning. Once the implant positions have been captured, the scanner defaults to its intra-oral scanning camera and moves on to capture the surrounding soft tissue, jaw relationships and adjacent teeth. This integration of both hard and soft tissue into a single digital model streamlines the workflow, reducing the time and effort required to create a comprehensive digital representation of the patient's oral anatomy (Figs. 6a & b). The resulting model can be directly transferred to CAD/CAM software (Fig. 7) for immediate use in the design of the restorations.

Case demonstration: Dentate arches

For healed ridges after implant placement, a simplified workflow is employed by leveraging both intra-oral scanning and IPG technologies. If a provisional prosthesis is present, an initial intra-oral scan of the prosthesis, opposing arch and occlusion is conducted. Once this has been captured, the provisional prosthesis is removed, and a subsequent intra-oral scan is performed to document the position of the multi-unit abutments in relation to the soft tissue (Fig. 8). After this, the horizontal scan markers are placed on to the abutments (Fig. 9), and the IPG camera is then utilised for a quick photogrammetric capture of these markers, ensuring that the acquisition overlaps the scan markers relative to one another for enhanced precision. Increasing the number of overlapping images obtained allows for faster and more accurate registration of each scan marker within the software.

Next, the workflow transitions back to the intra-oral scanning camera, which is used for scan matching (Fig. 10). To optimise the results, capturing at least two sides of the arch is recommended. The scan marker data and soft-tissue data will automatically merge, providing a comprehensive virtual digital model. At this stage, the scan markers can be digitally converted (Fig. 11) into the preferred scanning abutment type (by manufacturer), as the software supports an extensive library of options. Once complete, the final file is exported or transmitted via the cloud to the laboratory of the clinician's choice for further processing and prosthetic fabrication.





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The most intriguing application of the combined intra-oral scanning and IPG device is in the realm of surgical interventions. A major challenge when using photogrammetry in surgical cases has been the maintenance or adjustment of the vertical dimension of occlusion (VDO). Conventionally, EPG systems have relied on fiducial markers, which can be effective but present difficulties in accurate matching in third-party software after surgery. This can often necessitate the use of pre- and post-surgical CBCT scans with radiopaque markers to determine VDO and bone reduction. However, this method introduces additional radiation exposure and presents challenges in acquiring clean images, particularly after prolonged surgical procedures.

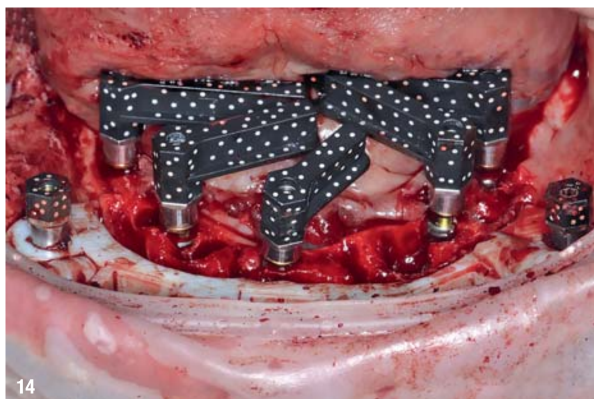
The scan matching capabilities of IPG have proved to be highly beneficial in overcoming these challenges. For dentate surgical cases, preserving a few strategic teeth before extractions (Fig. 12) can greatly simplify the matching process for the scan markers. Initial scans are taken with the remaining teeth, capturing the opposing arch and occlusion. After non-essential teeth have been extracted, bone reduction can performed if necessary, implants are placed and multi-unit abutments are connected. Once the multi-unit abutments are in place, scan markers are inserted and captured using the IPG camera. The intra-oral scanning system then matches these to the remaining teeth, ensuring seamless alignment. After this step, the remaining teeth can be extracted, grafting can be performed as needed and a final tissue scan can be captured, providing data for the emergence profile and pontic site design. An all-in-one project file can then be utilised for prosthetic design.

If the preserved teeth are not ideally positioned or interfere with the surgical procedure, alternative fiducial markers can be used to facilitate scan matching (Figs. 13a & b). Bone screws, surgical bars or other stable reference points can be employed, as the software is capable of recognising any device that remains consistently present from the initial scan for the duration of the surgery (Fig. 14). These markers or remaining natural teeth help maintain the VDO throughout the entire surgical and design process, ensuring accuracy and predictability for the final restorative outcome.

Case demonstration: Edentulous arches

For patients with edentulous arches, utilising a well-fitting denture can greatly enhance the efficiency and accuracy of data acquisition (Fig. 15). One conventional method involves taking a denture wash impression to capture the healing caps, providing a stable reference for matching to the IPG scans (Figs. 16a-e). This technique is similar to EPG, for which a 360° scan of the denture wash impression is performed to capture comprehensive data. Alternatively, small openings can be created within the denture to accommodate fiducial markers, establishing reliable reference points relative to the removable prosthesis. These markers enable precise alignment of the IPG scan data with the intra-oral scan data, ensuring that the VDO remains consistent throughout the procedure. Once this alignment has been verified, a detailed soft-tissue scan is performed to capture essential data for pontic site design, which can then be integrated into an all-in-one project file for streamlined prosthetic planning and fabrication.

These advanced techniques highlight the versatility and precision of the integrated intra-oral scanning and IPG workflow, which offers a robust solution for both routine and complex implant cases. By leveraging the strengths of photogrammetry and intra-oral scanning,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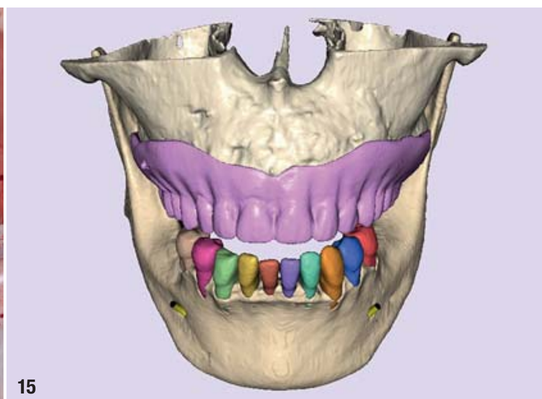
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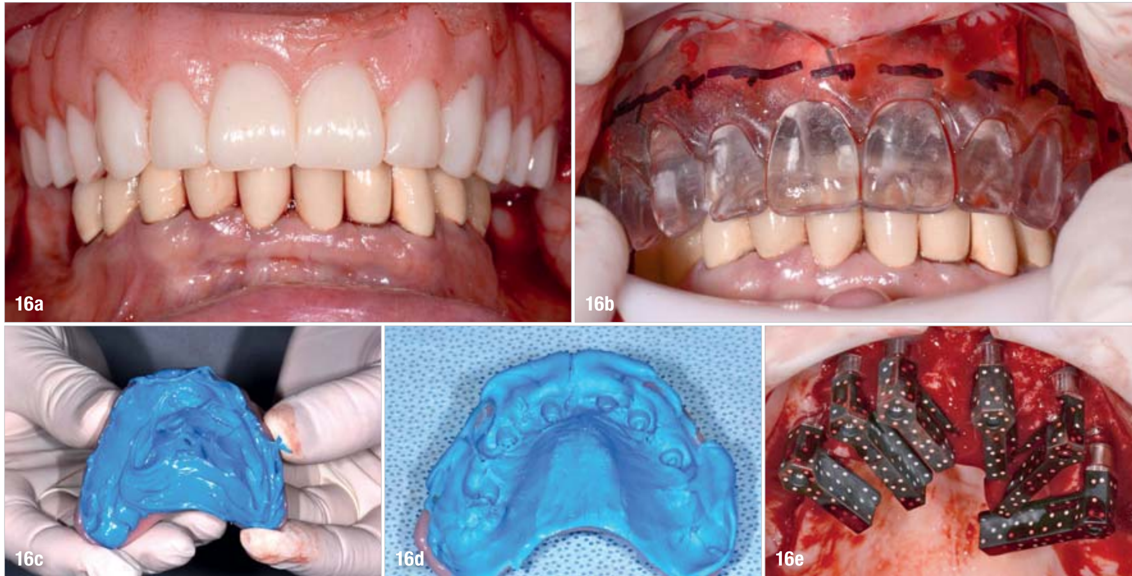

clinicians can achieve higher levels of accuracy, minimise chair time and deliver highly precise provisional prostheses faster without the need for a conversion prosthesis. This increases clinicians' confidence in providing provisional screw-retained prostheses or definitive monolithic full-arch prostheses, ultimately improving patient outcomes. This integration sets a new standard for digital workflows in implant dentistry, paving the way for more predictable and efficient management of complex restorative procedures.

Discussion: The benefits of IPG

IPG technology presents numerous benefits that make it an appealing option for clinicians working on complex implant cases. The system offers enhanced accuracy compared with conventional intra-oral scanners, which are often unable to maintain precision over larger areas, leading to distortions and poorly fitting restorations. IPG overcomes these challenges by utilising coded markers that establish a stable reference throughout the scanning process, ensuring high precision, even in full-arch cases. Recent trials have indicated that IPG can achieve positional accuracy of less than 20 µm in multi-implant scenarios, making it one of the most precise digital methods available today. One of the key advantages of IPG technology is its streamlined workflow, which simplifies the digital process by capturing all the necessary data in a single scan and efficiently converting the files. This eliminates the need for multiple scans or manual alignment of data points, enabling clinicians to transition seamlessly from scanning to designing and fabricating the restoration. The integration of fiducial markers within the workflow further ensures precision by maintaining consistent alignment throughout the entire surgical procedure. In complex cases where preserving some natural teeth is necessary, utilising fiducial markers up until scans are completed allows for continuous and accurate software alignment without interruptions.

In addition to improved accuracy and workflow efficiency, the simplified, all-in-one-device configuration of IPG has demonstrated the potential to considerably reduce chair time compared with conventional impression techniques, offering a substantial time-saving advantage for both clinicians and patients. By capturing both implant position and surrounding soft tissue in a single pass, the overall time required for impression taking is substantially minimised. This leads to shorter patient appointments, fewer retakes and an overall enhancement of the clinical workflow. The minimisation of errors is another critical benefit of IPG technology. The implementation of coded markers ensures precise recording of all implant positions, significantly lowering the risk of alignment discrepancies, which are often observed with conventional intra-oral scanning methods. This heightened accuracy results in a more predictable outcome and a superior fit of the definitive prosthesis, thereby decreasing the likelihood of adjustments or costly remakes. Additionally, these markers can be converted into scanning abutments, allowing them to be exported as unified project files, which helps mitigate technical errors during subsequent CAD software processing.

IPG allows for comprehensive data capture. The ability to capture both hard and soft tissue in a single scan results in a digital model that is a more complete and accurate representation of the patient's oral anatomy. This comprehensive capture leads to better-fitting prostheses, fewer adjustments during the restorative phase and an overall more efficient treatment process. With all these advantages, IPG is setting new standards for accuracy,

Table 1: Extra-oral photogrammetry vs. intra-oral photogrammetry

Extra-oral photogrammetry	Intra-oral photogrammetry
Two devices, an intra-oral scanner and an EPG device	One device, combining an intra-oral scanner and an IPG device
Additional software for matching the scan marker/scanning abutment to tissue	Simplified matching of the scan marker/scanning abutment to tissue
Increased time for conversion of the scan marker/scanning abutment position to the implant position	Efficient conversion of the scan marker/scanning abutment position to the implant position
Separate files require manual matching in CAD software, e.g. exocad, 3Shape, Dental Wings	All-in-one CAD file population
Expensive scan marker/scanning abutment	Affordable scan marker/scanning abutment

workflow efficiency and patient satisfaction in complex implant dentistry (Table 1).

The future and benefits of IPG technology

As with any emerging technology, the true potential of IPG is still being explored. Future advancements include the integration of software that employs artificial intelligence (AI) to further enhance accuracy by automatically detecting and correcting minor errors during the scanning process. AI has the potential to refine the scanning process by identifying and addressing inconsistencies in real time, providing immediate feedback to clinicians and reducing the risk of inaccuracies.

Another area of potential growth is the development of multimodal imaging systems that combine IPG with other imaging technologies, such as CBCT and facial scanning. This integration enables clinicians to create a comprehensive digital model or dental avatar that includes both intra-oral and extra-oral structures, providing a more holistic view of the patient's anatomy. Multimodal systems can help clinicians better understand the relationship between implants and facial structure and contours, improving treatment planning and outcomes.

The integration of these technologies not only provides a more detailed digital representation of the patient's anatomy but also allows for better communication and collaboration among dental professionals. For example, orthodontists, oral surgeons and prosthodontists could work together using a single unified digital model to plan and execute complex treatments more effectively. This collaborative approach leads to more predictable results and a higher standard of care for patients.

The adoption of IPG technology in full-arch implant procedures has the potential to significantly affect clinical outcomes and patient satisfaction. One of the most important benefits of IPG is its ability to provide a more accurate digital model without the need for a verification index or physical model. This approach is faster and less invasive for the patient and provides better-fitting restorations. A well-fitting prosthesis not only enhances the patient's comfort and function but also reduces the risk of complications such as peri-implantitis, bone loss, and prosthesis or even implant failure. Additionally, IPG technology allows for the expedited creation of digital mock-ups and simulations that can be used to educate patients about their treatment options. By visualising the potential final outcome before the procedure is completed, patients can have a clearer understanding of the treatment process and what to expect. This transparency can help build trust and improve patient compliance, as they feel more involved in the decision-making process. Moreover, IPG enables a more streamlined workflow, reducing the time required for impression taking and prosthetic fabrication, using only *one* device instead of two. This efficiency translates into shorter treatment times, fewer appointments and less time spent in the dental chair for patients. For individuals undergoing complex full-arch restorations, this reduction in treatment time can significantly improve their overall experience and satisfaction. In suitable cases when timing is essential and with a fully equipped dental office, it is possible to surgically place implants, scan the patient with IPG technology, send off the files to the laboratory technician for immediate design of a full-arch screw-retained prosthesis, receive the STL file back from the laboratory technician, 3D-print, stain and glaze the prosthesis in the office and deliver it to the patient on the same day.

The path forward: Integrating IPG into routine practice

The journey to integrating IPG into routine practice begins with understanding its role in enhancing the accuracy and predictability of full-arch implant procedures. Successful integration requires not only investing in technology but also investing in training and support. Dental professionals must be adequately trained to handle the nuances of photogrammetry, from fiducial marker placement to data interpretation, in order to leverage the full potential of IPG systems.

Implementing IPG also requires a shift in mindset, from a conventional intra-oral scanning or impression-taking approach to a more sophisticated, data-driven process.

Practices must consider how IPG fits into their current workflows and be willing to adjust as needed to accommodate the new technology. This may involve upgrading existing equipment, revising digital workflows and adopting new protocols for capturing and analysing implant positions. Collaboration with technology providers and ongoing professional education will be key to making this transition successful.

As digital technologies continue to evolve and become more accessible, the boundaries of what is possible in dental implantology will continue to expand. IPG is just one example of how innovation is reshaping the field, offering clinicians new tools to enhance precision, streamline workflows and improve patient outcomes. By embracing these advancements, dental professionals can stay at the forefront of their field and continue to provide the highest standard of care.

Conclusion

IPG represents a new standard in digital dentistry for full-arch implant capture. By combining the precision of photogrammetry with the convenience of intra-oral scanning, IPG offers a streamlined, accurate and patient-friendly solution that addresses many of the challenges associated with full-arch restorations. As technology continues to evolve with new devices and supporting software, its adoption is likely to grow, paving the way for even more sophisticated and efficient digital workflows in implant dentistry. For clinicians and patients alike, IPG offers a glimpse into the future of digital dentistry, one where precision, efficiency and patient comfort are no longer mutually exclusive.

In conclusion, IPG is more than just a new technology; it represents a paradigm shift in how full-arch implant cases are approached and executed. As it becomes more widely adopted, its impact on the field of digital dentistry will only grow, setting the stage for a future where digital workflows are not just an option but the standard of care for complex restorative and implant procedures. For both clinicians and patients, this evolution promises a future of precise, faster and more predictable treatment outcomes.

about

Dr Isaac D. Tawil received his DDS from the New York University College of Dentistry and has a master's degree in biology from Long Island University, both in the US. He is a fellow of the International Congress of Oral Implantologists and the Advanced Dental Implant Academy, a diplomate of the International Academy of Dental Implantology and a co-director of Advanced Implant Education. He has received recognition for outstanding achievement in dental implant treatment from the Advanced Dental Implant Academy, as well as the President's Volunteer Service Award for his volunteer work in places such as Honduras, Mexico, the Dominican Republic, China and Peru.
Dr Tawil lectures internationally on advanced dental implant procedures using the latest technology and teaches live surgery seminars in his office and abroad, as well as hands-on courses globally. He maintains a general private practice in New York, where he focuses on implant therapy. He can be reached at tawildental@gmail.com.

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He is widely published and conducts clinical research on cutting-edges technologies to integrate into the digital workflow in clinical practice. He won the 2013 Judson C. Hickey Scientific Writing Award in the clinical report category and is a fellow of the Academy of Osseointegration. He is co-author of Volume 2 of the textbook *Fundamentals of Implant Dentistry* (Quintessence Publishing, 2017), adopted by several universities worldwide to train their students in implant dentistry. He has lectured at the most prestigious congresses and academies since 2010 and gives international training courses on digital implant dentistry and aesthetics at his practice. He is an active member of the Italian Academy of Esthetic Dentistry and serves on the editorial boards of *Clinical Implant Dentistry and Related Research* and the *International Journal of Oral Implantology.*