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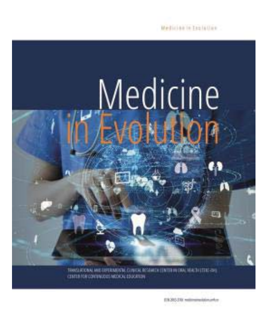
3D facial Scanning Technologies - Comparative Analysis of Three Modern Three-Dimensional Acquisition Systems



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Abstract

1.Background: Three-dimensional (3D) facial scanning technologies have advanced rapidly, offering new possibilities for clinical, engineering, and educational applications. However, performance varies substantially across mobile, portable, and professional systems, and a direct comparison using standardized acquisition protocols is essential for determining their suitability in medical practice. *2.Methods*: Eight healthy adults (20–25 years old) were scanned using three technologies representing different levels of complexity: the iPhone LiDAR sensor with Qlone, the CR-Scan Ferret structured-light scanner, and the professional ProMax 3D Mid ProFace system. All participants were scanned under controlled conditions, maintaining identical positioning and acquisition procedures. Raw data were processed using each system's dedicated software and analyzed comparatively with respect to geometric visual consistency, texture quality, model completeness, artifacts, processing workflow, and cost–performance ratio. *3.Results*: The iPhone LiDAR system produced the least accurate models, characterized by surface discontinuities, loss of fine anatomical detail, and low-resolution texture. The CR-Scan Ferret achieved higher geometric fidelity and more coherent color mapping but remained sensitive to lighting conditions and operator stability. The ProMax 3D Mid ProFace system generated the most complete, consistent, and photorealistic models, with minimal artifacts and fully automated processing. These differences reflect the technological capabilities of each device category. The comparison was qualitative, as no objective numerical measurements of geometric deviation were performed. *4.Conclusions*: The findings confirm that no single scanning technology is universally optimal. Mobile systems are suitable for rapid, non-clinical, or educational applications; portable structured-light scanners offer a balance between visual consistency and accessibility; and professional systems remain the gold standard for advanced clinical environments requiring high precision.

Keywords: 3D facial scanning; LiDAR; structured light scanning; ProMax 3D Mid ProFace; CR-Scan Ferret; photogrammetry; 3D reconstruction; medical imaging.

INTRODUCTION

The rapid advancements in three-dimensional scanning technologies have transformed the way anatomical data is generated, analyzed, and used in medical engineering, especially in oral and cranio-maxillofacial fields [1]. 3D facial scanning has become an essential tool in numerous clinical specialties, from dentistry and cranio-maxillofacial surgery to dermatology, facial aesthetics, and functional rehabilitation [7,8]. By combining geometric visual consistency with the ability to produce detailed digital reconstructions, these technologies facilitate an in-depth understanding of facial morphology and enable personalized treatment planning [2].

The accelerated evolution of optical sensors, compact laser systems, and structured-light techniques has led to the emergence of an increasingly wide range of 3D scanners designed for different levels of precision and complexity [6]. Recent studies have shown that professional three-dimensional capture systems offer superior visual consistency, yet portable solutions or those integrated into mobile devices are becoming increasingly relevant due to their greater accessibility [3,9]. In particular, the introduction of LiDAR sensors in smartphones has expanded the use of these technologies beyond the traditional clinical environment, although their precision remains variable compared with dedicated systems [10].

In this context, the present study aims to provide a comparative analysis of three representative technologies of the moment: the LiDAR sensor integrated into iPhone devices used with the Qlone app – a mobile, accessible, and intuitive solution; the Creality CR-Scan Ferret – a portable structured-light scanner targeted toward users who require medium-to-high fidelity; the professional ProMax 3D Mid ProFace system, used in advanced medical imaging and known for its sub-millimetric accuracy as reported in the literature [1,5].

In this study, visual consistency is examined qualitatively through surface continuity, anatomical detail reproduction, and texture coherence, rather than through quantitative deviation measurements.

The analysis is methodologically structured around essential criteria for medical applicability, such as geometric accuracy, texture quality, acquisition and processing time, ease of use, and the cost–performance ratio. These criteria align with parameters frequently used in previous validation studies of 3D facial scanning systems [4,12].

Through this comparative approach, the study seeks to provide a rigorous and practical evaluation for professionals who must select the appropriate technology for a specific type of application. The results highlight that there is no “ideal universal scanner”, but rather a range of technological solutions that must be chosen according to the clinical context, available resources, and the required level of detail [11].

MATERIALS AND METHODS

The study was designed to comparatively evaluate three distinct 3D facial scanning technologies, each representing a different level of technical complexity and accessibility. The methodology aimed to structure the process so that the results would be reproducible, comparable, and relevant for applications in medical engineering.

The study was conducted on a group of eight participants, consisting equally of four male and four female subjects, aged between 20 and 25. This selection aimed to maintain a high degree of demographic homogeneity, reducing inherent variations linked to skin changes, soft tissue distribution, or age-related asymmetries. All subjects were evaluated under controlled conditions and were instructed to adopt a neutral head position and a relaxed facial expression to minimize the influence of involuntary movements during acquisition. Ethical approval and written informed consent were obtained prior to participation.

Each participant was scanned successively with all three technologies under analysis, following the same procedural protocol so that the differences observed between models would reflect solely the performance of the capture systems, not interindividual variability. Using the same set of subjects throughout all stages of the study enabled a direct and rigorous comparison of the visual consistency, texturing, and completeness of the models generated.

For the comparative analysis, three representative 3D facial scanning systems were selected, covering different levels of technological sophistication. The selection was intended to span the full spectrum of currently available technologies—from mobile and accessible solutions to professional equipment used in advanced medical imaging. Each system was analyzed not only in terms of technical performance but also regarding how well it can meet the practical requirements of clinical applications. No external geometric reference or quantitative deviation analysis was used; therefore, visual consistency assessments were qualitative and based on visual comparison of surface continuity and anatomical detail.

The iPhone LiDAR System used with the Qlone Application

The first material investigated was the LiDAR sensor integrated into recent generations of iPhones. This system stands out due to its accessibility and mobility, as it enables 3D scanning without the need for additional dedicated equipment. In the study, the LiDAR sensor was used in combination with the Qlone application, which manages the entire process—from data acquisition to the photogrammetric reconstruction of the digital model. This configuration represents the category of emerging technologies aimed at regular users or professionals who require a fast, intuitive, and easily transportable solution (Figure 1).

Figure 1. Geometry and color texture of Subject 1 obtained with LiDAR (Qlone Application).

Creality CR-Scan Ferret Scanner

The second system analyzed, the Creality CR-Scan Ferret, was selected as a representative of the intermediate-level class of portable scanners. It operates based on infrared structured light and is equipped with a high-frequency depth sensor, complemented by an RGB camera for capturing color information. Through this combination, the device offers superior geometric fidelity compared to technologies integrated into smartphones, while maintaining good portability. The CR-Scan Ferret was included in the study to evaluate the performance of a solution that combines accessibility with a higher level of detail, being frequently used in educational, engineering, and basic clinical contexts (Figure 2).

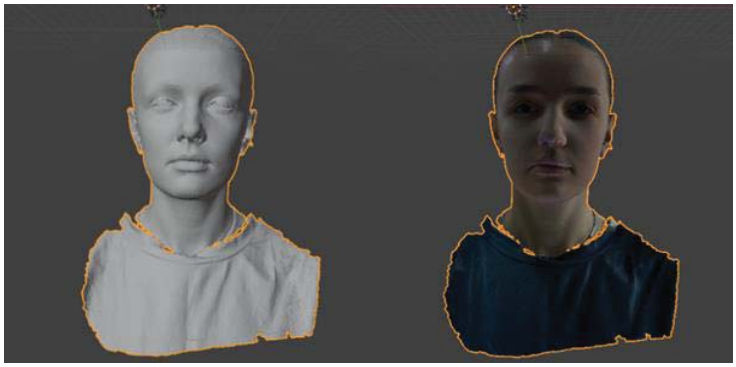

Figure 2. Geometry and color texture of Subject 2 obtained with the CR-Scan Ferret.

The Professional ProMax 3D Mid ProFace System

The third system, ProMax 3D Mid ProFace, represents the category of high-precision professional equipment used in specialized medical imaging. Integrated into the Planmeca ProMax 3D Mid unit, the ProFace system enables the acquisition of a 3D facial photograph without the use of radiation, through a combination of lasers that capture geometry and digital cameras that record texture. This technology is also compatible with CBCT data, making it an indispensable tool for maxillofacial surgery, orthodontics, and the planning of complex treatments. In this study, ProFace served as the technological benchmark for evaluating the highest level of precision and detail available in current medical practice (Figure 3).

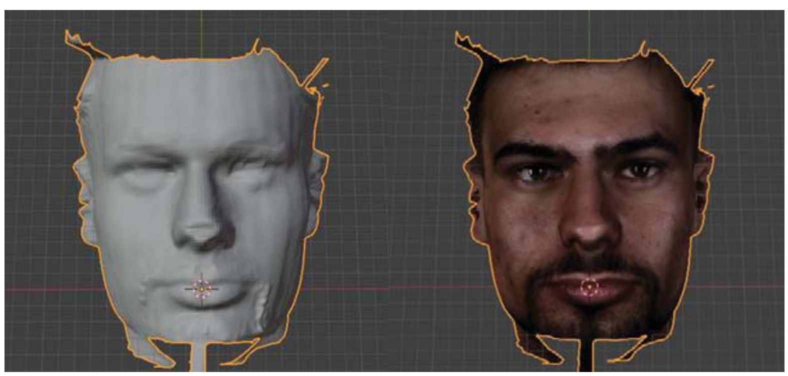

Figure 3. Geometry and color texture of Subject 3 obtained with the Planmeca ProMax 3D ProFace.

The methodology of this study was designed to enable a rigorous and coherent comparison between the three facial scanning systems analyzed. The entire process was organized in logical sequence—from raw data acquisition to the final evaluation of technological performance—aiming to minimize variability and ensure a solid methodological foundation.

To obtain a comparable dataset, all 3D models were acquired under controlled conditions, using the same subject in a neutral position and a static environment. This standardization ensured that the differences observed later reflected only the specific characteristics of each technology and not variations in the procedure.

Each of the three scanning systems required an acquisition protocol adapted to the technology it employs.

For the LiDAR–Qlone combination, scanning was performed by moving the operator in a circular path around the subject, following the visual guidance provided by the application. This procedure enabled simultaneous capture of depth information from the

LiDAR sensor and the images required for photogrammetric reconstruction, resulting in a three-dimensional model generated by combining both data sources.

For the CR-Scan Ferret scanner, the process involved handling the device close to the subject, within the optimal distance specified by the manufacturer (150–700 mm). The operator traced the facial contours from multiple angles, using modes dedicated to capturing geometry and texture, so that the final model would accurately reproduce both the shapes and the chromatic details of the face.

For the ProMax 3D Mid ProFace system, acquisition was carried out differently—in a single, fully automated sequence. The system captured facial geometry and texture simultaneously, without radiation exposure, generating the 3D photograph through the standard workflow integrated into the Planmeca equipment.

To reduce the influence of random errors, each scan was repeated several times. Among the generated models, the version with the best surface continuity and the fewest artifacts was selected, ensuring that the subsequent analysis relied on the most stable and representative results.

Data processing

The raw data obtained from the three technologies were subjected to a processing workflow adapted to the particularities of each system, ensuring that the final models accurately reflected the technical potential of the devices tested.

For the dataset generated using the LiDAR sensor and the Qlone application, reconstruction was performed within the app's software environment. This allowed the alignment of successive frames, stabilization of the photogrammetric reconstruction, and export of the models in standardized formats such as OBJ and STL.

The models produced with the CR-Scan Ferret were processed in the Creality Scan platform, where the point clouds were aligned and merged, and residual noise was removed. The same software also enabled the application of the color texture, contributing to a coherent three-dimensional model in terms of both geometry and visual representation.

For the ProMax 3D Mid ProFace system, data processing was carried out in Planmeca Romexis, the unit's dedicated software. It processed the 3D photograph generated by the system, delivering a complete model with detailed geometry and high-fidelity color mapping—a result of the integrated workflow specific to this type of technology.

After the individual processing steps were completed, all models were imported into a common analysis environment to ensure uniform evaluation conditions. This stage enabled the direct comparison of the models from both geometric and visual perspectives, eliminating the influence of differences between software platforms and strengthening the basis for the comparative analysis.

Evaluation criteria

To rigorously characterize the performance of each scanning system, the evaluation was structured around a coherent set of methodological criteria designed to capture both the technical accuracy of the generated models and their practical applicability. The analysis focused primarily on geometric visual consistency—an essential element in any 3D reconstruction process—by examining surface continuity, fine facial details, and contour fidelity. The quality of visual representation was assessed through the texture criterion, which evaluated color uniformity, realism of facial markings, and the coherence between the geometric model and its color mapping.

Another important aspect of the methodology was the time required for scanning and processing, measured to determine the operational efficiency of each system. This variable is critical in clinical contexts, where procedure duration influences both patient comfort and the integration of technology into existing workflows.

The evaluation also included an analysis of system-specific artifacts and errors, aiming to identify distortions, missing areas, or residual noise in the point clouds. These elements serve as direct indicators of technological limitations and significantly affect the usability of the generated models.

In addition to technical performance, the study examined ergonomics and ease of use—factors reflecting operator experience, procedural stability, and workflow complexity. These criteria were essential for determining the feasibility of adopting each system in a real clinical environment.

Finally, the analysis incorporated economic considerations by assessing the cost–performance ratio, evaluating the extent to which the required investment is justified by the quality and usefulness of the outcomes. This approach enabled not only a technical comparison between devices but also an evaluation of their practical value in diverse clinical and engineering contexts.

To coherently integrate the results, the evaluation criteria were combined into a comprehensive comparative analysis structured to highlight both the advantages and limitations of each scanning system. Synthesizing these criteria into a comparative matrix allowed direct observation of performance differences, revealing how each technology meets the specific requirements of 3D facial reconstruction.

This stage was essential in forming the overall interpretation of the study, as it allowed the correlation of technical performance with practical applicability. The analysis did not limit itself to a mechanical comparison of parameters; it aimed to capture the relevance of each result within the clinical context. Through this approach, the study evaluated how geometric fidelity, texture quality, workflow duration, procedural stability, or cost–benefit balance can influence the decision to integrate a technology into various medical scenarios.

The final interpretation sought to identify the compatibility between the observed performance and the real needs of medical engineering, diagnostic processes, and treatment planning, emphasizing how each system can support, limit, or improve clinical workflows.

RESULTS

The analysis of the results obtained from the three 3D facial scanning technologies revealed notable differences among the devices in terms of geometric fidelity, texture quality, procedural efficiency, and overall acquisition stability. Each system produced a distinct model, reflecting both the limitations and strengths of its underlying technology.

The model generated using the LiDAR system combined with the Qlone application showed satisfactory overall geometry but lower resolution in areas requiring fine detail, such as the nasal edge, cheekbones, and lip contours. The surfaces exhibited minor local fragmentation, and regions less exposed to the camera required photogrammetric completion, leading to some nonuniformities. The applied texture was generally realistic, though less well integrated in areas with abrupt facial relief changes. Total processing time was short, confirming the speed advantage characteristic of mobile technologies.

In contrast, the model produced with the CR-Scan Ferret demonstrated significantly better geometric fidelity. Facial surfaces displayed superior continuity, and anatomical details—particularly those of the nose and cheeks—were captured with noticeably higher clarity. The color texture also stood out for its improved visual consistency and better coherence between relief and coloration. However, the scans were sensitive to lighting variations, and very dark or reflective areas required repeated captures. Processing time was moderate, reflecting the need to integrate and clean a larger volume of data.

For the ProMax 3D Mid ProFace system, the results showed the highest quality among all technologies analyzed. The geometric model exhibited high precision, with no significant interruptions or artifacts, and the facial texture was reproduced with near-photographic fidelity, featuring smooth chromatic transitions and visibly superior uniformity. Designed for advanced clinical use, the final model provided a complete and highly detailed facial representation, ideal for applications requiring precision, such as surgical planning or orthodontic analysis. Acquisition and processing times were consistent and predictable due to the fully automated workflow.

Comparing the three technologies, a clear differentiation in performance levels was observed (Table 1). The LiDAR–Qlone solution stands out for accessibility and speed but offers limited precision. The CR-Scan Ferret provides a balanced compromise between cost and performance, generating models of considerably higher quality than mobile solutions. The ProMax 3D Mid ProFace system distinguishes itself through exceptional visual consistency and realism but requires complex equipment designed exclusively for professional environments.

Table 1. Comparative results of the three 3D facial scanning technologies

Criteria	*LiDAR + Qlone*	*CR-Scan Ferret*	*ProMax 3D Mid ProFace*
Geometric Visual consistency	Low visual consistency; loss of fine detail (nose, eyelids, jawline); smoothed surfaces and visible interruptions.	Significantly better visual consistency; well-defined details; some sensitivity to lighting and distance.	Highest visual consistency; continuous surfaces with no major artifacts; highly faithful anatomical reproduction.
Texture Quality	Low-resolution texture; uneven color; flat appearance.	Realistic RGB texture thanks to dedicated camera; natural and coherent color mapping.	Photorealistic texture; uniform and smooth chromatic transitions.
Model Completeness	Incomplete model; missing areas on sides and submental region.	Mostly complete model; minor gaps in difficult-to-reach zones.	Fully complete model with no missing regions.
Artifacts	Frequent artifacts due to movement, reflections, and LiDAR limitations.	Moderate artifacts related to lighting, distance, or software errors.	Minimal artifacts; automated workflow reduces operator-dependent variability.
Scan Time	Fast (mobile), but motion consistency affects quality.	Moderate to fast depending on mode (wide / high precision).	Most consistent: single standardized scan sequence.
Processing Time	Very short; processed within the app.	Moderate; requires alignment, fusion, and cleanup.	Automated in Romexis; predictable processing time.
Ergonomics	Very easy to use; requires only an iPhone.	Portable and lightweight; requires stable hand positioning.	Stationary clinical system; high-end ergonomic workflow.
Cost	Lowest cost (existing device).	Medium cost; accessible for labs or engineering work.	Highest cost; professional clinical equipment.
Best Use Case	Telemedicine, education, non-clinical applications.	Prosthetics labs, engineering projects, mid-level clinical tasks.	Surgery, orthodontics, cranio-maxillofacial reconstruction.

These results confirm that selecting the optimal technology depends directly on the clinical or technical context and on the level of detail required for the intended application.

DISCUSSIONS

The results obtained in this study align with trends described in the scientific literature, which consistently emphasize that the visual consistency of a 3D facial scanning system is directly influenced by the technology used, the density of captured points, and the integrated reconstruction algorithms [1]. Recent studies on the use of mobile technologies in cranio-maxillofacial imaging—such as those using iPhone LiDAR—confirm the variable performance of these systems, especially in anatomical areas with complex relief or subtle curvature variations [3,10]. Our findings regarding the limitations of smartphone LiDAR are therefore fully consistent with international reports, which highlight lower precision compared with professional systems [9,10].

Regarding the CR-Scan Ferret, the results confirm observations from other studies focused on portable structured-light technologies, which underline their ability to generate 3D models with higher geometric fidelity than mobile solutions [5]. Clinical and engineering studies evaluating similar devices indicate that structured light offers robust performance but remains sensitive to lighting conditions and operator movement—an aspect also observed in this study [4,6]. This category of scanners occupies an important intermediate space between the accessibility of mobile technologies and the precision of professional systems, confirming the conclusions of recent meta-analyses in the field [9].

The ProMax 3D Mid ProFace system demonstrated, as expected, the best results in terms of both geometric fidelity and texture quality. Previous studies on high-fidelity stereophotogrammetric and structured-light professional systems have consistently shown sub-millimetric precision, making them suitable for applications such as orthodontics, cranio-maxillofacial surgery, or virtual reconstruction [2,7,8]. Our results are consistent with these findings and confirm the major advantage provided by automated workflows and advanced calibration algorithms in these platforms.

The differences observed between technologies can be explained through the fundamental principles of the optical methods used. Commercial LiDAR-based systems have limited point density and simplified reconstruction algorithms, which restrict their ability to capture fine details [10]. In contrast, structured-light technology projects a patterned sequence onto the surface and uses advanced triangulation, giving it higher fidelity according to technical descriptions in the literature [6]. Professional systems combine multiple sensor types and include internal routines for compensating motion or lighting variations, as noted in numerous clinical validation studies [1,5,12].

Considering clinical relevance, the literature clearly distinguishes that mobile solutions can be useful for educational applications, telemedicine, or quick monitoring, while portable scanners are suited for applied research and prototyping, and professional systems are indispensable for interventions requiring high precision [3,7,8]. The findings of our study fully align with these technological classifications and highlight that choosing a solution must be based on the intended purpose, required detail level, and available resources [11].

This indicates that 3D facial scanning technologies should be evaluated not only in terms of precision but also according to the context of use. The results obtained, corroborated with scientific literature, justify the need for a differentiated selection between mobile, portable, and professional systems, in accordance with specific clinical or engineering requirements.

The model obtained using the LiDAR–Qlone system confirms what the literature has emphasized for several years: LiDAR sensors integrated into smartphones represent an accessible and practical solution for general applications, but they do not reach the level of precision required for advanced clinical analysis. Studies published between 2020 and 2023 highlight that commercial LiDAR models exhibit systematic errors in reproducing fine facial details, especially in regions with pronounced curvature or complex textures, which is consistent with the findings of the present study.

In the case of the CR-Scan Ferret, the results align with research confirming the potential of portable structured-light technologies. The scientific literature shows that such devices can provide high geometric fidelity, approaching that of mid-range professional systems, although their performance remains dependent on ambient lighting and operator experience. This was also reflected in our data: the overall quality of the model was superior to that obtained using the smartphone solution, but required increased operator attention during acquisition.

The ProMax 3D Mid ProFace system generated the best results, in full agreement with established literature on professional systems used in craniofacial imaging. Both manufacturer documentation and independent research published in dentistry, cranio-maxillofacial surgery, and orthodontics consistently report that these systems can reproduce facial morphology with sub-millimetric precision, making them suitable for clinical use and advanced research. The results of this study fully confirm these observations.

The significant differences observed among the three systems can be explained through fundamental technological principles. Smartphone LiDAR operates with a relatively low point density and limited spatial projection, whereas dedicated scanners use higher-resolution optical sensors, more advanced triangulation algorithms, and artifact-compensation mechanisms. Professional systems such as ProFace integrate complex optical assemblies and standardized calibration procedures, contributing to the extremely accurate reproduction of facial geometry.

The literature emphasizes the importance of lighting, subject movement, and operator expertise in obtaining valid results. Our observations confirm this: mobile and portable technologies are more vulnerable to environmental variations and require strict control of the acquisition procedure, whereas the ProFace system offers superior consistency due to its automated workflow [2–7].

Clinical relevance of the results

Comparing the three technologies within the context of clinical applications shows that only systems dedicated to medical imaging can provide the level of detail required for surgical interventions, orthodontic analysis, or virtual reconstructions. Mobile solutions can be useful for telemedicine, rapid monitoring, or educational applications, while portable structured-light scanners occupy an intermediate position, suitable for prosthetic laboratories, engineering projects, and applied research.

The literature confirms this technological hierarchy, emphasizing that the choice of a scanning device must be adapted to clinical objectives, the required level of visual consistency, and the available resources. The results of our study align closely with these conclusions [3–6,8–9].

Study limitations

This study presents several limitations that should be considered when interpreting the results. First, the sample size was small, consisting of only eight healthy young adults aged 20–25, which restricts the generalizability of the findings to other age groups or individuals with complex craniofacial conditions. Second, the portable scanning technologies used—particularly the iPhone LiDAR system and the CR-Scan Ferret—are sensitive to environmental factors such as lighting, operator movement, and distance from the subject. Despite standardized procedures, complete control over these variables is difficult to achieve.

Another limitation lies in the reliance on proprietary software for data processing, as differences in alignment, fusion, and smoothing algorithms may influence the final models independently of the hardware. Moreover, the study did not employ an external geometric reference (such as a calibrated phantom), meaning that the results are based on relative comparisons rather than absolute error measurements. Finally, the study did not assess longitudinal reproducibility, leaving open the question of how consistently each system performs over multiple sessions.

It is important to note that, because the study did not employ a quantitative reference standard, all accuracy-related observations are qualitative and based solely on visual assessment of geometric detail and surface continuity.

Because the study involved only healthy young adults, the findings may not directly translate to clinical populations with facial asymmetries, deformities, or variable soft-tissue characteristics. Such cases may introduce additional challenges for surface acquisition and reconstruction, particularly for lower-resolution systems.

The small and demographically narrow sample restricts generalization to broader clinical populations. The professional systems demonstrated superior qualitative surface fidelity in this study; however, their suitability for precise clinical measurement requires quantitative validation beyond the scope of this work.

Although multiple scans were acquired, no numerical reproducibility metrics were calculated; the model with the fewest visible artifacts and highest surface continuity was selected subjectively for analysis.

CONCLUSIONS

This study provided a qualitative comparison of three contemporary 3D facial scanning technologies, each representing a distinct level of complexity and accessibility. Based on visual assessment of geometric fidelity, texture coherence, model completeness, artifact frequency, and workflow characteristics, clear differences were observed among the systems.

The LiDAR–Qlone configuration offered the most accessible and rapid solution but produced models with limited surface detail and greater variability in reconstruction quality, making it more suitable for general, educational, or non-clinical applications. The CR-Scan Ferret delivered models with higher visual geometric fidelity and more consistent texture mapping, representing a practical intermediate option for engineering tasks, prototyping, and basic clinical documentation. The ProMax 3D Mid ProFace system generated the most complete and visually consistent reconstructions, with smooth surfaces and coherent texture integration, reflecting the capabilities of a fully automated professional platform.

These findings highlight that each system presents strengths aligned with its technological design and intended use-case. Selection should therefore be guided by the required level of visual detail, workflow constraints, and available resources. Because the comparison was qualitative and no quantitative deviation analysis was performed, the conclusions reflect observed visual and procedural differences rather than validated metric accuracy. Further research incorporating standardized geometric references and expanded clinical populations is needed to determine the quantitative precision and broader clinical applicability of these technologies.

Conflicts of Interest

The authors declare no conflict of interest.

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