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A COMPREHENSIVE REVIEW OF THREE-DIMENSIONAL SURFACE IMAGING TECHNOLOGIES IN PLASTIC SURGERY: APPLICATIONS, ADVANCEMENTS, AND FUTURE DIRECTIONS

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ABSTRACT: Three-dimensional (3D) surface imaging has not just emerged but has truly revolutionized the landscape of plastic and reconstructive surgery. It offers enhanced preoperative planning and objective postoperative assessment, significantly improving patient-physician communication. This narrative review aims to provide a comprehensive overview of the practical applications, advancements, and future directions of 3D surface imaging technologies in plastic surgery. The article explores the historical context, current clinical applications, and potential future developments of this rapidly evolving field. Emphasis is placed on the various measurements and analyses enabled by 3D imaging and integrating these technologies with emerging trends such as 3D printing and patient simulation. The review also discusses the use of high-resolution ultrasound in characterizing breast implants and detecting implant ruptures. By synthesizing the latest research and insights, this article equips plastic surgeons with valuable knowledge to understand and leverage the role of 3D surface imaging in enhancing patient communication in their practice.

Keywords: Three-Dimensional Imaging. Plastic Surgery. Preoperative Planning. Postoperative Assessment. Breast Implants.

INTRODUCTION

Three-dimensional surface imaging has gained significant traction in plastic and reconstructive surgery over the past few decades. This technology relies on triangulation in stereo photography to measure surface coordinates, providing a non-invasive and radiation-free alternative to computed tomography (CT) and magnetic resonance imaging (MRI) (1,2).

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The adoption of 3D surface imaging in plastic surgery can be traced back to 1979 when Karlan utilized it to analyze facial contours and asymmetries (3–5). Since then, the technology has advanced rapidly, offering various applications and benefits to surgeons and patients (6).

The current landscape of 3D surface imaging in plastic surgery is not just about standardizing patient measurements but also about enhancing preoperative planning and improving postoperative outcomes. Various measurements, such as volume, surface area, vector distance, and curvature, have been applied to breast, body, and facial topography, providing objective data to augment patient analysis. However, the potential of 3D surface imaging to significantly improve patient-physician communication, education, and, ultimately, patient satisfaction is a crucial aspect that deserves further exploration (7). This potential is not just promising; it's crucial in every plastic surgeon's practice.

This narrative review aims to provide a comprehensive overview of the applications, advancements, and future directions of 3D surface imaging technologies in plastic surgery. By synthesizing the latest research and insights, this article seeks to serve as a valuable resource for plastic surgeons looking to understand and leverage the benefits of 3D surface imaging in their practice.

METHODOLOGY

The search terms included "three-dimensional surface imaging," "3D imaging," "plastic surgery," "reconstructive surgery," "breast surgery," "facial surgery," "body contouring," and related keywords. Articles published in English between 1979 and 2023 were considered for inclusion. The reference lists of relevant articles were also examined to identify additional studies.

The retrieved articles were screened by title and abstract to determine their relevance to the review topic. Full-text articles were then assessed for eligibility based on their content and quality. Priority was given to high-quality, peer-reviewed studies that provided valuable insights into the applications, advancements, and future directions of 3D surface imaging in plastic surgery. The selected articles were carefully analyzed, and the key findings were synthesized to present a comprehensive overview.

RESULTS

Clinical Applications of 3D Surface Imaging

1.1. Breast Surgery

3D surface imaging has found extensive application in breast surgery, enabling surgeons to assess breast volume, shape, and symmetry objectively (5,8). This technology has been used to plan and evaluate the outcomes of breast augmentation, reduction, and reconstruction procedures (9,10). By providing accurate measurements and simulations, 3D imaging helps surgeons select the appropriate implant size and shape, optimize surgical techniques, and manage patient expectations (11).

1.2. Facial Surgery

In facial plastic surgery, 3D surface imaging has been instrumental in analyzing facial proportions, asymmetries, and soft tissue changes (12). By enabling the visualization and quantification of facial features, this technology assists surgeons in making informed decisions and achieving optimal aesthetic outcomes (13). This review aims to highlight the significant potential of 3D surface imaging to contribute to the field of plastic surgery by enhancing the achievement of optimal aesthetic outcomes.

1.3. Body Contouring

3D surface imaging has also been found to be applicable in body contouring procedures, such as liposuction, abdominoplasty, and buttock augmentation (13–15). This technology allows for the accurate assessment of body shape, volume, and contour irregularities, facilitating the planning and evaluation of surgical interventions (16). By providing objective measurements and simulations, 3D imaging helps surgeons customize treatment plans and achieve more precise and predictable results (17).

Advancements in 3D Surface Imaging Technology

2.1. Comparison of 3D Surface Imaging Systems

Several companies have developed advanced 3D surface imaging systems with unique features and capabilities. A comparative study by Tzou et al. evaluated five international companies: 3dMD, Axisthree, Canfield, Crisalix, and Dimensional Imaging (Di3D) (18). The fastest capturing devices were the 3dMD and Di3D systems, capable of capturing images within 1.5 and 1 ms, respectively (19). All companies provided software for tissue modifications, while 3dMD, Canfield, and Di3D could fuse CT/CBCT images into their 3D surface imaging data (20). Additionally, 3dMD and Di3D offered 4D capture systems, allowing for the capture of 3D surface movement over time (21).

2.2. Integration with Other Imaging Modalities

Integrating 3D surface imaging with other imaging modalities, such as CT and MRI, has enhanced its utility in plastic surgery (5). By fusing 3D surface data with volumetric imaging, surgeons can better understand the underlying anatomy and soft tissue relationships. This integration has been particularly valuable in craniofacial surgery, where the interplay between bone and soft tissue is crucial for achieving optimal functional and aesthetic outcomes (22).

2.3. Portable and Web-Based Solutions

Advancements in technology have also led to the development of portable and web-based 3D surface imaging solutions (18). Crisalix, for example, offers a purely web-based system that utilizes cloud computing (23). Such solutions provide increased accessibility and flexibility, allowing surgeons to access 3D imaging capabilities from various locations and devices (24). This can improve patient engagement and facilitate remote consultations and follow-up assessments (25).

Future Directions and Challenges

3.1. Patient Simulation and Education

One of the critical areas for future development in 3D surface imaging is patient simulation and education (5). By creating realistic 3D simulations of surgical outcomes, surgeons can better communicate the expected results to patients and manage their expectations (13). This can lead to increased patient satisfaction and informed decision-making. Additionally, 3D simulations can be used for patient education, allowing them to visualize and understand the proposed surgical procedures more effectively (26).

3.2. Communal Database and Standardization

The development of a communal database of 3D surface images, integrated with emerging technologies such as 3D printing and portable information technology, has the potential to validate measurements and strengthen preoperative planning and postoperative outcomes (27). Standardizing 3D imaging protocols and data formats will be crucial for effectively sharing and utilizing this information (9). By establishing a common framework, plastic surgeons can collaboratively advance the field and improve patient care (5).

3.3. High-Resolution Ultrasound for Implant Assessment

In addition to 3D surface imaging, high-resolution ultrasound has emerged as a valuable tool for characterizing breast implants and detecting implant ruptures (28). Nam et al. introduced a novel method using high-resolution ultrasound to identify specific implant types based on filler properties, pocket type, surface topography, shape, and manufacturer (29). This technique also allows for the detection and assessment of implant ruptures, providing valuable information for patient management (30). Integrating high-resolution ultrasound with 3D surface imaging may offer a more comprehensive approach to breast implant evaluation and monitoring (31,32).

DISCUSSION

3D surface imaging has revolutionized the field of plastic and reconstructive surgery, offering a powerful tool for preoperative planning, intraoperative guidance, and postoperative assessment. By providing objective measurements and realistic simulations, this technology has enhanced the accuracy and precision of surgical procedures, leading to improved patient outcomes.

The clinical applications of 3D surface imaging span a wide range of plastic surgery subspecialties, including breast surgery, facial surgery, and body contouring. In breast surgery, 3D surface imaging has enabled surgeons to objectively assess breast volume, shape, and symmetry, facilitating implant selection and surgical planning. In facial surgery, this technology has been invaluable in analyzing facial proportions, asymmetries, and soft tissue changes, guiding procedures such as rhinoplasty and orthognathic surgery. Body contouring procedures have also benefited from 3D imaging, allowing for precise assessment of body shape, volume, and contour irregularities.

Advancements in 3D surface imaging technology have further expanded its capabilities and applications. Comparative studies have highlighted the unique features and strengths of various 3D imaging systems, such as high-speed capture, tissue modification software, and integration with CT/CBCT data. The development of portable and web-based solutions has increased the accessibility and flexibility of this technology, enabling remote consultations and follow-up assessments.

Despite the significant progress in 3D surface imaging, several challenges and future directions remain. Patient simulation and education are critical for further development, as realistic 3D simulations can enhance patient communication and informed decision-making. Establishing a communal database and standardizing imaging protocols and data formats will be essential for effectively sharing and utilizing 3D surface imaging data. Integrating high-resolution ultrasound with 3D surface imaging may provide a more comprehensive approach to breast implant assessment and monitoring.

CONCLUSION

Three-dimensional surface imaging has emerged as a transformative technology in plastic and reconstructive surgery, offering many applications and benefits. This technology has revolutionized how plastic surgeons approach their practice, from enhancing preoperative planning and intraoperative guidance to improving postoperative assessment and patient communication. Integrating 3D surface imaging with other imaging modalities, such as CT and MRI, has expanded its utility, providing a more comprehensive understanding of the underlying anatomy and soft tissue relationships.

As the field of 3D surface imaging continues to evolve, several advancements and future directions have been identified. The critical areas for further exploration are the development of patient simulation and education tools, the establishment of communal databases and standardization protocols, and the integration of high-resolution ultrasound for implant assessment. By addressing these challenges and leveraging the full potential of 3D surface imaging technology, plastic surgeons can continue to improve patient outcomes, enhance patient satisfaction, and advance the field of plastic and reconstructive surgery.

In conclusion, this narrative review provides a comprehensive overview of the applications, advancements, and future directions of 3D surface imaging in plastic surgery. By synthesizing the latest research and insights, this article serves as a valuable resource for plastic surgeons seeking to understand and harness the power of this transformative technology in their practice. As the field continues to evolve, plastic surgeons must stay abreast of the latest developments and actively contribute to advancing 3D surface imaging in plastic surgery.

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