Image Fusion in Preoperative Planning

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• Preoperative planning • Facial surface imaging

A PATIENT-CENTRIC SURGICAL PLANNING PARADIGM

To achieve the best possible outcomes in facial cosmetic and reconstructive surgery, many clinicians are starting to embrace the use of powerful software tools that enable them to plan surgeries in a digital three-dimensional (3D) environment. The foundation of these tools is based on the patient's unique anatomic model that fuses the patient's 3D soft tissue surface with the underlying 3D skeletal structure (**Fig. 1**). Although morphing a 3D surface to generate a desired result is generally accepted in the animation and character modeling world, true surgical planning requires that the software tool incorporate a firm understanding of the various anatomic components, their relative positions to one another, and the biomechanical relationships within the craniofacial complex.

Significant technological advances in the areas of computing, 3D imaging, and the Internet in the last 10 years, in combination with the adoption of 3D patient imaging protocols, are starting to push a next-generation, truly patient-centric care paradigm. With a patient-specific anatomic model that fuses the patient's computed tomography (CT)/cone beam CT (CBCT), magnetic resonance imaging (MRI), and surface images from a single point in time, treatment planning for both the physician and patient becomes clear and understandable. Moreover, the proliferation of Web-based applications increases availability and decreases costs, enabling the virtual patient to be studied and improved treatment protocols to be developed.

Although the use of virtual anatomic reality in surgical planning can improve precision and reduce complications, it also promotes a larger health community goal of improving overall surgical results. Correctly planning and accurately simulating surgical outcome is paramount in facial surgery and the tools used should:

1. Provide a patient treatment plan to achieve the desired result
2. Give the patient a reasonable preview and understanding of the outcome
3. Serve as a communication tool among multiple specialists (eg, orthodontists, surgeons) on the treatment team.

At the center of this approach is the true digital patient or "patient-specific anatomic reconstruction" (PSAR). The PSAR is not just a series of 3D images or traditional photographs/radiographs available in a file to view separately, it is an anatomically accurate record in which all of the patient's 3D images (ie, CT/CBCT, MRI, facial surface images, teeth and so forth) are superimposed into 1 valid 3D structure and combined with the relevant biomechanical properties. This process, resulting in a single dataset from the combination of relevant information from 2 or more independent datasets, is called image fusion.

STRATEGIES FOR 3D FACIAL IMAGE FUSION

When treating the face from a maxillofacial perspective, multiple imaging modalities are required to produce an accurate PSAR model of the patient. Depending on treatment, there is typically a protocol defined that requires a series of 3D images (in 1 or several different modalities) to be

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Fig. 1. 3D photogrammetric facial scan and cone beam computed tomography (CBCT) 3D radiology scan. The realistic 3D soft tissue scan has been made semitransparent to view the underlying bony anatomy.

taken at specific points in time throughout the treatment cycle. The imaging modalities currently relevant to the maxillofacial region include:

1. Traditional CT or the less invasive CBCT
2. 3D facial surface imaging (extraoral)
3. 3D dental study model surface scanning (intraoral).

Most commonly, the primary modality is CT/CBCT, to which other datasets are fused. Imaging technologies are emerging that may become important secondary modalities to which CBCT datasets may be fused, including[1,2]:

1. Ultrasound to document airway function
2. MRI to isolate muscle and generate a basic facial surface image (Takács and colleagues, 2004)[3]
3. 3D optical intraoral scanners to replace the dental impression technique and/or scanning physical study models
4. Dynamic facial (four-dimensional [4D]) surface imaging to record facial movement and expression
5. Positron emission tomography (PET).

THE IMPORTANCE OF THE 3D SURFACE IMAGE IN SURGICAL PLANNING

The face is the foundation for communications and interaction with the world, and thus patients are concerned with the effect a treatment might have on their appearance. This awareness is placing more emphasis on the importance of accurately documenting the patient's external facial features and characteristics before treatment, and then using this as a basis to plan treatment and monitor progress throughout treatment. Although a series of photographs has been used traditionally for this function, the limitations of a 2D medium significantly reduce the ability to objectively quantify treatment results for patients. How patients sees themselves in photographs may be totally different than how a clinician sees the patient in the same photograph irrespective of the lack of 3D reality (Fig. 2).

With a highly accurate 3D surface image of the patient's face, this debate becomes objective because the treating physician can measure the geometric shape changes that resulted from treatment and/or growth (ie, the effects of a mandibular advancement, a palate expander, cleft repair, and so forth). The need for quantification of this effect and the minimizing of subjectivity is fueling the adoption of enabling technologies. Because of the exposure risks associated with the production of 3D images using ionizing radiation, noninvasive modalities and techniques are being investigated for incorporating 3D data into a patient's PSAR. Optics-based 3D surface imaging systems are available to noninvasively capture anatomically precise 3D facial images of the patient. Not only can a patient's surface image be taken before and after treatment in conjunction with the CT/CBCT images, the clinician has the option to image the patient as often as required depending on the treatment protocol. Soft tissue only procedures can be planned and monitored only using the 3D surface imaging modality. Dental impressions can be taken producing physical

Fig. 2. 3D photogrammetric facial scan with patient smiling.