Advances in Technology for Functional Rhinoplasty
The Next Frontier

Sachin S. Pawar, MD[a,*], Guilherme J.M. Garcia, PhD[a,b],
John S. Rhee, MD, MPH[a]

KEYWORDS

• Finite element modeling (FEM) • Computational fluid dynamics (CFD) • Virtual surgery • Computer modeling • Simulation • Nasal surgery • Rhinoplasty • Septoplasty

KEY POINTS

- Computer modeling and simulation technologies have the potential to provide facial plastic surgeons with information and tools that can aid in patient-specific surgical planning for rhinoplasty.
- Finite element modeling and computational fluid dynamics (CFD) are modeling technologies that have been applied to the nose to study structural biomechanics and nasal airflow.
- Patient-specific computational models can be modified to simulate surgical changes or perform virtual surgery. CFD tools can then be used to study the effects of these changes on nasal function and, in the future, aid in surgical planning and in predicting surgical outcomes.

INTRODUCTION

Among all of the procedures in facial plastic surgery, rhinoplasty demands the highest level of understanding in aesthetics, soft and hard tissue dynamics, and the delicate interplay between form and function. Adding to the complexity of this procedure are individual patient factors that can impact patient outcomes, including variable anatomy and medical comorbidities. The techniques currently used have evolved through many years of hard work, ingenuity, and experimentation of numerous rhinoplasty surgeons. Collectively, this comprises decades of knowledge that has largely been developed through individual surgeon experience and, undoubtedly, trial and error.

Advances in computer-based modeling and simulation are now providing ways to better study and understand individual anatomy, tissue dynamics, and specific surgical techniques. Modeling has been used in engineering fields for decades and has helped engineers design complex processes and products for numerous industries. Methods for finite element modeling (FEM) and computational fluid dynamics (CFD) were first introduced in the 1950s and 1960s, and limited to applications within various engineering fields. As computing technology has advanced, applications for modeling and simulation have slowly expanded to medicine and, more recently, applied to nasal anatomy and rhinoplasty techniques.

Surgical modeling is not an entirely new concept. Craniofacial surgeons have been performing model surgery for decades, using cephalometric measurements and physical resin molds to plan and design orthognathic surgery and facial skeletal dimensions preoperatively.[1] Using model surgery, they could make better informed decisions about the specific maneuvers needed to achieve the desired outcome for a patient, specific to that patient's anatomy and clinical requirements. In short, this type of model surgery minimizes the

[a] Department of Otolaryngology and Communication Sciences, Medical College of Wisconsin, 9200 West Wisconsin Avenue, Milwaukee, WI 53226, USA; [b] Department of Biomedical Engineering, Marquette University & the Medical College of Wisconsin, 9200 West Wisconsin Avenue, Milwaukee, WI 53226, USA
* Corresponding author.
E-mail address: spawar@mcw.edu

Facial Plast Surg Clin N Am ■ (2017) ■–■
http://dx.doi.org/10.1016/j.fsc.2016.12.009
1064-7406/17/

guesswork needed to achieve a desired result. Similarly, computer modeling and simulation techniques have the potential to provide facial plastic surgeons with information that could aid in patient-specific surgical planning.

The accessibility to affordable, yet powerful hardware and software has fueled the emergence of very sophisticated computer modeling tools. Historically, modeling of biological hard and soft tissue modifications with endless variation and intrinsic tissue properties has been challenging. Medical imaging has been a key transformative technology in this regard because computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound can now achieve extreme high levels of resolution and detail. This has facilitated the development of computations and simulations that were never previously possible. Additionally, commercially available software programs now provide tools to manipulate imaging data to simulate surgical modifications of specific anatomy.

Over the past several years, there have been an increasing number of studies using computer modeling tools to study the nose. This article reviews the specific modeling technologies of FEM and CFD, and their application to nasal surgery.

FINITE ELEMENT MODELING

FEM is a computational technique used to quantitatively study the biomechanics of a structure and provides a method to analyze structural stress, strain, and energy distributions on 3-dimensional (3D) structures.[2] The first multicomponent FEM of the nose incorporating bone, cartilage, and skin-soft tissue was reported by Manuel and colleagues.[3] Over the past several years, there have been an increasing number of studies applying FEM to various nasal constructs in addition to studying effects of specific rhinoplasty techniques.

Nasal Septum and Dorsum

Some of the initial studies applying FEM to the nose studied biomechanics of the septal L-strut.[4,5] Lee and colleagues[5] created several models by altering material properties of the septum and nasal tip support to determine the overall deformation and stress distribution in the L-strut. They found that the most consistent points of maximum stress were the bony-cartilaginous junction and the nasal spine, highlighting the importance of maintaining adequate cartilage support within the L-strut at these 2 locations. In more recent work, they further analyzed the caudal segment of the septal L-strut and highlighted the importance of maintaining at least 1 cm of septal cartilage width along the inferior portion of the L-strut, at the junction with the anterior spine.[2] In another recent study, Tjoa and colleagues[6] used FEM to simulate wound healing forces and surgical maneuvers that may lead to the inverted V-deformity.

Cephalic Trim

FEM modeling of the nose has also been used to study effects of lower lateral cartilage resection on the overall mechanical stability of the nose and nasal cartilages. In an initial study, Oliaei and colleagues[7] developed an FEM of 3 different lower lateral cartilage widths, simulating differing amounts of cephalic resection. Using this model, they showed that there was no statistically significant decline in structural support of the cartilage when a minimum 6 mm width of lateral crus was maintained, suggesting that this width could potentially resist contractile forces related to postoperative scar tissue. In a more recent study, Leary and colleagues[8] applied FEM to study the potential impact of cephalic resection on the strength and stability of the lateral crus. They identified the common clinical problem of alar retraction after cephalic trim, and used FEM techniques to better understand the complex forces and factors that contribute to this complication. As they pointed out, objective analysis of rhinoplasty maneuvers is difficult to perform on patients due to the overall long period of time during which changes in nasal shape occur. Unfortunately, a limitation of current modeling techniques is the overall lack of experimental data to simulate these complex wound healing processes.

Nasal Tip Support

Other studies have applied FEM to investigate nasal tip dynamics and support.[3,7–11] Shamouelian and colleagues[10] examined relative contributions of 2 major tip support mechanisms: attachment between the lower and upper lateral cartilages (scroll region) and attachment of the medial crura to the caudal septum. Computer models were modified by removing various intercartilaginous connections to simulate various rhinoplasty maneuvers (transfixion and intercartilaginous incisions). Each model was then subjected to a nasal tip force to simulate nasal tip depression. Results of this modeling showed disruption of the medial crura attachment to the caudal septum had a greater impact on nasal tip support compared with disruption of the scroll region. In another study, FEM was used to study how columellar strut graft size, shape, and attachment to the medial crura affect nasal tip support.[11] Interestingly, suture placement to fixate the graft was found to be just as important as the strut size, with the most important point of fixation at