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ORIGINAL ARTICLE

Digitizing rhinoplasty: a web application with three-dimensional preoperative evaluation to assist rhinoplasty surgeons with surgical planning

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Abstract

Purpose Rhinoplasty is one of the most common and challenging plastic surgery procedures. The results of the operation have a significant impact on the facial appearance. The planning is critical for successful rhinoplasty surgery. In this paper, we present a web application designed for preoperative rhinoplasty surgery planning.

Methods The application uses the three-dimensional (3D) model of a patient's face and facilitates marking of an extensive number of facial features and auto-calculation of facial measurements to develop a numerical plan of the surgery. The web application includes definitions, illustrations, and formulas to describe the features and measurements. In addition to the existing measurements, the user can calculate the distance between any two points, the angle between any three points, and the ratio of any two distances. We conducted a survey among experienced rhinoplasty surgeons to get feedback about the web application and to understand their attitude toward utilizing 3D models for preoperative planning.

Results The web application can be accessed and used through any web browser at digitized-rhinoplasty.com. The web application was utilized in our tests and also by the survey participants. The users successfully marked the facial features on the 3D models and reviewed the auto-calculated measurements. The survey results show that the experienced surgeons who tried the web application found it useful for preoperative planning and they also think that utilizing 3D models is beneficial.

Conclusions The web application introduced in this paper helps analyzing the patient's face in details utilizing 3D models and provides numeric outputs to be used in the rhinoplasty operation planning. The experienced rhinoplasty surgeons that participated to our survey agree that the web app would be a beneficial tool for rhinoplasty surgeons. We aim to further improve the web application with more functionality to help surgeons for preoperative planning of rhinoplasty.

Keywords Rhinoplasty · Web application · Surgery planning · 3D model · Facial features · Facial Landmarks · Facial measurements · Face analysis · Survey

Introduction

Rhinoplasty is a plastic surgery procedure for correcting and reconstructing the nose. It is one of the most frequently performed aesthetic surgeries with more than 200 K annual cases in the USA [1]. There are two types of rhinoplasty surgeries;

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functional rhinoplasty to improve the form and functions of the nose and cosmetic rhinoplasty to improve the appearance. Rhinoplasty is a very complex surgical procedure where the surgeon seeks to achieve the combination of esthetic harmony with the surrounding facial features and preservation or establishment of nasal function and support [2].

The success of a rhinoplasty operation is very important for a patient as the operation fundamentally changes a part of their appearance that has bothered them for years. However, rhinoplasty has relatively low satisfaction rates compared to other cosmetics procedures [3], causing high revision operation rates (about %15) and hence more physical and financial discomfort for the patient [4].

One of the reasons for the low satisfaction rate is failing to set the patient's expectations right due to the lack of the right communication tools [3]. The perception of the patient and the surgeon might be different for the results of the operation. It is of utmost importance to reach a mutually agreeable set of expectations during the pre-surgery consultation [5] utilizing the tools available for pre-surgery planning.

In this paper, we present a web application that is designed to be used for rhinoplasty pre-surgery planning. The application provides an interface to the three-dimensional (3D) model of a patient's face for detailed numerical planning of the surgery with feature point identification and metric measurements. The web application uses 3D face scans of the patients as input that provides an accurate model of the patient's face. This model enables the 3D measurements and eliminates the requirement of a scale reference such as a ruler, which is used in most of the existing approaches. The application provides an extensive set of feature points to be marked by the surgeon on the surface of the 3D scan. As the feature points are marked by the help of a user-friendly interface, the corresponding metrics and measurements are calculated automatically and presented on the screen. The details of how the web application functions are explained in the following sections. This paper also presents the results of a survey performed on a group of experienced rhinoplasty surgeons to evaluate the web application and to express the surgeon's attitude toward the usage of 3D modeling.

Background and related work

Computer simulations improve the communication and help setting the expectations right for both the patient and the rhinoplasty surgeon [6–8]. With the help of computer simulations, patients with unrealistic expectations can be identified, and the surgery can be avoided for patients who cannot find computer simulations suiting their esthetic goals [9]. 2D computer imaging (photography) has been a recommended tool for rhinoplasty consultation for decades [6, 10]. However, 2D computer imaging has its limitations due to representing a 3D structure (nose) in 2D medium [10]. It is challenging to understand the details accurately from a series of 2D images for the patient, even for the surgeon. On top of that, 2D imaging does not provide reliable measurements because of variances in equipment, head position, and magnification from setting to setting [11].

There are various tools proposed for the planning, execution, and validation of rhinoplasty surgeries. Rhinobase [12] is a well-known example, serving both as a patient database and a surgery planning software. Rhinobase provides surgeons with the capability to use three images of each patient for facial analysis. The images are calibrated with the help of a ruler in the photograph, and the landmarks are identified to be used in operative planning. Preoperative computer simulation [13] also uses images from three different angles, and the proposed changes are simulated on these images according to the expectations from the patient and the advice from the surgeon. Ozkul et al. [14] used images for surgery planning. They used WinMorph software on the images to visualize the expected outcomes [15] and focused on the accurate prediction of the surgery results. Larrosa et al. [16] presented a smartphone application with a similar surgery planning goal. Even though the application gave promising results, the calibration and accuracy are remaining concerns for the approach.

Recent advances in 3D computer modeling address some of the limitations inherent to 2D imaging [7] and provide the ability to perform absolute measurements [17]. Measurements from 2D imaging have to be recalibrated to actual size by using measurements of known distances (a ruler in the photograph or the expected diameter of the iris and cornea) as in Rhinobase 2D imaging software for rhinoplasty [12]. However, simple point-to-point measurements reflect the actual difference in 3D modeling [17]. Besides distances and angles, it is possible to calculate volumes and topographic distances using 3D models [7, 17]. Moreover, utilizing 3D computer modeling helps for better communication between the surgeon and the patient, thus contributes significantly to the patient's comprehension and eases their apprehension via improved participation. Hence, 3D modeling results in improved planning and a higher percentage of post-surgery satisfaction [18]. Given these advantages, computer imaging is progressing from 2D to 3D models [5, 7, 10, 19] to improve communication and to enable more precise planning [18].

While a majority of the computer modeling approaches focus on two-dimensional images, 3D scans started to be used more frequently with the advances in cameras and scanning systems [20]. Bottino et al. [21] proposed a quantitative approach to automatically suggest modifications to facial features using 3D scans. Jamrozik et al. [22] scanned the patient faces using 3D structured light scanner and transferred the resulting data into Autodesk 3dsMax software [23]. However, the approach included no rhinoplasty specific features to assist in surgery planning.

'Bergamo 3D Rhinoplasty' [24] is a software application consisting of a database and surgery components for record tracking and surgery activity simulation. The main goal of the application is self-analysis and education. There are also several approaches which leverage sophisticated medical imaging equipment for three-dimensional planning of rhinoplasty procedures. The radiologic viewers are among these tools, and they provide segmentation of the model for the analysis of different tissues. The study by Moscatiello et al. [18] showed that this method provided better patient satisfaction compared to traditional photo morphing methods. Wang et al. [25] used laser scan and lateral X-ray images to provide high-quality prediction of the postoperative appearance, and to design the prosthesis models. Despite their high accuracy, these methods are difficult to scale as they require complex equipment and software. Some commercial tools have become available such as Vectra Face Sculptor [26]; however, they are not affordable by most of the healthcare practices and provide only a limited number of facial features and measurements. Recently, mobile device applications emerged for 3D facial analysis such as Crisalix 3D [27] and GlamFace 3D [28]. These promising apps do not work on web browsers and they include a limited number of facial features and measurements.

Preoperative web application

In this section, we lay out the details of the web application designed for 3D preoperative planning of rhinoplasty. The web application presented in this paper helps identify and measure the positional and angular properties of facial feature points before a rhinoplasty surgery. The web application can be accessed at http://digitized-rhinoplasty.com [29]. The current version of the web application is implemented using the JavaScript programming language and works on any modern web browser. Three.js, a WebGL JavaScript library, is used to display 3D face models. Three.js is also used to capture the intersecting coordinates of the 3D model and the mouse click location as the user marks the facial features [30]. The formula for a measurement calculation is displayed using the MathJax JavaScript library [31] when the user views the details of a measurement on a popup dialog. Through an extensive literature review, we identified over 80 facial features and over 100 measurements [32]. We utilize 68 facial features (59 points, four lines, three planes, and two areas) and 68 auto-calculated measurements from this review in the latest version of the web application[1]. We also have four generic facial feature points and three generic measurements included in the web application.

The facial features are listed in alphabetical order and organized in the following groups: points, lines, planes, and areas. The measurements are listed in alphabetical order and organized in the following groups: distances, angles, and ratios. The web application also provides the capability to measure the distance between any two points, the angle between any three points and the ratios of any two distances marked on the face.

The application automatically calculates the measurements as the user marks the feature points. The markings are done on a 3D model which increases the accuracy of the analysis. The existing approaches mostly work on 2D images and require a scale reference such as a ruler which can be error-prone. Marking the measurements on a 3D model eliminates the need for a scale reference since as the 3D model is created using a depth sensor camera, the size of objects is also captured. The use of depth cameras provides better precision [33].

The depth sensor camera that we utilized for our sample measurements is Bellus3D camera. Bellus3D Face camera provides high precision accuracy (less than 0.2 mm error) and quick scanning time (less than 20 s) to capture the 3D model of a face [34]. We scanned over 30 faces using the Bellus3D camera and tested our web application with those 3D models. The users were able to successfully mark the facial features on the 3D model and review the auto-calculated measurements.

How the application works

To analyze a face for rhinoplasty on our web application, the user first needs to upload 3D Model files (.obj, .mtl, and .jpg) to the website and then load the 3D Model using the "Load" button (see Fig. 1).

To mark a facial feature point (landmark), the user selects the feature point from the list and then clicks on the loaded 3D model. A green dot appears on the 3D model for the selected feature point. The X, Y, Z coordinates of the marked feature point are saved. If the location of the green dot needs to be minimally moved on the surface of the face, the user can utilize the up/down/left/right arrows to fine-tune the location of the marked feature point as shown in Fig. 2. If the users are satisfied with the marked location, they can continue with the next feature point by selecting its radio button from the list.

[1] The number of features and measurements might be different at the time you visit the web application since we might add new facial features and measurements with new versions.

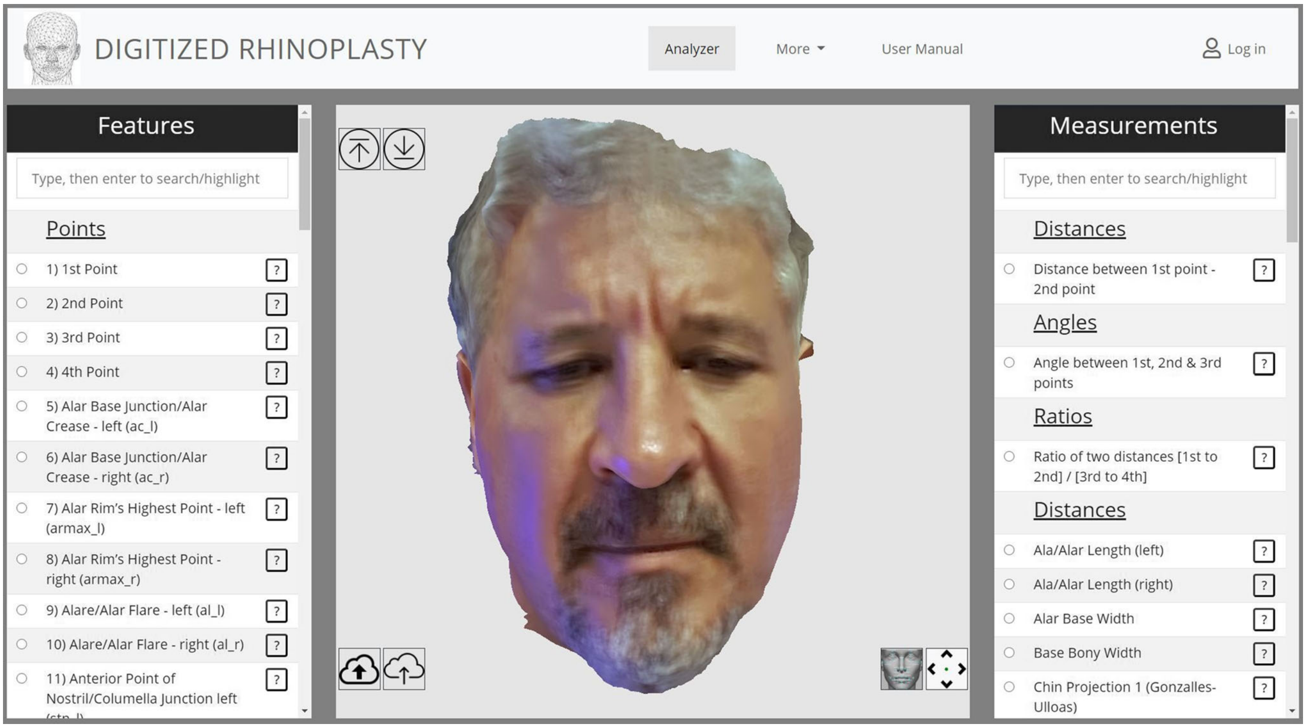


Fig. 1 Overview of the Website

Fig. 2 Fine tuning the location of the marked feature point

If the users want to go back to a previously marked location of a feature point, they can again select the feature point from the list and a green dot will be placed on the 3D model at the previously marked location. The user can update the location by clicking on another point or using the fine-tuning buttons. The user can display all the previously marked feature points by clicking on the "Display All" button on the right bottom part of the scene. All the feature points are placed on the 3D model along with a number that indicates the list number of the feature point as seen in Fig. 3.

Measurements are automatically calculated as the user continues to mark feature points. If the users want to see the feature points used in the calculation of a measurement, they can select that measurement's radio button from the measurements list and all the feature points involved in the calculation of that measurement are highlighted on the feature points list and a green dot is placed for each of these feature points on the 3D model. For example, when "Radix Depth" measurement is selected, a green dot is placed for both "Nasion" and "Supratarsal Crease left" (measurements that are used to calculate the Radix Depth) as shown from different angles in Fig. 4. The measurements are listed in alphabetical order and organized in the following groups: distances, angles, and ratios.

If the users want to review the description and a guidance figure showing where the feature point should be, they can click on the "Details–'Feature Point Name'" button and the details of the selected feature point are displayed on a popup window as shown in Fig. 5.

To see the details of a measurement (description, figure and formula), the user can click on the "Details–'Measurement Name'" button. For example, when the

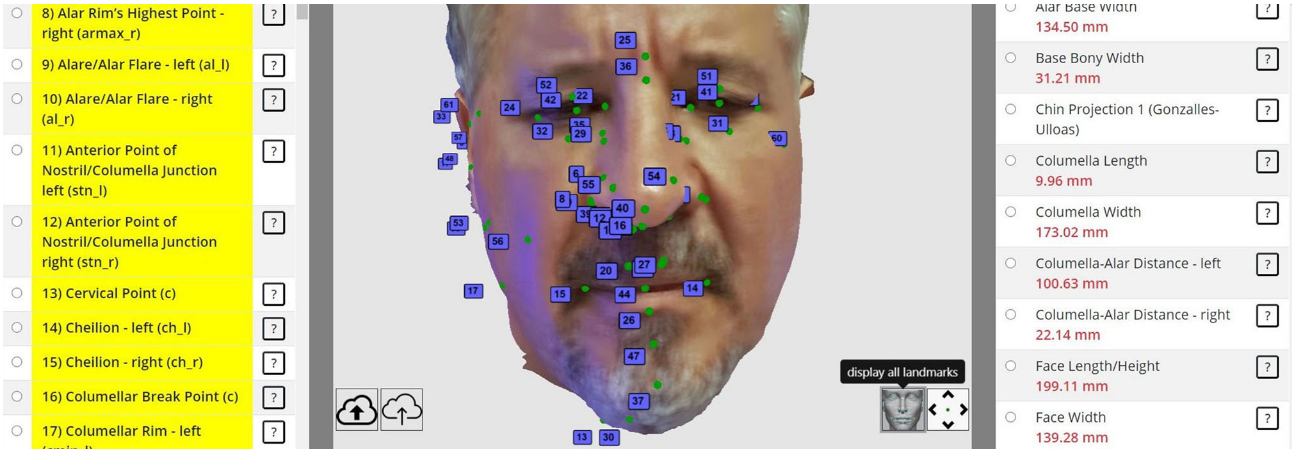


Fig. 3 Displaying all the marked feature points

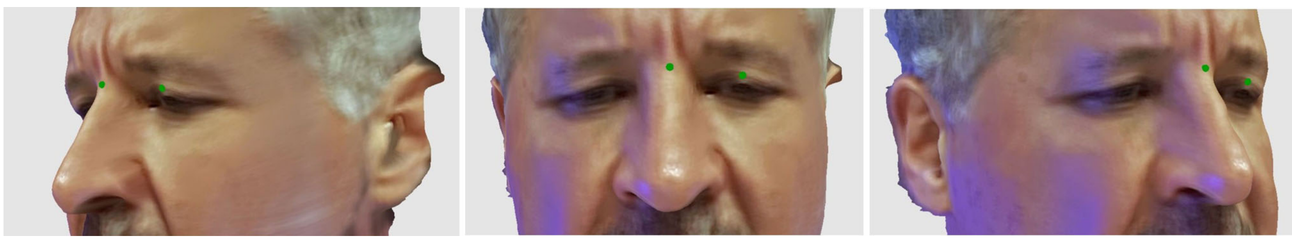


Fig. 4 Displaying all the feature points (green dots) that are used for calculating a measurements from three different angles

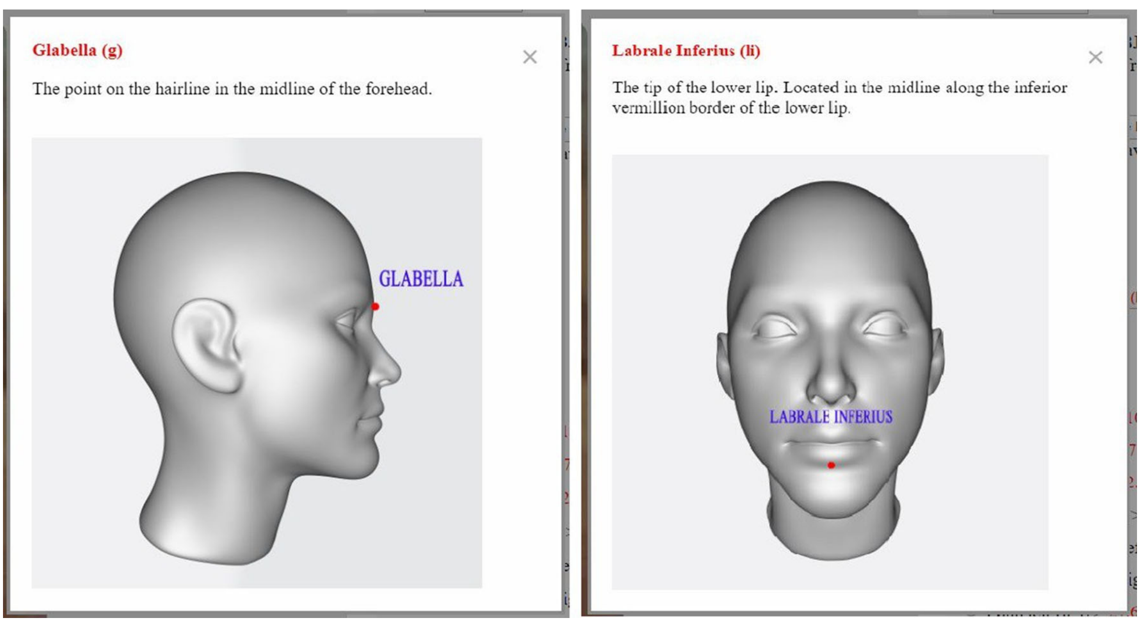


Fig. 5 Displaying description, location of the selected feature point

details button is clicked for "Mid-Facial Height" and "Radix Projection" measurements, the popup windows are displayed as in Fig. 6.

Besides the capability to mark 59 named facial feature points such as Glabella, Nasion, Pronasale, etc., and to have the results for 68 related measurements auto-calculated, the web application provides the flexibility to measure any distance, angle and ratio on the 3D model. Moreover, it also provides description and illustration of some important facial lines, planes and areas such as Dorsal Aesthetic Lines, Frankfort Horizontal Plane, and Keystone Area. The user can perform generic measurements by marking two or more of

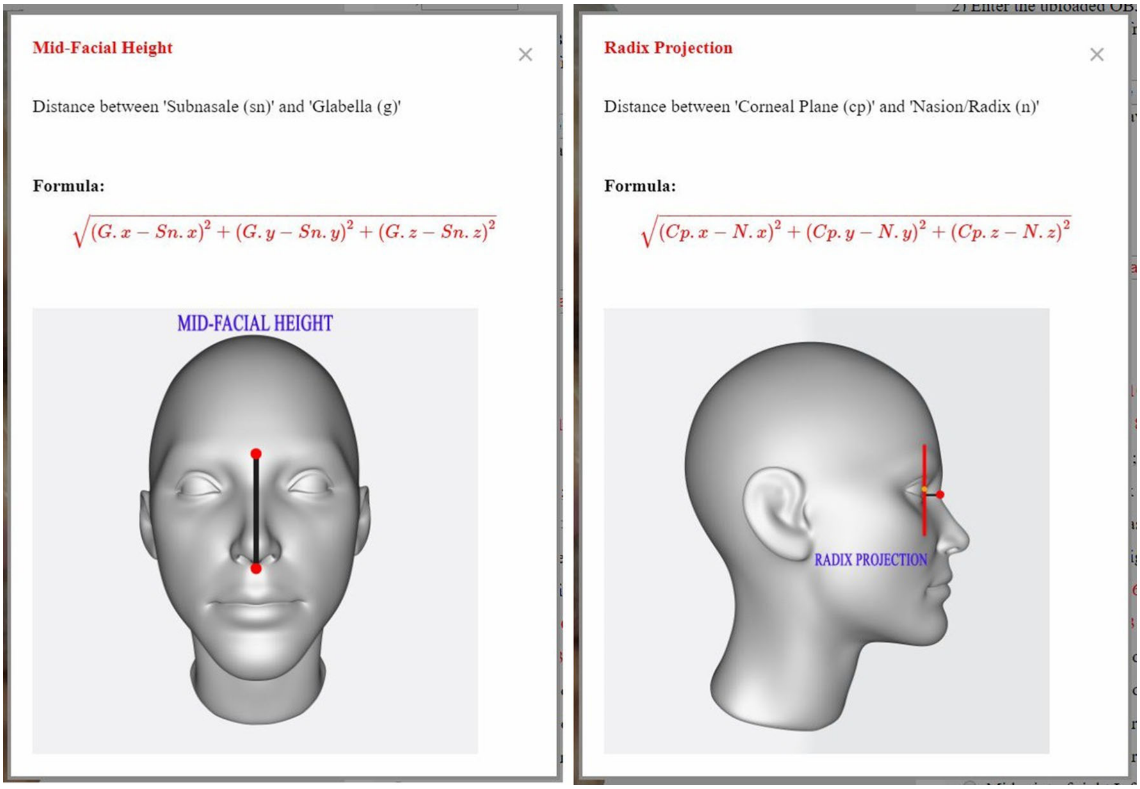


Fig. 6 Displaying description, formula and the visualization of the measurement

Fig. 7 Calculating distance between any two points, angle between any three points and ratio any two distances

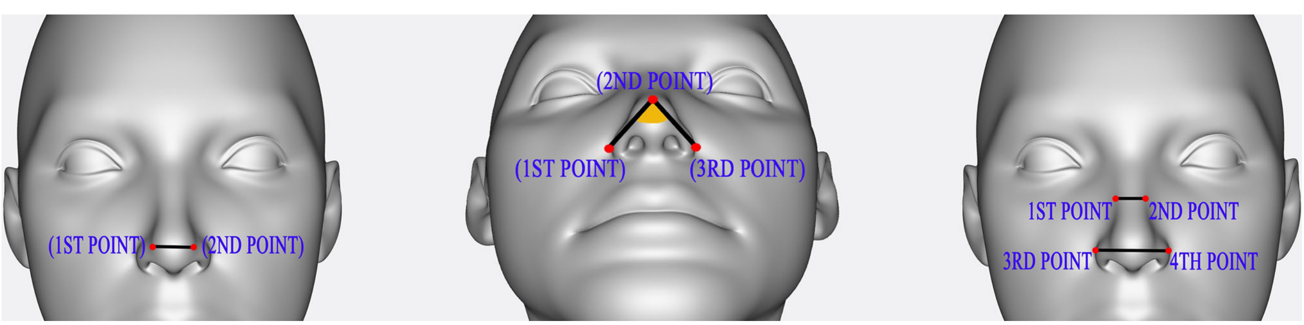
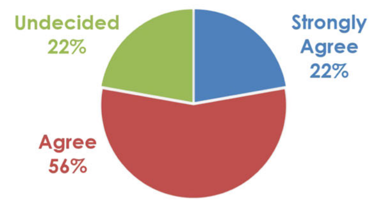
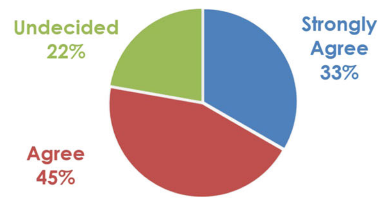


Fig. 8 Example marking of four points on the 3D model and getting distance, angle and ration measurements

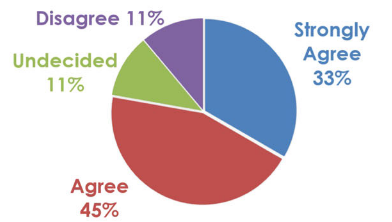
Fig. 9 Survey Results for the Web Application



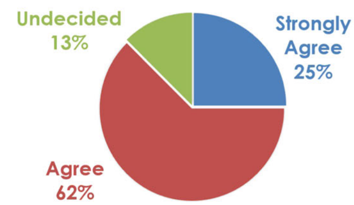
(a) The descriptions given for the features and measurements on the website are correct.



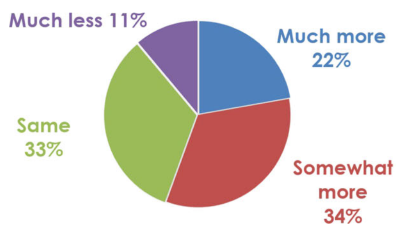
(b) The pictures for the features and the measurements helped me correctly visualize the features and measurements.



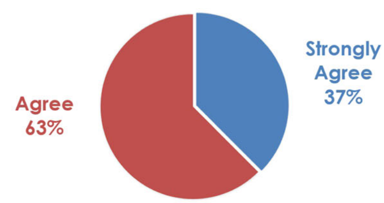
(c) It was easy to analyze 3D models on the website.



(d) The website is user-friendly.



(e) The time I spent for analysis using 3D models compared to 2D photography is.



(f) The web application would be a beneficial tool for rhinoplasty surgeons.

the generic points (1st Point, 2nd Point, 3rd Point, 4th Point) as shown in Fig. 7. The generic measurements: distance between the 1st and 2nd points, the angle between 1st, 2nd, and 3rd points, and the ratio of the distance between 1st and 2nd points to the distance between 3rd, and 4th points are auto-calculated. Example markings of the generic 1st, 2nd, 3rd, and 4th points are shown in Fig. 8.

The user can download the data for the marked feature point locations and calculated measurements into a JSON file to save the markings. Later, the JSON file can be imported to continue markings and to view the feature point locations and measurement values. This functionality also enables the transfer of facial feature point data among multiple users.

Survey

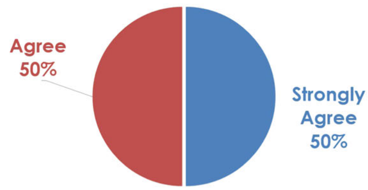
We have conducted a survey to get feedback about our web application for rhinoplasty pre-planning. We invited 12 experienced rhinoplasty surgeons to our survey and 10 of them participated. The participants are from USA, UK and Turkey.

The first part of the survey included questions to understand the participants' experience level and the importance that they give to pre-planning for rhinoplasty. According to these questions, 50% of them have been practicing rhinoplasty for over 20 years, 40% of them have been practicing for 10 to 20 years and 10% of them have been practicing for 5 to 10 years. The participants also indicated that 80% of them performed over 500 surgeries and 20% of them performed 250 to 500 rhinoplasty surgeries. The 80%, 10%, and 10% of the participant surgeons responded that the planning for rhinoplasty is very important, important, and moderately important, respectively.

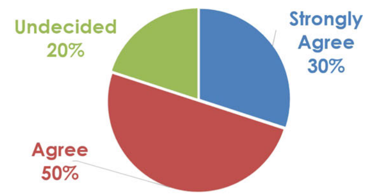
The rest of the survey was divided into three sections: (1) Multiple choice questions related to the use of the web application (see Fig. 9), (2) Multiple choice questions to compare 2D Computer Modeling (photography) and 3D Computer Modeling (see Fig. 10), (3) Open-ended questions (see Table 1). The multiple choice questions use the Likert Scale [35].

For the web application-related questions, we prepared a version of the web app that has the same functionality but only lists 13 facial features and 10 measurements. We limited

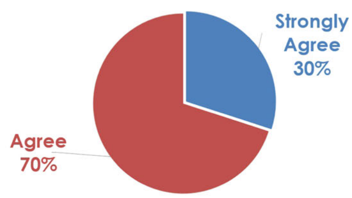
Fig. 10 Survey Results for the Comparison of 2D & 3D Modeling



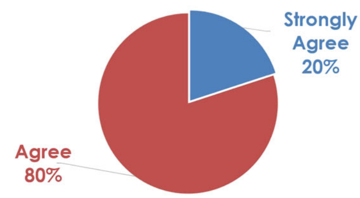
(a) Analyzing the patient's nose using 3D models is more useful than analyzing using 2D photography.



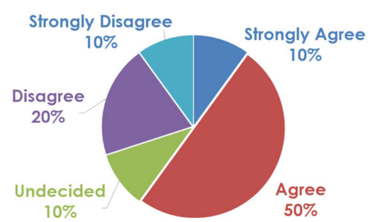
(b) Utilizing 3D models helps to overcome certain limitations, such as analyzing the patient's face from various angles.



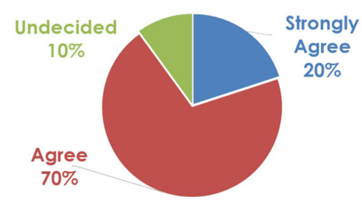
(c) Utilizing 3D models will provide more accurate measurements since there is no need to have reference material (e.g. a ruler) in the picture for calibration.



(d) The new measurements (i.e. volume,topological distance, and depth), that would only be possible by evaluation of 3D models, will further improve the preoperative planning.



(e) Analyzing 3D models might be more overwhelming for the patient than 2D photography.



(f) 3D modeling can be expected to set the patients' expectations closer to realistic levels.

Table 1 Survey Results for the Open-Ended Questions

Question	Answers
In your opinion, what would be the main benefit of using 3D modeling?	Better and more realistic visualization, better communication between surgeon and patient, objective, accurate, and reliable system for quantifying the soft tissue dimensions of the face
What would be the main blockage that would prevent you from using 3D models?	Cost, usability, patient's reaction to 3D system, new setting and resources required, extra time needed
What is the main thing that would make you utilize the website as a tool?	Accuracy, ease of use, easy guidance, cost

the number of the facial features and measurements so that it would take less time for the surgeons to grasp and evaluate the design and functionality of the web application. By this, we aimed to increase the percentage of the participants by decreasing the time needed to spend to complete the survey.

We also provided sample 3D models for the participants to test out the web application. Due to technical difficulties on their side, one participant was unable to use the web application; thus, the participant's answers for the web application-related questions were removed from the results presented in Fig. 9.

Figure 9 shows the survey questions about the web application and the answers given by the participants using the Likert scale. According to these results, rhinoplasty surgeons finds the web application as a beneficial tool for pre-planning (37% strongly agrees and 63% agrees). While we received mostly positive feedback, a small percentage of the surgeons did not find the web application easy to use. We will have a survey to discover the reasons behind the concerns that the surgeons might have about the web application to further improve it. We received some feedback suggesting that the time spent for analysis using 3D models is more. This might be because the surgeons did not have any tutorial regarding how to use the web application. To address this, we added a video tutorial on the user manual page and we plan to prepare a step-by-step onboarding tutorial for the web application to increase users' familiarity on how to use it.

Figure 10 shows the survey questions comparing 2D photography to 3D modeling and the answers given by the participants. The results show that our approach to utilize 3D models is supported by the rhinoplasty surgeons as well. All of the participants agree that analyzing the patient's nose using 3D models is more useful than analyzing using 2D photography. The majority of the surgeons' opinion is that utilizing 3D models will provide more accurate measurements and the new measurements that is possible by using 3D models will improve pre-planning for the rhinoplasty surgery. We received mixed responses regarding the surgeons' thoughts on how analyzing 3D models might be overwhelming (difficult to deal with) for the patients. The patients are not yet very familiar with seeing their face as a 3D model when compared to 2D photography. As the usage of 3D modeling becomes more spread, we believe, the patients will become more comfortable analyzing their face using a 3D model.

Table 1 shows the survey answers for the open-ended questions. These questions aimed to get the surgeon's opinions about using 3D models and the web application for preoperative planning. The answers show that rhinoplasty surgeons believe in the benefits of using 3D modeling and are willing to use it when the tools are easy-to-use, affordable and resource-efficient. According to the survey responses, the ease of use, accuracy and the cost are critical to utilize the web application for preoperative planning.

While the results of the survey are pretty positive, we acknowledge that the number of participants is small and we plan to conduct an enhanced survey with a large number of participants.

Results

The web application can be accessed and used through any modern web browser at digitized-rhinoplasty.com enabling the usage of this tool in any healthcare setting such as private practices or hospitals without the installation of any extra software. The web application provides the capability to mark 59 facial feature points and then reviews 68 auto-calculated measurements (distances, angles, and ratios). It also provides description and illustration of some important facial lines, planes, and areas such as Dorsal Aesthetic Lines, Frankfort Horizontal Plane, and Keystone Area. Moreover, the web application can be used to measure distance between any two points, and to measure angle and ratio between two lines on the face. The web application provides descriptions and illustrations for each of the features and the measurements. The web application is utilized in our tests using over 30 face scans and the users successfully marked the facial features for each 3D model.

According to the survey we conducted among experienced rhinoplasty surgeons, the web application is a promising tool to improve preoperative planning. The survey also shows that rhinoplasty surgeons believe in the benefits of utilizing 3D models for preoperative planning and are ready to transition from 2D photography to 3D modeling for preoperative planning.

Conclusion and future directions

This paper presents our web application software that is designed to be used by surgeons in preoperative planning. The application runs in a web browser and provides a set of feature points to be marked by the user on the 3D scans of patients' faces. The feature points are used by the application to calculate important distance, angle and ratio values automatically as they are marked. The application improves the abilities of the surgeon by utilizing the digital model of patient and will provide numeric outputs to be used in the planning and verification of the operation.

We continuously improve and release new versions of the web application based on the feedback and our roadmap. The version history and the associated changes for each version can be found on the website. We present some of the upcoming/planned functionalities and studies related to the web application as follows:

- Perform a study to evaluate the accuracy of measurements done via 3D modeling, manual measurements and 2D photography,
- Perform statistical analysis to find out range of measurement values and warn the user for possible errors if calculated measurements are outside the range,
- Auto-detect of facial features (points, lines, etc.),
- Add new measurements (i.e., volume, topological distance, and depth), which are only be possible by utilizing 3D models,
- Enable account creation for surgeons to securely store data on the cloud instead of storing them locally,
- Translate quantitative measurements to qualitative descriptions such as "normal", "wide", and "narrow" for alar base width or for tip and "divergent", "straight", and "convergent" for alar axis.
- Add functionality to manipulate the 3D model based on patient's preferences and calculate the measurements for the morphed 3D model.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent This article does not contain patient data.

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