Design and Development of *Sur-Face:* An interactive mobile app for educating patients regarding corrective surgery of facial deformities

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Abstract.

Corrective surgery of face, also known as orthognathic surgery, is a complex procedure performed to correct the underlying facial deformities. In case of elective surgeries like these, patients need to make voluntary decisions whether or not undergoing the surgery. Hence, it is very important for them to understand the intricacy of the techniques and potential side effects of the surgery before they sign the consent form. Conventional methods of patient education using leaflet-based instructions were found to be ineffective in providing them the required information.

Sur-Face, named after **sur**gery of **face** is a healthcare app exploring a new dimension in patient education with the help of interactive 3D visualizations and serious gaming elements on a mobile platform. It demonstrates the surgical process and it's after effects using high quality 3D animations. The aim of this study is to evaluate the efficacy of *Sur-Face* by comparing two methods of delivery of instructions: a mobile app with interactive 3D animations and an audio file containing only verbal instructions. To evaluate these methods, participant's ability to understand and retain the instructions was analyzed using a questionnaire. The null hypothesis was that there would be no difference between the two methods of instructions. On analysis, participants of the 'app' group performed significantly better ($p<0.0034$) than the 'voice' group suggesting the role of interactive visualizations in improved understanding, intuitive knowledge transfer and communication. This paper describes the principles of design, development and potential advances of *Sur-Face*. Further it also explores the application of serious games in patient education and informed consent process.

Keywords: Mobile apps, 3D modeling, Visualization, mHealth, Facial deformities, Orthognathic surgery.

1 Introduction

Face is one of the most visible and important organs of our body. Thus deformities of the face, which can be of skeletal or dental origin, distress the patients both physically and psychologically. Severe skeletal deformities can debilitate patients of their normal functions like breathing, eating and also disturb the overall aesthetics of the face. Orthognathic surgery or corrective jaw surgery is performed in these cases to re-establish proper functioning of the jaws and enhance facial aesthetics.

As patients voluntarily consent to undergo orthognathic surgery for correction of a prolonged functional deformity or an aesthetic requirement, informed decisions are to be made before undergoing the surgery (1). Having a good knowledge of the surgery helps patients to take responsibility of their health (2, 3) and give a well-comprehended informed consent. In addition to the actual surgery, knowledge about post-operative complications is imperative as any form of surgery has some potentially unpredictable outcomes. Given that orthognathic surgery is a prolonged procedure, which can last for more than a year (4), the consent process usually begins long before the surgery. Hence, it is vital that the patients completely understand the surgical instructions and also remember the possible outcomes. However, this part of patient care has often been an underestimated factor (5) leading to poor post-operative satisfaction levels, and to litigation in some severe cases (6).

Research on the post-surgical satisfaction levels of the patients found that, the method in which the information was delivered has an equally important role as that of the information itself (7). Conventionally, Surgeons use a verbal or leaflet-based method to communicate with the patients in their face-to-face meetings. But given the problems like complexity of medical terminology, cultural and educational gaps, it was found that these methods were not effective. When multimedia graphics were used for patient instructions, they gave better results (8, 9). However, in most of the existing resources information is in the form of static text with images stressing a need for better representation. These arguments were further supported when Azem et al., 2014 (10) have used 2D animations on a tablet device to deliver instructions regarding Le Fort I osteotomy. On evaluation of non-patient volunteers, this study showed that the participants who were given 2D graphical illustrations could understand and retain the instructions better than those who were only given verbal instructions.

The application of animations in the explanation of medical procedures makes complex concepts easy to understand for the non-medical community. Though various companies (11, 12) have done a significant work in medical animation, they did not include 3D visualizations for patient education of surgical procedures. The recent rise in production and development of Internet using smart phones and mobile tablets has revolutionized their impact on patient behavior and decision-making. Health care apps are special category in mobile apps, which provide information regarding the issues concerning health. IMS Healthcare report, 2013 (13) has recently stated that

there are over 43000 health apps on iTunes store and over 35,000 of them on Google Play store. Touch Surgery (14) is one of the first mobile apps that explain surgical procedures through pre rendered 3D animations. Essential Anatomy (15) is another popular mobile application, which demonstrates dental problems in a fully interactive 3D visualization format helping the patient to understand various treatment options. In case of orthognathic surgery, 3D animations by Dolphin imaging system's Aquarium (16) were commonly used. But most of the currently available visualizations oversimplify the treatment or complicate it leading to unrealistic expectations in patient's minds about the outcome of the surgery (17). Moreover, developments of apps, which misinterpret the healthcare guidelines, cause a lack of confidence on them by the physicians (18). Despite these studies clearly suggesting that patients are increasingly depending on Internet and mobile apps for healthcare decisions, a multimedia mobile app that can comprehensively explain about orthognathic surgery has not been found.

Sur-Face aims to fill this gap by explaining the surgery in a realistic and easily understandable format using 3D animations developed under the guidance of surgeons. This paper aims to provide an insight on development and impact of mobile apps in patient education by presenting the design and evaluation study. Further, it includes a note on role of gaming elements in mobile apps like *Sur-face*.

2 The Design of *Sur-Face*

2.1 3D Modeling

The entire application was built leveraging on realistic 3D modeling and interactive elements. Among the various available software packages, Autodesk Maya (19) was used as it allows creation of high quality animations and exports them to gaming platforms.

The content of Sur-face was strategically divided into pre surgical preparation, surgery and post-surgical complications for easy navigation and understanding of the entire procedure. Pre surgical preparation scenes explain the instructions to be followed by the patient before undergoing the surgery. 3D models of doctor, patient and a patient wearing hospital gown as shown in the Fig.1 and Fig. 2 were created from Zygote human body (20).

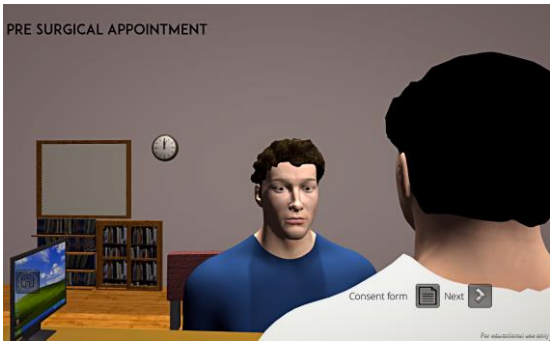

Fig. 1. Pre-operative appointment

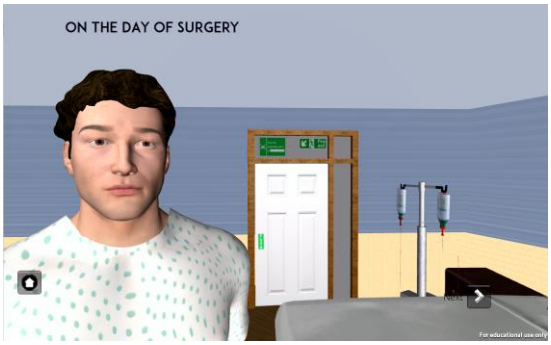

Fig. 2. Patient in hospital gown

In the design of surgical procedures, five surgeries namely, the upper jaw surgery, lower jaw surgery, double jaw surgery, chin surgery and bone graft from hip were represented. This section contains interactive 3D animations that demonstrate bone cuts, movements and final rigid fixation. Patients can also visualize the pre and postsurgical variations for each procedure with the help of a slider interactively as shown in the Fig.3.

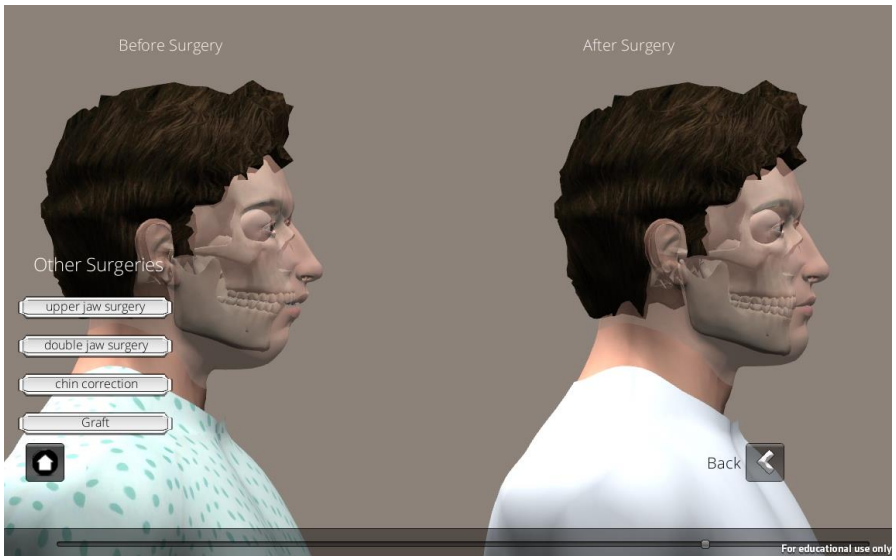

Fig. 3. Slider to show changes in face before and after surgery

Postsurgical complaints like numbness, pain and swelling as shown in fig. 5 were illustrated in a way that the patient is not scared of the procedure, but still gets the

knowledge of complications that are involved. To further explain the surgery, verbal instructions without scientific jargon were recorded using Avid Pro tools (21) and Apple Garage Band.

Fig. 5. Swelling after the surgery

2.2 Addition of Interactive elements

There are various methods to add interactive user elements to 3D model. In the design of Sur-face, Unity 3D game engine was used as it can build mobile apps. It also allows creation of custom animations or import them from third party modeling applications like Maya or 3D Studio Max. In Unity 3D game engine, animation is a game component which can be of Legacy or Mechanim type. These animations can be played automatically or controlled based on a script. Most of the animations in *Sur-Face* are of Legacy type and are script controlled.

When an animation is imported into Unity3D from third party applications, care must be taken regarding the scale of the model and other import settings. Longer duration animations were divided into multiple smaller animations using the play back functionality and selecting the required key frames. After naming each animation, a c# script was used to activate each one of them at a separate instance. Addition of user interface with navigation buttons was done once all the animations were edited. The app was then built for mobile devices and distributed.

3 Development, distribution and evaluation of *Sur-Face*

3.1 Development of *Sur-Face*

Before the final Unity project is exported to a mobile platform, software development kit of Android was installed and target device is allocated. The Android developer portal (22) provides more guidance into how to install software development kit. Building the project for mobile devices on Unity 3D needs special attention towards textures, movie playback functionality and scripts (23). Unity 3D compresses all the textures into RGB (A) format automatically when exported to Android or iOS platforms. Also, the size of the texture files will be compressed to reduce the total file size. When movies are imported into Unity, it is possible for the system to apply movie files as textures to the selected game objects. However, this functionality is only limited to the Desktops. Because Sur-Face was built for Android and iOS devices, instead of movie playback, all the animations were either created in Maya or Unity 3D. Prior to the distribution of the app, it was built specifically for tablet devices as the resolution and details were well represented.

3.2 Distribution of *Sur-Face*

Google Play store and iTunes Store distributes the apps developed for Android and iOS platforms respectively (24). A developer account was created before exporting Sur-Face app into the app store. Once the upload was done, the cost was set to free and in 24 hours, it was made available for download. The app was downloaded 167 times till date with most number of downloads from Brazil followed by Russia and United Kingdom. Figure 6 shows the statistics of total installs by users in a month wise manner as represented in Android developer portal.

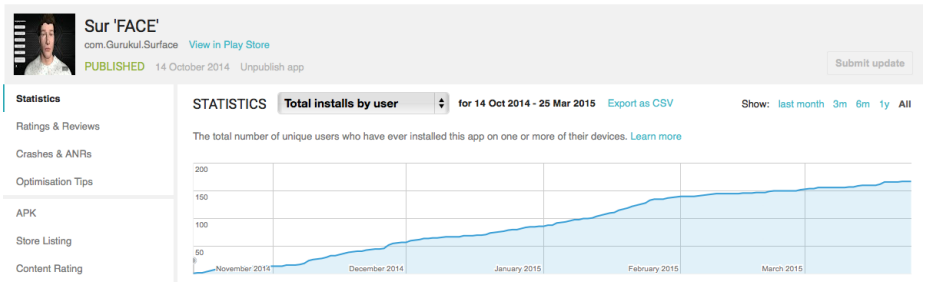

Fig. 6. Statistics showing total user installs of *Sur-Face* in a month wise manner. Source: Android developer portal (22)

3.3 Evaluation of *Sur-Face*

50 non-patient volunteers were recruited after giving brief overview about the purpose of this research and its scope, focusing on the need for prospective patients to properly understand the information before signing the consent form. Participants were randomly divided into two groups, namely "App" group and "voice" group based on the method used for delivering the instructions. Members of the app group were provided with *Sur-face* on a 10.1-inch Motorola zoom tablet, whereas voice group participants were provided with audio instructions on the same device along with a printed leaflet containing the same content. Instructions were given on navigating the app where and when required. After allowing the participants to use all the modules in the application and listen to all the instructions, they were given a questionnaire to complete. 13 questions were structured, 12 of which focus on the surgical process, side effects and post-operative complications of the surgery, as they are the most important aspect of consent process. One question on the signs of infection was asked to know the extent of knowledge about infection in general. Once the questionnaire was answered, results were analyzed using independent student t test on SPSS (25) to compare the statistical difference between the two groups. Null hypothesis states that, there would be no difference between the participants of app and voice groups. The total number of questions answered and the number of correct answers given by each group was analyzed to represent the understanding and retaining capacity of the participants. The results showed that the participants of the 'app' group have answered significantly ($p=0.0366$) more of number of questions than those in the 'voice' group. Out of 12 questions, the app group has answered an average of 11.12 questions whereas the voice group could answer an average of 9.56. Similarly, participants of the app group have given significantly higher ($p=0.0034$) number of correct answers than the voice group. Out of 12 questions, the app group has answered an average of 9.72 questions correct, where as the voice group has answered 7.64 of them. Hence, null hypothesis can be rejected and we can that interactive 3D visualizations are better than verbal instructions in improving patient understanding of complex surgical instructions. Also the 3D graphical visualizations support patients in remembering the details regarding the procedures.

4 Conclusion and Future work

Innovations in technology when applied to healthcare provide a scope for development of novel interaction methods between patients and clinicians. Sur-Face was successful in providing the essential knowledge regarding orthognathic surgery in an interactive manner. 3D visualizations developed under the guidance of the surgeons were accurate in their representation. Additionally, easily understandable voice over instructions helped this app to comprehensively demonstrate the surgical process. Evaluation of the app clearly indicated the advantages of 3D visualizations over 2D

graphics and verbal methods. All these findings further strengthen the need for redesigning the consent process. Inclusion of instructions through well-developed mobile apps helps patients to take responsible decisions on their health.

The main aim of the *Sur-Face* app is to provide knowledge regarding the basic surgical procedures and potential postoperative complications to help the patients give a well-understood informed consent. Based on the findings during the process of development, evaluation and user feedback, potential future developments to the current version of the app were charted for it to perform better.

Serious game elements:

Application of gaming elements can provide patients with motivation, control and game based learning. During pre-operative preparation, various steps to be taken by the patient can be represented in the form of buttons.

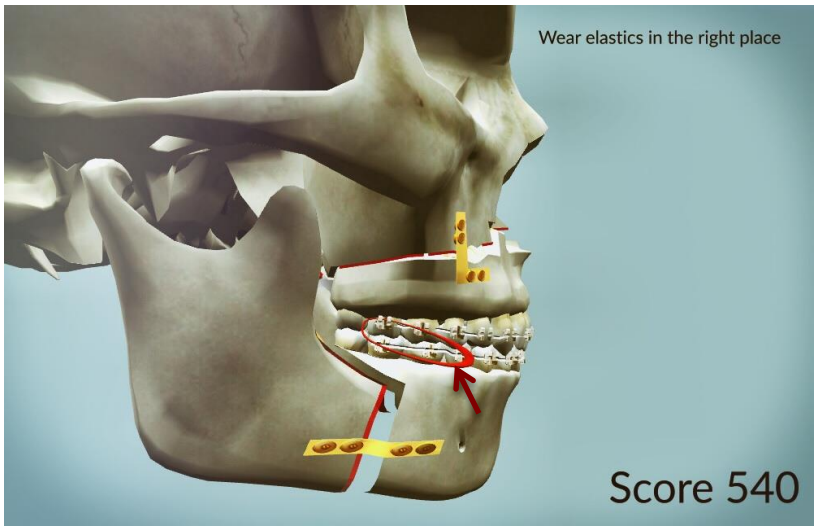

Fig. 8. Gaming elements to help patients wear elastics

A right answer increases the score and denotes that the patient is well prepared for the surgery. Inclusion of features like these may reduce pre-operative anxiety in patients. Animations showing the surgical procedure can be made interactive by swipe functionality on touch devices. Similar to gaming, swiping at the right spot moves the bones in right direction. Features like these would help patients to get a deeper insight of the surgery they are about to undergo. As the questionnaire in evaluation of the study has proved that patient education through 3D graphics is significant, a real time quiz to assess patients' knowledge can be very useful. If a patient doesn't answer a question correctly, either because of lack of understanding or their inability to remember, feedback can be provided using audio or verbal aids along with scores. This will indicate their knowledge about the procedure and also reinforces the need for

proper expectations about the outcome of the surgery. Image based questions allowing drag and drop features can be added regarding the side effects and complications of surgery. Because the patients will answer these questions interactively, they can remember the post-surgical complications for long. After the surgery, patients are advised to wear elastics in between the teeth to prevent movement of the bones. Post-operative instructions on how to wear elastics can be added using interactive drag feature as shown in the figure 8. Addition of this feature may help patients to learn complex instructions in a simple and engaging manner.

Further developments:

Animations describing the nature of dentofacial deformity and postoperative instructions help the patient understand what needs to be done after the surgical process. This is very important as proper maintenance after surgery helps in a good recovery.

Leveraging on advances in mobile technology like camera, accelerometer and gyroscope can further enhance its usability. Currently apps like Colorimetrix (26) and Instant Heart Rate (27) use the phone's camera to perform various functions. In a similar way, if a camera on a mobile device could track the skeletal landmarks, it can be used to predict the outcome of the surgery and thereby help patients to get a realistic expectation.

Accessibility to the Internet is one of the key advantages of smart devices. By incorporating search functionality to help user find answers to their questions regarding the surgery makes the app more user friendly.

Access to other third party apps like Calendar, Evernote and Health-kit (28) helps the user to integrate the appointments of the doctor in the same app. These also play a key role to remind the patients about medications.

Evolution of mobile technology into health care has significantly changed the way people make their decisions regarding the treatment. At the pace at which the technology is advancing, there is an increasing need for creation of more apps like SurFace with interactive 3D graphics and gaming elements in them.

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