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Poster

Calvariam: Visual Educational Resources for Maxillofacial Surgery

Ariadna Cherit Hernández, Anna Shilo, Paul Péry, and Renata G. Raidou

TU Wien, Austria

Abstract

Maxillofacial surgeries are complex interventions that require detailed planning and highly specialized surgeons. We propose Calvariam*, an AR application, to provide future generations of surgeons with a better training experience, via 3D models and detailed videos that showcase detailed structures and spatial relationships. We curated and processed a patient's CT data using MeVisLab. To determine the optimal placement of implants after trauma, we performed bone density calculations and biomechanical analysis of the forces of mastication at the mandibular joint. Anatomically correct 3D models were implemented into an educational animated movie using Maya, Blender, and Adobe After Effects. Finally, we integrated the processed data, models, and animated clip into an AR application using Unity. Initial discussions with domain experts indicate that* Calvariam *is a first step towards obtaining visual and interactive feedback for maxillofacial surgery education.*

1. Introduction

Maxillofacial surgery is an intellectually and physically demanding field, which entails actions to treat illnesses, injuries, and deformities in jaw bones, surrounding tissues and the mouth. Such conditions are primarily caused by trauma, disease, and congenital malformations [PEH*98]. Maxillofacial interventions require fast planning at a high level of detail and the process embodies the following steps: first, a drilling risk assessment is conducted to avoid damage on adjacent structures; then, sheer stress analysis on the mandibular joint determines if the prosthetic implants withstand the forces of mastication; finally, the optimal placement of biocompatible osteosynthesis implants, enduring mechanical stress and promoting ossification, is determined.

Recently, trauma management in maxillofacial surgery has evolved drastically due to advancements in medical imaging, as well as materials used for reconstructions. Although there are educational portals and applications for dentistry, there are currently no anatomical education visualization tools and simulations related to maxillofacial surgical interventions. We propose *Calvariam*, an augmented reality (AR) approach that offers specialized and self-contained visual educational tools for future maxillofacial surgeons with interactive and informative visualization approaches (Figure 1). *Calvariam* comprises three main components:

- Curate and process the data from a real patient's Computed Tomography (CT) scans;
- Create and segment anatomically correct 3D models from the reconstructed data to create an educational animated movie about maxillofacial surgery;
- Combine the generated 3D models and educational animated movie into an interactive mobile AR application.

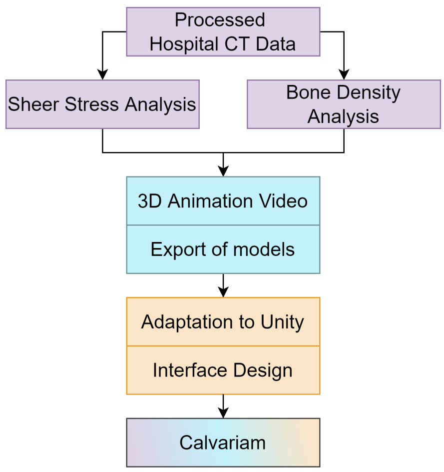

Figure 1: *Preprocessing steps for* Calvariam*. The color coding (, ,) indicates three main components to create the final product.*

Calvariam is ongoing work and the first step towards AR-based personalized patient treatment scenarios, where anatomical information can be rendered over anatomical landmarks of a patient in the future. It currently allows us to generate educational videos that can be employed as part of medical education and patient–doctor communication.

2. Methods Used in *Calvariam*

Raw Data Processing. Clinical cranial CT data sets were curated and improved for contrast. Bone density calculations were performed in MeVisLab and the sheer mechanical stress properties at the mandibular joint (Von Misses) were derived with Simscale, a

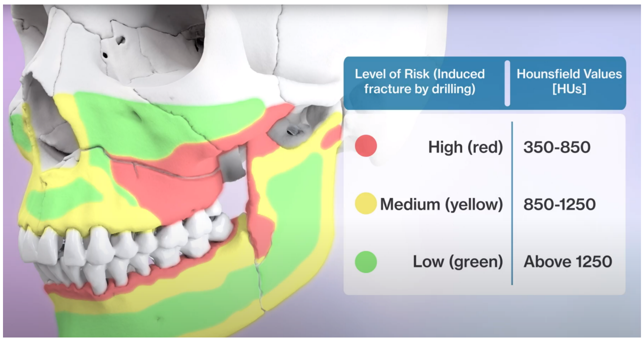

Figure 2: *The* Calvariam *interface, showing the bone density analysis and the optimal positioning of the osteosynthesis prosthesis.*

finite element analysis software, which allows color-coding different values and mapping the bone density on the skull. According to the Mish classification, high density (D1) corresponds to values greater than 1250 Hounsfield Units (HU) and is encoded as green, medium (D2) corresponds to 850–1250 HU and yellow encoding, and low density (D3) corresponds to 350–850 HU and red encoding [CJJ*13]. The bode density encoding is shown in Figure 2.

3D Models and Animated Video Production. A reference 3D free stock model was used in addition to the clinical CT data sets to model a more accurate skull, to test the animation environment in Blender and Maya. Advanced surface/volume rendering techniques and illustrative medical visualization workflows were implemented to render anatomically correct structures. The model was optimized for animation by material meshes, tools for mapping textures, and by tweaking their colors on the skull. Also, shading/luminance dependencies with respect of the depth of the object were considered to obtain a clean—yet realistic—finish for the final version of the model. Addressing the fractures with the accurate placement of implants was a product of simulating tension and compression forces with the physics engine based on the Von Misses Stress Analysis. The mandible's superior portion is the tension zone, and the inferior part is the compression zone [YPSJ*95]. In addition, we are mapping the drilling risk areas based on the HU values obtained from the bone density analysis, as discussed above.

Video editing and motion graphics were done using Adobe After Effects: a digital post production tool that allowed us to create kinetic frames, explanatory texts and audio. The rendered and optimized 3D models underwent further corrections for color and illumination based on a selected palette scheme for the video aesthetic. Four final 3D models were produced for the AR application: an intact skull, a fractured skull, a skull with risk analysis color mapping, and a skull with risk analysis color mapping and optimal ostheosyntesis prosthetic collocation (Figure 2). The educational animated movie follows the sequence:

- Introduction: stating the importance of the topic and establishing a problem to be solved;
- Motion graphics: each structure that comprises the skull is highlighted and the anatomical names are indicated accordingly;
- Emphasizing structures of interest (the maxilla and the jaw) in light red.
- Highlighting the fractures in bright red;
- Explanations of bone density analysis, its origin (HUs), and purpose, in addition to the values that represent high-, medium-, or low-risk drilling areas;
- Optimal positioning of osteosynthesis prosthesis that avoids damage by drilling and allows ossification (bones healing).

Application Development. Parallel to the CT data processing and production of animated surgical guidelines, the application core of *Calvariam* was created in Unity. The improvement of the functionality was performed by writing and implementing C# scripts that perform the swiping action between Panel Gameobjects that holds the application manual and "About us" pages and the control of the video player (play, pause, and restart the video). In addition to building the application on Android, it is worth mentioning that Unity should operate using the Android Platform. In our case, the Minimum API level was 26 (Android 8.0), and the scene size is 1280 x 720 pixels portrait resolution. The final version of the *Calvariam* application contains four main functional buttons:

- Application manual and section "About us";
- AR model of a fractured skull with/without titanium implants;
- AR model of a fractured skull with color-coded risk areas with/without titanium implants;
- Video player with maxillofacial surgery animation.

To watch a video about *Calvariam* and its 3D animation video, please use the following Google Drive link.

3. Conclusion and Future Work

Calvariam provides interactive user experience with 3D models based on real CT data that showcase the most common traumatic fractures on the jaw and maxilla. Initial discussions with clinical experts indicate the potential of our solution. At the moment *Calvariam* is an educational application, which could also be used in scientific museums. However, with further automatization developments regarding the image processing procedures, it could be used for preoperative planning and/or intraoperative image-guided surgical visualization. In personalized patient treatment scenarios by rendering visuals over anatomical landmarks of a patient.

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