EPiC Series in Health Sciences
Volume 5, 2022, Pages 25–30
Proceedings of The 20th Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery

# Cloud-Based Three-Dimensional Pattern Analysis and Classification of Proximal Humeral Fractures – A Feasibility Study

D. Baumann[1], A. Gerber Popp[2], M. Degen[1], D. Brodbeck[1], F. Coigny[1], T. Suter[3] and E. Schkommodau[1]
[1] FHNW University of Applied Sciences and Arts Northwestern Switzerland, Muttenz, Switzerland
[2] Schulter Ellbogen Emmental, Rüegsauschachen, Switzerland
[3] Kantonsspital Baselland, Liestal, Switzerland
{denise.baumann, markus.degen, dominique.brodbeck, erik.schkommodau}@fhnw.ch
gerberpopp@me.com, f_coigny@hotmail.com, thomas.suter@ksbl.ch

**Abstract**

For the complex clinical issue of treatment decision for proximal humeral fractures, dedicated software based on three-dimensional (3D) computer tomography (CT) models would potentially allow for a more accurate fracture classification and help to plan the surgical strategy needed to reduce the fracture in the operating theatre. The aim of this study was to elaborate the feasibility of implementation of such software using state-of-the-art cloud technology to enable access to its functionalities in a distributed manner. Feasibility was studied by implementation of a prototype application, which was tested in a usability study with five biomedical engineers.

Implementation of a cloud-based solution was feasible using state-of-the-art technology under application of a specific software architectural approach allowing to distribute computational load between client and server. Mean System Usability Scale (SUS) Score for the developed application was determined to be 63 (StDev 20.4). These results can be interpreted as a medium low usability with high standard deviation of the measured SUS score. We conclude that more test subjects should be included in future studies and the developed application should be evaluated with a representative user group such as orthopaedic shoulder surgeons in a clinical setting.

# 1 Introduction

Proximal humeral fractures belong to the most common osteoporotic fractures and remain a challenging clinical issue, especially in the elderly patient [1], [2]. There is lack of consensus to classify proximal humeral fractures and consequently decide about the most appropriate treatment option, which can mainly be explained by the fact that decision making is traditionally based on qualitative surgeon dependent evaluation of the fracture pattern obtained from two-dimensional (2D) x-ray images, computer tomography (CT) images and three-dimensional (3D) reconstruction [3]. Dedicated software based on 3D-CT models for quantitative assessment of fragment displacement would potentially allow for a more accurate diagnosis in terms of fracture classification, help to indicate surgery and to plan the surgical strategy needed to reduce the fracture in the operating theatre.

In a clinical setting, commonly workstation computers are used to perform such computationally intense tasks, which results in restriction of access to the planning functionality in terms of location and data sharing. The aim of this study was to elaborate the feasibility of using state-of-the-art cloud technology [4] to enable access to fracture pattern analysis functionality for humeral head reconstruction in a distributed manner. Therefore, the implementation of computational resource intense software functionality for proximal humeral fracture planning towards a cloud-based solution was studied. Software architectural concepts of computational load distribution between client and server were investigated. The implemented solution was tested in a usability study with five biomedical engineers.

# 2 Materials and Methods

## 2.1 Test Data

For performance and usability tests data of a CT scan containing 978 slices (slice spacing 0.4 mm, pixel spacing 0.248 mm, bit depth 16 bit) with a resolution of 512x512 pixels of an artificial humerus bone (Synbone) was used. Total memory size of the dataset was 517MB.

## 2.2 Initial development of functionalities in a desktop-based software

All needed functionalities for proximal humerus fracture classification and surgery planning have firstly been developed as a desktop-based software using Java 8. Functionalities include segmentation and surface reconstruction of bony fragments from CT images, definition of a local anatomical coordinate system and different bony fragments and virtual fracture reduction. While using the functionality of virtual fracture reduction, the surgeon is provided with data for fracture classification, but also with a virtual overview of the surgical procedure (Figure 1).

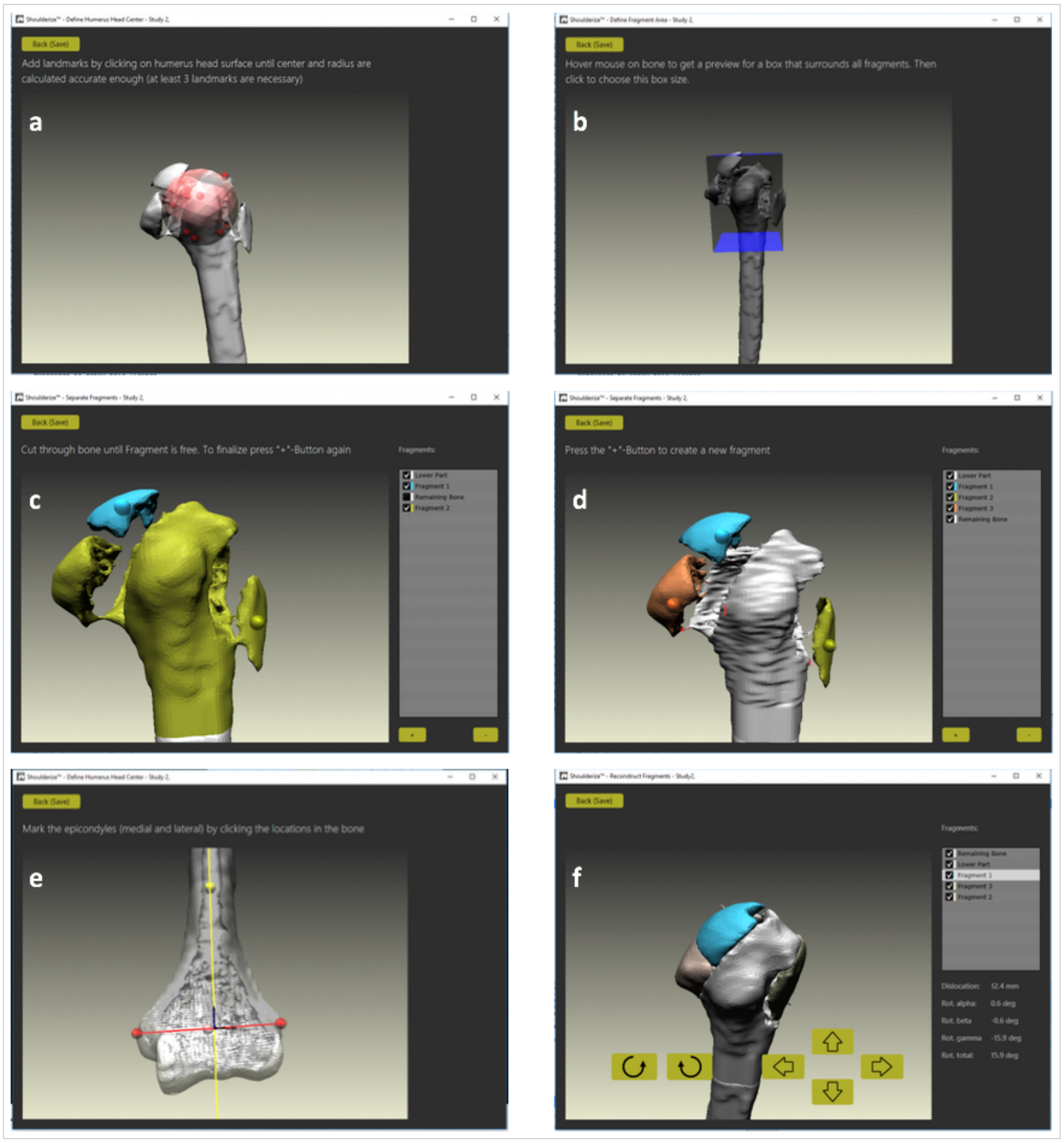

**Figure 1:** Subsequent steps towards anatomic fracture reduction of a proximal humeral fracture using the developed planning software. a. Definition of humerus head center; b. Definition of fragment area; c. Separation of fragments; d. Separated fragments and cuts (red) to separate fragments; e. Definition of humerus related coordinate system; f. Virtual fracture reduction with indication of translation and rotation applied for the selected fragment.

## 2.3 Implementation on cloud technology

For porting of previously described functionality (Section 2.2) to cloud technology, server-side data processing was implemented using Java 8 and as a client, a website was developed using TypeScript (Microsoft) and React (Facebook). Visualization of 3D objects was implemented using WebGL and Three.js (threejs.org).

Three software architectural concepts for computational load distribution were studied: (1) A thin client application with server-side computation of all operations and the streaming of rendered images to a mobile client; (2) A zero-footprint client [4]: Client-side computation of all operations including CT image segmentation and graphical representation of UI elements through a website within an internet browser; (3) A hybrid approach: Server-side computation of intense operations such as CT image segmentation, client-side rendering of graphical representation of UI through a website and a browser application.

## 2.4 Usability Study

The developed prototype application was tested in a usability study with five biomedical engineers. Test subjects were given the task to perform virtual reconstruction of a fracture including segmentation of the humerus bone and definition of the anatomical coordinate system and bone fragments using the developed website. Usability was evaluated using the SUS Score according to the System Usability Scale [5].

# 3 Results

## 3.1 Implementation of a prototype cloud-based application for a usability study

Architectural concept (1) was considered not feasible for the addressed problem due to high dependence on network bandwidth. Implementation of variant (2) revealed that processing of a relatively large amount of data necessary for fracture reduction from the test dataset was unfeasible to be executed using an internet browser, as browsers restrict the number of operations allowed to be performed by one website for safety reasons.

The hybrid approach (3) allowing to distribute computational load between client and server as desired was implemented as a prototype application to be tested in a usability study. Therefore, reconstruction of the humeral bone from the CT image test data was computed on server-side using Hounsfield unit threshold-based segmentation and Marching Cubes algorithm [6]. The obtained surface model was sent to the client for visualization and interaction within the developed website (Figure 2).

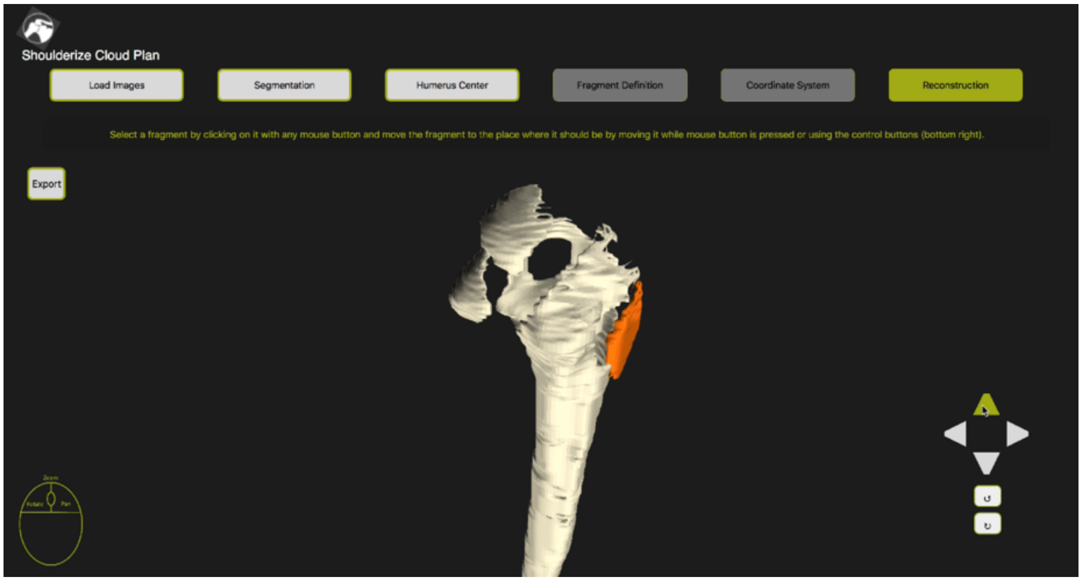


**Figure 2:** Screenshot of the implemented website: fragment reduction based on the reconstruction of the fractured proximal humerus.

## 3.2 Usability study

All test subjects completed the given task successfully. Mean SUS Score for the developed application was determined to be 63 (StDev 20.4).

# 4 Discussion and Conclusion

Implementation of computational resource intense software functionalities for classification and planning of proximal humeral fractures was feasible using state-of-the-art cloud computing technology. Out of three investigated architectural concepts the implementation of a hybrid approach of distribution of computational load between a cloud-hosted server and a client website was most favored.

The developed prototype application showed medium usability with a SUS Score [5] of 63. According to Bangor, Kortum and Miller [7] this represents a medium low usability score. Further taking into account the high standard deviation of the measured SUS scores, it can be concluded that more test subjects should be included in future studies. In particular, the developed application should be evaluated with a representative user group such as orthopaedic shoulder surgeons in a clinical setting.

# References

[1] J. E. Bell *et al.*, “Trends and variation in incidence, surgical treatment, and repeat surgery of proximal humeral fractures in the elderly,” *J. Bone Jt. Surg. - Ser. A*, vol. 93, no. 2, pp. 121–131, 2011.

[2] B. O. Sumrein, T. T. Huttunen, A. P. Launonen, H. E. Berg, L. Felländer-Tsai, and V. M. Mattila, “Proximal humeral fractures in Sweden—a registry-based study,” *Osteoporos. Int.*,

vol. 28, no. 3, pp. 901–907, 2017.

[3] H. Resch *et al.*, “Classification of proximal humeral fractures based on a pathomorphologic analysis,” *J. Shoulder Elb. Surg.*, vol. 25, no. 3, pp. 455–462, 2016.

[4] G. C. Kagadis *et al.*, “Cloud computing in medical imaging,” *Med. Phys.*, vol. 40, no. 7, pp. 1–11, 2013.

[5] J. Brooke, “A quick and dirty usability scale,” *Usability Eval. Ind.*, vol. 189, no. 194, pp. 4–7, 1996.

[6] W. E. Lorensen and H. E. Cline, “Marching Cubes: A High Resolution 3D Surface Construction Algorithm,” *Comput. Graph. (ACM).*, vol. 21, no. 4, pp. 163–169, 1987.

[7] A. Bangor, P. T. Kortum, and J. T. Miller, “An empirical evaluation of the system usability scale,” *Int. J. Hum. Comput. Interact.*, vol. 24, no. 6, pp. 574–594, 2008.