Int. J. Oral Maxillofac. Surg. 2019; 48: 1084–1087
https://doi.org/10.1016/j.ijom.2018.12.011, available online at https://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Technical Note
TMJ Disorders

Augmented reality for temporomandibular joint arthrocentesis: a cadaver study

Y.-Y. Wang[1,2], H.-P. Liu[3], F.-L. Hsiao[1], A. Kumar[2]

[1]Graduate Institute of Photonics, National Changhua University of Education, Changhua, Taiwan; [2]IRCAD-AITS, Chang Bing Show Chwan Memorial Hospital, Changhua, Taiwan; [3]Oral and Maxillofacial Surgery Department, Chang Bing Show Chwan Memorial Hospital, Changhua, Taiwan

Y.-Y. Wang, H.-P. Liu, F.-L. Hsiao, A. Kumar: Augmented reality for temporomandibular joint arthrocentesis: a cadaver study. Int. J. Oral Maxillofac. Surg. 2019; 48: 1084–1087.

Abstract. Temporomandibular joint (TMJ) arthroscopic procedures require the identification of a skin puncture point. The puncture point is conventionally estimated using the surface anatomy of the canthal-tragus line. However, the conventional puncture technique has been reported to fail at the first attempt in 18% of cases. We propose an augmented reality (AR) system-based method to identify the puncture point on the skin. A three-dimensional virtual model was reconstructed from computed tomography images of a cadaver head, and its rendered image was superimposed on the cadaver head before skin puncture. The skin puncture point was marked on the skin under the guidance of the AR system. The TMJ was punctured through the mark and the endoscope was introduced through the puncture point. The outcome of the procedure was classified as successful or unsuccessful based on the visualization of the TMJ. The system was applied on the left and right sides of three cadaver heads. Puncture with the AR method was successful in all six cases. This study presents a system to provide AR visualization during TMJ arthrocentesis to increase the precision of skin puncture. However, a comparative study of the AR method with the conventional method is required to evaluate its advantages.

Key words: temporomandibular joint; arthrocentesis; augmented reality.

Accepted for publication 24 December 2018
Available online 26 January 2019

Arthrocentesis of the temporomandibular joint (TMJ) is required for arthroscopic lysis and lavage of the TMJ, which are common methods of treatment for TMJ disorders[1]. Such procedures require the identification of a skin puncture point in line with the upper space of the TMJ. This point is conventionally estimated using the surface anatomy of the head (conventional puncture technique); however, this method is reported to fail at the first attempt in 18% of cases[2], mainly due to anatomical variations among different patients[2].

Although image-guided puncture techniques using cone beam computed tomography (CBCT) and ultrasound (USG) have been investigated[3,4], such methods have their own limitations and may not provide a better outcome than the conventional method.

We propose an augmented reality (AR) system, in which a patient-specific three-dimensional (3D) virtual model reconstructed from computed tomography (CT) images is superimposed on the patient's head before the procedure and the skin puncture point is marked on the skin with the guidance of the superimposed view. This appears to be a novel method for TMJ arthrocentesis.

0901-5027/0801084 + 04

Overview of the method

The method is summarized in Fig. 1. The AR system comprises a calibrated camera–projector system and a visualization software interface. The major steps of the method flow are as follows: (1) reconstruct a 3D virtual model using a CT scan of a cadaver head and visualize this via the software interface; (2) calculate the intrinsic and extrinsic parameters of the camera, and the geometrical transformation between the camera and projector positions; (3) update the virtual camera position to match the position of the real camera; (4) superimpose the 3D virtual model image on the cadaver head to locate the point of skin puncture under an AR view.

Virtual 3D model reconstruction

The study was conducted at IRCAD-Taiwan (the Research Institute Against Digestive Cancer in Taiwan). Three cadaver heads were donated by the Institute to be used in this study. A 3D virtual model of different parts of the cadaver head was reconstructed from CT scan images using 3D-VPM (IRCAD-France, Strasbourg, France)[5]. Models of the skin, skull, and mandibular bone of the head were used in this study.

Transformation between the camera and projector image planes

A camera (Logitech C920 HD Pro; Logitech) and a projector (Vivitek Qumi Q5; Vivitek) were fixed on a connector. Intrinsic and extrinsic parameters of the camera were calculated using the method described by Wang et al.[6] and applied to the camera of the render window in the visualization software. To align the image captured by the camera and that projected by the projector, the following steps were performed:

(1) A checkerboard (5 × 4) image file was displayed in an image plane in the render window.
(2) The rendered image was projected onto a plane surface ('target plane') using the projector.
(3) The projected checkerboard image was captured with the camera.
(4) The corners in the checkerboard image captured by the camera and the rendered image captured by render window screenshot were detected by Harris corner detectors[7].
(5) The corresponding pairs of the corners in two images were used to calculate a homography matrix (T) between the projector and the camera using the method described by Park and Park[8].
(6) The images acquired by the camera were then transformed by T matrix and re-projected onto the target plane to check the re-projection error of the camera.
(7) Using the same homography matrix, the rendered image of the 3D virtual model of the head was projected over the target plane.

Render window camera pose and skin puncture

The 3D virtual model of the head was displayed in the render window of the visualization software and the render window was projected onto the cadaver head. The image of the render window (V_{image}) and the image of the scene captured from the camera (R_{image}) were displayed on an interactive window. The corresponding landmarks on the V_{image} and R_{image} were selected manually. The landmarks on the V_{image} provided the 3D coordinates of the points, while the R_{image} provided two-dimensional pixel coordinates. This information was used to calculate the camera pose in the render window using the EP*n*P algorithm[9], and the camera pose in the render window was updated.

The render window containing the virtual model of the head was projected onto the cadaver head, and the skin model was made translucent so that the TMJ space in the skull model was visible through the skin model. Keeping the view of the TMJ space, the skin of the cadaver head was marked for the puncture point ($Point_{AR}$). The surgeon used the superimposed view as a guide and performed the puncture of the skin to reach the target, which is defined by surgeons as the top of the upper joint space of the TMJ. The needle was inserted perpendicular to the skin towards the target point to a depth of about 20–25 mm from the skin surface.

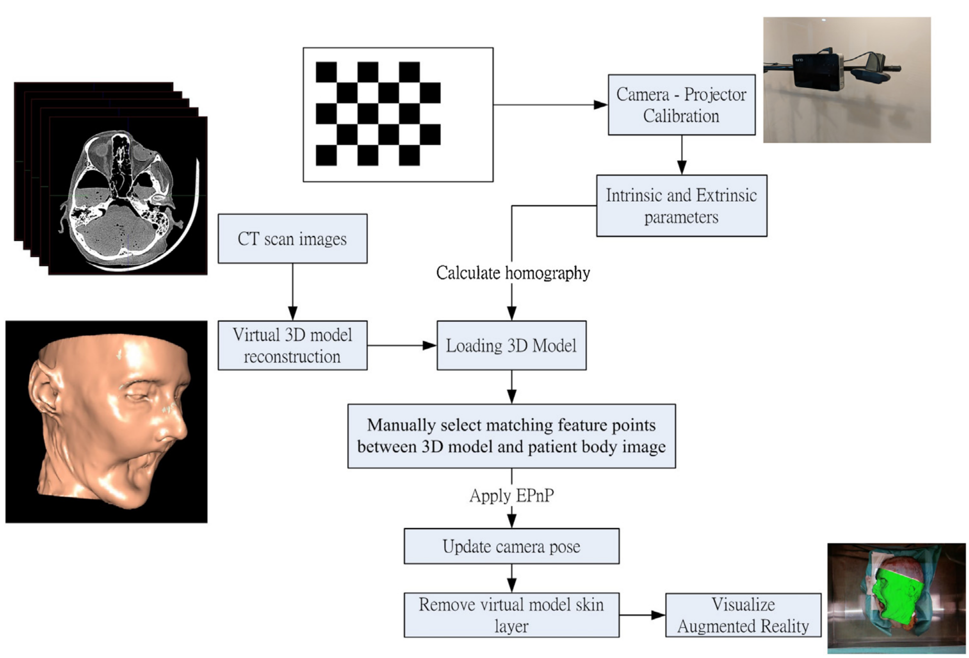

Fig. 1. Overview of the method.

Evaluation

A procedure was considered successful if the endoscope could be entered into the puncture site and the upper joint could be visualized directly, or after changing the direction of the needle after the puncture; otherwise the procedure was considered unsuccessful.

After the needles had been introduced, the cadaver head CT scan images were acquired and segmented again to reconstruct a 3D virtual model of the head with the inserted needle (Fig. 2). The 3D model was visualized in a render window and the skin model was made translucent so that the TMJ space was visible. Using that view, an ideal point for puncture ($Point_{Ideal}$) was defined by the surgeon on the skin model. The proximity of the skin puncture point made with the AR method ($Point_{AR}$) to the ideal point ($Point_{Ideal}$) was measured.

Application

The software for AR uses C++ and its libraries (Qt 4.8.2, OpenCV 2.4.9, and VTK 5.10.1) for computer vision in a Windows 10 computer with Core i74702, 8 Gb RAM, and GPU GTX870m.

After setting up the system, the surgical procedure was done by a maxillofacial surgeon. The system was applied on the left and right sides of three cadaver heads. With the AR method, the puncture was successful in all six cases. The average distance of the puncture point made with AR ($Point_{AR}$) from $Point_{Ideal}$ was 3.49 ± 0.62 mm.

Discussion

In this study, an AR system for TMJ surgeries was developed with the aim of increasing the precision of the TMJ access. The system was tested on cadaver heads. This method is novel in applying AR for endoscopic procedures in the TMJ.

The goal of an AR system is to provide additional information to an image of a scene captured by camera. AR used for surgery can provide information behind the surface that is not usually available without AR. The AR method described here allowed the puncture point to be marked on the surface of the skin while the skull model was visible through the semi-transparent skin model. A similar technique for locating the internal structures and then placing marks for incisions on the skin has been found useful for several other surgeries.

Studies supporting the use of AR in surgeries, including maxillofacial surgeries, have been reported[10]. Such studies have suggested that the AR view is useful in placing the endoscope (arthroscope), as well as reducing the time in placing the scope. The results of the present study corroborate the findings of other studies. Moreover, in arthroscopic joint surgery, the endoscope needs to be entered into a narrow canal (a few millimetres in diameter) of the bone before entry into the joint space, and the conventional method of using the surface anatomy as a guide may fail because of the variations in the anatomy in the general population.

The skin puncture point marked on the skin surface of the cadaver head using AR did not completely match the ideal point. This may be because of the inherent error in the segmentation, registrations, and calibrations used in AR, as well as the flexibility of the skin, which may lead to displacement of the puncture mark while the needle is inserted. However, the outcome of the puncture was unaffected by this disparity.

The method whereby external markers are used to determine the angle and distance for the point of puncture provides better accuracy than the conventional method[3]; however this is a cumbersome procedure to implement before surgery. Moreover, USG-guided arthrocentesis was found not to be more successful than the conventional method[4]. The method presented in this study does not require the use of any external markers but instead uses a preoperative 3D CT model. Since the anatomy of the bone would not change before the surgery as compared to the preoperative 3D CT model, this method does not need any real-time imaging system such as USG.

The AR system has some limitations, including (1) a preoperative calibration of the camera–projector system is necessary; however this only requires the acquisition of a few images; (2) the accuracy of the AR is dependent on the accuracy of each step in the calibration, segmentation, and registration; (3) the system requires an expensive imaging modality (CT scan); however, a scan is typically done in a patient planned for TMJ arthrocentesis.

In conclusion, this study developed a software system to provide AR visualization during TMJ arthrocentesis to increase the precision of the puncture. The AR system helped in successful visualization of the TMJ; however, the accuracy depends on several factors, such as good image segmentation, registration, and calibration. The system needs to be evaluated on patients to investigate its advantages over the conventional method.

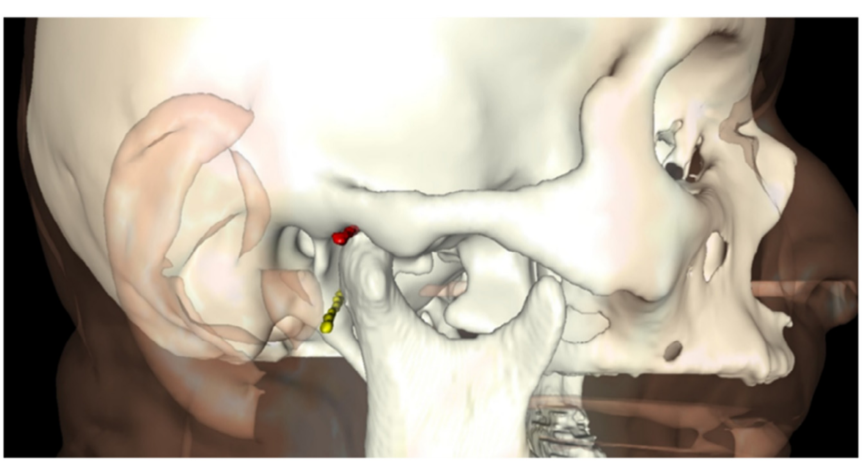

Fig. 2. Red: Needle placed with the augmented reality method. Yellow: Needle placed without the augmented reality method. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Funding

Ministry of Science and Technology, Taiwan (grant number 106-2221-E-758-001); Chang Bing Show Chwan Memorial Hospital, Taiwan (grant number RD 106075).

Competing interests

None.

Ethical approval

Not required.

Patient consent

Not required.

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Address:
Atul Kumar
IRCAD-AITS
Chang Bing Show Chwan Memorial Hospital
Changhua
Taiwan
E-mail: sharmaatul11@gmail.com