Haptic interface for computer-assisted patient specific preoperative planning in orthopedic fractures surgery

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Abstract: This study presents a haptic-based patient specific preoperative planning tool for orthopedic surgeries designed to restore pelvic bone fractures. The tool allows planning of both of mains steps of an orthopedic surgery: reduction and fixation. The planning is carry out by a surgeon interacting with computer tomography (CT) scan based models of bone fractures. Such planning is important for: understanding of the surgery order: surgeon hand motions that should be done in order to restore the fracture; to determine the optimal shape, size, location and quantity of the fixation hardware.

1. Introduction
Trauma surgeries in the pelvic area are often difficult and prolonged processes that require comprehensive preoperative planning [1]. This study describes a new haptic-based system for patient-specific preoperative planning and training of pelvic fracture surgery [2, 3]. In a virtual environment, the manipulation of objects is more difficult for the user in the absence of depth perception and tactile sensation.

2. Goal
Our goal is to develop a haptic interface and an intuitive haptic spatial interface for the manipulation of bone fracture 3D models “Fig. 1.a.” extracted from CT images, fracture surface annotation, selection and placement of orthopedic screws, and creation of fixation plates with an anatomically fit shape.

3. Method
To plan the orthopedic procedure, the surgeon is required to carry out the following steps. The first stage consists of exploring the fracture in detail from different points of view, thereby identifying its complexity. The next step involves bone fracture reduction “Fig. 1.b.” designed to align the fracture from an anatomical and functional point of view, interactively or semi-automatically. The interactive process allows the surgeon to understand the order and the motions by which he restores the fracture, and to recognize the difficulties he will be faced with during the operation. The semi-automatic procedure facilitates an accurate anatomic reduction with minimal effort and in a shorter period of time. The surgeon is then ready to plan the fracture fixation by using orthopedic screws and plates. This enables him to determine the exact length and diameter of screws and create an anatomically fit shaped plate models “Fig. 1.c.”. The screws fixate separate fragments, thereby enabling them to become a single object. As a result the procedure becomes more realistic for the user and allows a local correction of a single reduction instead of repeating the whole process. Finally, the surgeon exports the restored and fixated model of the fracture to be utilized by the orthopedic navigation system during the operation.

4. Results
The method allows a high accuracy reduction planning procedure less than 1 mm. To evaluate the alignment in terms of quantity we have created a model of an artificial fracture in a healthy pelvis bone. Once we have created the model fracture it is placed in its anatomic location thus allowing us to measure the error in relation to its initial position. We calculate the anatomic alignment error by measuring the Hausdorff distance in mm between the fragment positioned in the desired location and the fragment placed by the surgeon. The surgeon begins the planning process “Fig. 1.d.” as the artificial fracture is in displacement in relation to its original position. The orthopedist aims to align the fragment to its initial location.

5. Conclusion
The study introduces a number of contributions in terms of interactive reduction, semi-automatic reduction and fixation planning. The tool incorporates ligament models in the planning process that facilitates the interactive reduction operation for the surgeon while turning it into a more realistic procedure. The system also provides an ability to view the fracture from different angles thereby allowing the surgeon to perform a more accurate and speedy reduction. In addition, the tool has an ability to work with two hands. The system provides a better input for the semi-automatic reduction algorithm in order to achieve more accurate results, making use of the haptic-based marking of the relative bone fragment surfaces and the ability to improve an initial position of the fragments. The system also simplifies and accelerates the fixation planning process making it more comfortable for the surgeon. The option transparent view mode allows the navigation within the bone fragment during the screw insertion. The system constraints the screws to remain
within the bone fragments by using haptic forces. The derivation of plate 3D model provides the possibility to produce an anatomically accurate plate relating to a respective fracture.

References


Figure 1: (a) bone fracture 3D model; (b) bone fragments before and after interactive reduction process; (c) a fracture after fixation by screws and plate in semitransparent view mode; (d) Orthopedic surgeon during the planning process