DIGITAL PREOPERATIVE PLANNING FOR LONG-BONE FRACTURES

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Abstract. *Nowadays, fracture management is an essential part of everyday clinical decision-making prior to any fracture-related surgery. The way to carry out such preoperative planning involves tracing the bones over paper using the X-Rays, and then placing the resulting drawings together as if reconstructing the fractured bones. This action, although proven effective, is quite rudimentary and time consuming. In recent years, a significant effort has been dedicated to the building of computer systems for aiding the preoperative planning of fracture-related surgeries. This paper describes a new CAOS (Computer Aided Orthopedic Surgery) system for fractures, which considerably reduces the time required for the surgeon to plan a surgery. While planning can often take up to 25 minutes, the described system can reduce this time to a maximum of 5 minutes. The system also includes a database of fracture types and a database of implants.*

Key words: Preoperative planning, X-Ray images, Long-bone fracture, CAOS

1 INTRODUCTION

Since Wilhelm Röentgen discovered the X-Rays in 1985 [6], medical imaging have evolved considerably into techniques such as: Fluoroscopy, Ultrasound (US), Computed Tomography (CT), Magnetic Resonance (MR), etc. All these imaging modalities are a fundamental base to medical diagnosis in modern healthcare systems. Currently, most imaging modalities produce digital images. These images can be displayed and analyzed in a medical workstation for a prompt medical diagnosis. This is the motivation for the creation of modern CAD (Computer Aided Diagnosis) systems.

CAD systems that give support to an orthopedic surgeon in preoperative surgery planning for musco-skeletal system are called CAOS. Preoperative surgery planning is an important step before an orthopedic surgery, since it defines which procedures should be followed during surgery. Additionally, it is an exact guide to determinate the final result of the surgery. Preoperative planning can be done manually, although this is often imprecise, requires many tools and it could take a considerable amount of time. When a CAOS system is used instead, the planning is very precise, it requires nothing additional to the medical workstation and it can be done in a timely manner.

Nowadays, although manually planning is still performed in some hospitals, the use of CAOS systems is rapidly spreading as more hospitals acquire digital imaging systems [7]. This paper describes the design and development of a new CAOS system for preoperative planning for bone fractures. The system allows the surgeon to plan the surgery using the X-Rays images directly, and includes a database of fracture types as defined by the AO (*Arbeitsgemeinschaft für Osteosynthesefragen* - Association for the Study of Internal Fixation) Foundation, and a database of plates, screws, pins and nails from different manufacturers. It also allows interactive plate deformation for fracture reduction. In this paper, we describe our solution to preoperative planning for long-bone fracture to produce an interactive and low-cost system.

The following section presents an overview on preoperative planning for bone fractures. Section 3 describes our proposed preoperative planning scheme for CAOS systems. Section 4 shows the results we obtained after testing the system. Section 5 describes conclusions and future work.

2 PREOPERATIVE PLANNING FOR BONE FRACTURES

Preoperative planning is an important step that all surgeons should follow prior to performing any surgical procedure. The main purpose of this planning is determining the final result of the surgery and set up the surgical technique to apply.

As explained in [5], preoperative plans for bone fractures can be done manually tracing preoperative drawings in paper, see Fig. 1A. Using the trace paper it is possible to understand the complexity of the fracture, shape of the reduction, treatment of the biomechanical principle and choosing the correct implant to use.

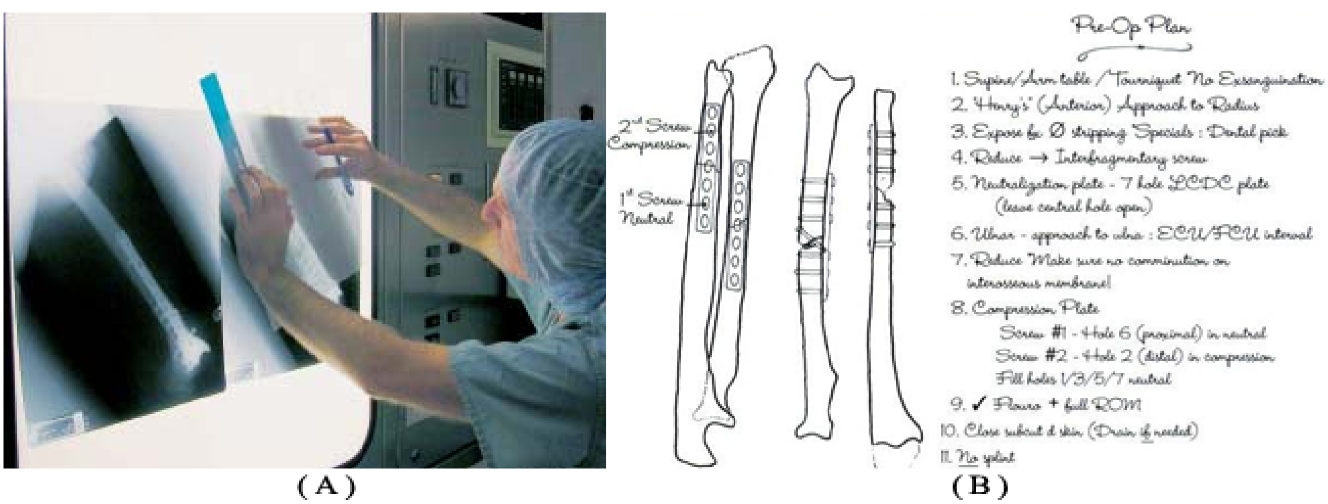

Figure 1: (A) Making a trace paper. (B) Illustration of preoperative plan detailing operative surgical steps, implants and equipment.

Preoperative planning consists on creating the trace paper of fracture segments and obtaining a surgical guide corresponding with the area that is going to be operated. For the planning to be performed, the following materials are necessary: fracture X-Ray plate, paper for tracing, implant templates, goniometer, markers and a viewbox with acceptable lighting.

To construct the plan it is important to have an X-Ray of good quality. Place the X-Ray in the viewbox for a better contrast. Next, draw the border of the bones using markers. Use a goniometer to obtain different measurements for different fractured areas. After applying this procedure it is possible to obtain different pieces of fractures. The main idea is puzzling these pieces and placing them on their correct position. Moreover, it is possible to use implants for fracture reduction. These implants can be plates, screws, pins or nails. The implants should also be measured and taken into account in the planning. Finally, over the trace paper, certain information must be written such as: patient name, surgical procedure, additional tools, post-operative care, etc. see Fig. 1B . The selection of the surgical procedure is based on many characteristics of the fracture or osteotomy such as: bone, sector, trace type, number of fragments, size of fragments and others. Before performing a surgery, a plan has to include all sorted steps necessary for the surgery.

Although this manual procedure has proven useful, it is very time consuming and error prone. In past years [1], a variety of support software systems to surgery in fracture reduction has been used. These systems are called CAOS. They are the center of attention of different research centers worldwide. With a CAOS system it is possible appending any implant over a preoperative plan just using a digital repository of implants. Computerized templates are now available that allow preoperative planning to be perform directly on digital images, eliminating the pen-and-paper method. This situation makes the process more accurate and repeatable than the manual technique. The following sections describe a new preoperative planning scheme, implemented in a new CAOS system completely developed at our research center.

3 PROPOSED PREOPERATIVE PLANNING SCHEME

In our proposed planning scheme, we shown an eight-step-process: image acquisition, calibration, segmentation and puzzling, implant placement, implant deformation, tracing paper generation and report generation, see Fig 2. In a previous work [2], we describes this scheme only from a theoretical point of view. In the following subsections, we present implementation details of a CAOS system based on this scheme.

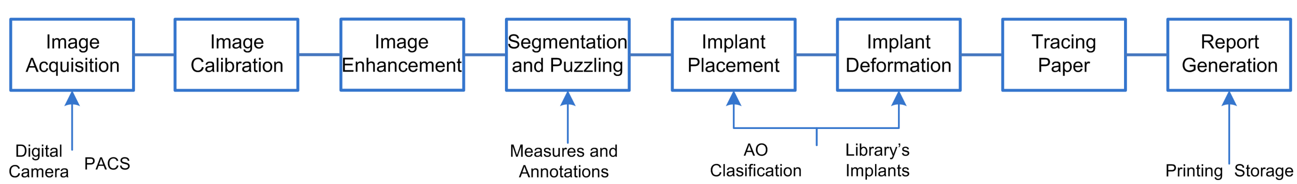

Figure 2: Proposed Preoperative Planning Scheme.

3.1 Image Acquisition

In this stage, images are captured using a digital camera or loaded from DICOM (Digital Imaging and Communication in Medicine) files. With the first approach, doctors can place the X-Ray over a viewbox and take a picture to obtain a digital image. In this way, we can use a conventional X-Ray plate. Note that image acquisition is essential in the planning process and therefore the pictures taken should be taken under optimal conditions (lighting, distance to shoot, etc.). With the second approach the images can be loaded from CR (Computer Radiography) or RG (Radiographic Imaging) DICOM files.

3.2 Image Calibration

Frequently, surgeons need to take measurements for many reasons, such as calculating the dimension of the implants for the patient, calculating the width/height of a bone segment, etc. Generally, these measurements are given in millimeters. Our system provides tools to perform different kinds of measures (length, angle, etc.) along with tools for comments and annotations. However, images taken with digital cameras might have been taken from different distances, providing different pixel resolutions. Assuming a fixed pixel resolution for all images leads to huge mistakes in the measurements. This problem should be fixed using a calibration procedure.

Our calibration process starts opening holes in the X-Ray plates with a two-hole paper punch, see Fig. 3A . The holes are detected automatically using morphological operations. This requires a multipass algorithm using a Structuring Element (SE) to search for both circles. The size of the SE is dynamic and dependent on the region where the circles are placed. Since the distance between the holes in the punch is known, once the holes are detected in the image it is possible to calculate the pixel resolution and calibrate the images.

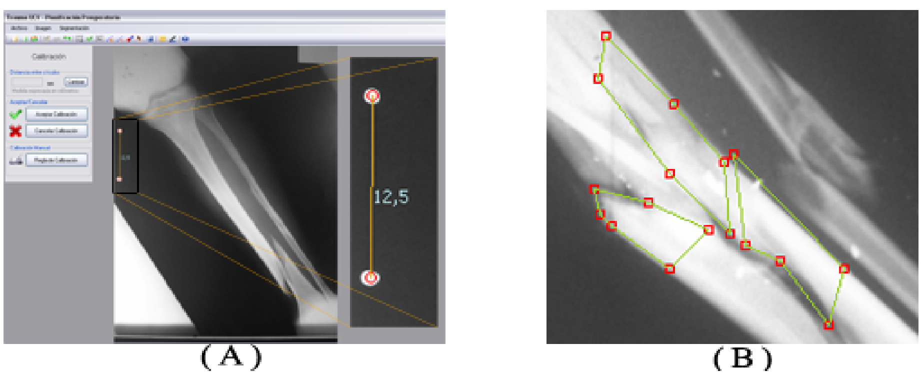

Figure 3: (A) Holes opened with paper punch allows image calibration. In this image there is a distance of 12.5 mm. between holes. (B) Segments with their control polygons over a long-bone fracture.

3.3 Image Enhancement

This stage is required so as to obtain a better contrast on the images. A manual window/level adjustment is performed at a workstation, and the user is responsible for the quality and enhancement of the displayed image. This stage is commonly used for medical images enhancement.

3.4 Fracture Segmentation and Puzzling

This is a very important step in our scheme. In this stage, surgeons can use the mouse to place the fragments produced during fracture reduction in their anatomically correct places (puzzling). The segmentation sub-stage can be manual or semi-automatic. In manual mode, a surgeon marks a series of points around fracture fragments of interest. These points define a control polygon. A fracture may have several of them. In semi-automatic mode, a Canny border detection algorithm is used [4]. This algorithm finds a possible border of the fragment. The user is allowed to modify the border if necessary. Fig. 3B shows an example of this process.

In the puzzling sub-stage, each fracture segment is selected and placed in their correct anatomical position over the bone. Segments can be rotated and translated but not scaled. Although it might happen that not all segments fit perfectly in their correct position, a very close approximation is enough for planning.

3.5 Implant Placement

When the puzzling process is completed, the surgeon could decide to place an implant on the patient. Our system provides a library of implants that contains plates, screws, pins and nails from different manufacturers. Our system also includes a complete library of AO fracture classifications [8]. In our system, a MySql™ database is used to store implant information such as type, size, category, etc. Each implant is represented using a STL (stereolithography) format file generated by Autodesk Inventor ™, which stores the 3D triangulated surface of the implant.

3.6 Implant Deformation

Once the implant is placed, the surgeon might need to bend it to make it fit in the correct anatomical position. The bending process is defined as a deformation applied to a metal part by pressure along a curved path. Implants generally are made of metal or any alloy of it. This deformation is made by the surgeon in the operation room using a specialized groove plier over an implant. Our system allows the digital deformation of the implant prior to the operation, using a variation for X-Ray images of the algorithm proposed in [3].

3.7 Tracing Paper and Report Generation

Once the previous stages are completed, the results are saved in a digital tracing paper, similar to the one in Fig. 1B. This is the tracing paper the surgeon will use as a guide for the surgery. It contains annotations, measurements, fragments of bones, implants and the input X-Ray.

In the Report Generation stage, the user can print a document reviewing the planning process. Information such as number of implants used, surgical technique, etc. are placed in this report. This document is intended to be printed like a report or for storage in a database of clinical cases.

4 RESULTS

The time it takes for surgeons to create a preoperative planning manually varies from 8 to 25 minutes approximately. We installed our system in a standard PC without specialized hardware at the Radiology Department of the HUC (University Hospital of Caracas) in Venezuela, and instructed two experts on how to use the system. Once the experts became familiar with the system, the planning time varied from 2 to 5 minutes. This is a considerable reduction of the planning time. In addition, the experts learned how to use the system in a short time with minimal training.

5 CONCLUSIONS AND FUTURE WORK

We have presented a scheme for preoperative planning for fractures that uses image-based techniques over a conventional PC. We proposed several stages with the purpose of creating a scalable, detailed and maintainable workflow. Each stage can be extended with new sub-stages and functionality without affecting the rest. The library of implants reduces the time for the surgeon to choose the correct implant for a fracture. In addition, the possibility of digitally bending an implant using a 3D geometry allows a better proximation to the actual surgery. Since no special hardware is required, it is possible to use the system even in rural medical facilities.

Several improvements are possible. First, a better border detection algorithm can be used. We are planning to try algorithms based on active contours or deformable models. Second, for the calibration process we used a paper punch because it is a common supply in any medical healthcare center, but this might not be the case, and therefore we are planning to provide other calibration options. Finally, we are planning to exploit current technology to speed up the annotation process, e.g. speaker annotations, medical tablet PCs, etc.

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