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Simulation of Internal Fixation Surgery for Calcaneal Collapse with 3D full-sized Computer-Aided Technology

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ABSTRACT

A computer-assisted preoperative simulating system for calcaneal collapse's internal fixation surgery by integrating different CAD software's function has been developed in this paper. This system uses the full-scaled 3D reverse engineering technique in designing and developing preoperative simulation modules for the calcaneal internal fixation surgery. The simulating system presents a real-sized 3D image of the calcaneus, and provides detailed interior measurements of the calcaneus from various cutting planes. This study applied computer-assisted technology to integrate different software's function to a surgical simulation system, which includes a 3-D image model capturing, cutting, moving, rotating and measurement for relevant foot anatomy. Surgeons can utilize it as part of preoperative simulation to develop efficient operative procedures. This system also has an extendable databank which provides the clinical cases to different users for experience learning.

Keywords: computer-aided surgery, RE, calcaneal internal fixation surgery.
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1 INTRODUCTION

Traditional calcaneal fracture surgery with internal fixation operation generally involves lifting a bone graft from wounded parts or using an allograft to fill the affected area. Although this method does not involve risks of strength or biocompatibility, calculation of the sectional region of the bone graft and bone placement position must be precisely measured and calculated. Preoperative planning time of most surgeons is usually consumed on x-rays or computed tomography (CT) scans, which are planar images that can only be transformed into three dimensional (3D) models by estimation. However, this method has been resulted in surgical quality and precision being affected by personal factors, and therefore, consistency of quality of outcomes cannot by assured for each operation.

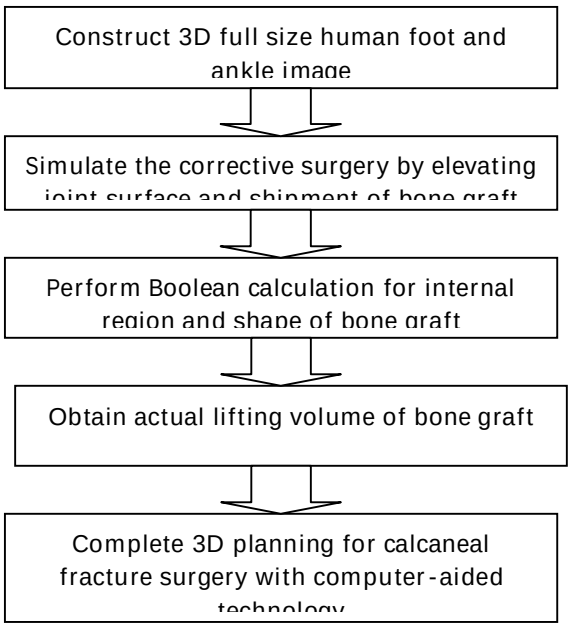
Computer Assisted Surgery (CAS) of the reverse engineering has been successful applied in clinical usage [1-9]. Current researches in performing 3D computerized-aided simulation of preoperative planning systems have shown significantly shortened operation time and improved surgical outcome by minimizing the possible pitfall during surgery [1-4]. The use of CAS techniques for surgical preparation is becoming a common practice, although it is still not the norm. We believe that these techniques enhance precision and, as a result, decrease wound complications, increase osseous healing potential, and minimize many soft tissue problems that can occur with imprecise operative manipulations. For these reasons, we applied CAS techniques for the internal fixation operation for calcaneal collapse. By using this method of surgical planning for internal fixation operations, highly accurate data pertaining to manipulation of Böhler's angle, internal fixation location and orientation, graft size and configuration, and screw placement, and so forth, can be ascertained in the preoperative environment, and subsequent surgery could be performed without complications.

CAS offers the 3D images that can be rotated freely and viewed from various angles, and it is functional in integrating the preoperative planning and clinical engineering application. In other word, it must address the functional aspects of the surgical planning system and should be based on an understanding of the requirement of the clinical surgeons. The resulting surgical simulation system would be applicable to all stage of the planning process and would proffer several benefits. Consequently, this simulation system not only reconstructs computerized 3D images of the calcaneus, but also provides surgeons with cross-sectional views, measuring angles and volumes, surgical route, as well as utilizes the reverse engineering technique and facilities (Tab. 1) in creating the preoperative 3D real-sized simulation of the actual surgery. The process shown in Tab. 2 allows the surgical strategy to be simulated and practiced as many times as required.

The treatment of calcaneal joint-depression fractures has to be tailored not only for individual fracture pattern damage but also for functional demand, comorbidity, and patient compliance [10]. By using this planning process to perform surgery for calcaneal joint-depression fractures, highly accurate data, such as Böhler's angle, location of cortical screws, and volume of bone graft etc., can be obtained as part of preoperative planning; hence, instances of surgical mishaps during actual surgery could be minimized.

Facilities	*Application*
Mimics® (3D image constructor)	Constructs 3D CT image
Geomagic Studio® (3D image editor)	Edits foot and ankle 3D image Identifies wounded area
Magics® (3D solid model system)	Calculates Böhler's angle Evaluates bone-graft size of calcaneal fracture surgery
Autoplay Media Studio® (Multimedia operation system)	Integrates the following: -Full-scale 3D image module -Computer-assisted simulating module -Databank of clinical cases

Tab. 1: Computer-aided facilities of 3D calcaneal internal fixation preoperative simulating system.



Tab. 2: Presurgery simulating process of calcneal internal fixation surgery based on computer-aided technology.

2 MATERIAL AND METHODS

Correction of malunited calcaneus aims at the restoration of the overall shape of the calcaneus, anatomical reduction of the affected joint surfaces and stable fixation. Various lateral, medial, plantar, posterior and combined surgical approaches have been presented. In non-arthritic condition, corrective osteotomy with/without bone graft has been established as standard therapy for malunited fractures and anatomical reduction of subtalar joint congruity and restoration of the overall shape of the calcaneus are the most important prognostic factors [12].

This work applied a multimedia interface to integrate a 3D image editor, CAD software, and a databank into a 3D multimedia presurgery planning system for internal fixation operation of calcaneal collapse. There are 3 major modules referred to Fig.1 (a), (b), (c) built by this study, and each module includes the following functions.

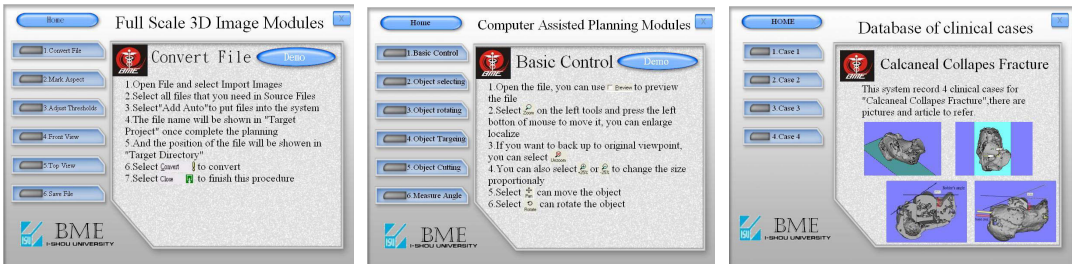


Fig. 1: From left to right : (a) Full-scale 3D foot bone image capture module, (b) Computer-assisted planning modules of calcaneal internal fixation operation, (c) Database module of clinical and simulation cases.

(1)Full-scale 3D image-capture modules (3D image editor) :

This module captures a digital 3D foot bone image for each case, walking physicians through the process of acquiring DICOM images from the CT, loading them into the 3D image editor, and then using the 3D image editor to acquire and view a 3D full-size foot bone image. This module can be executed in several sections as shown in Fig. 1(a), and it also has audio and video explanation and demonstration.

(2)Computer-assisted planning modules (CAD software) :

This module shows surgeons how to export 3D image files from the 3D image editor, and then import them into the CAD system. The CAD system can simulate the theory of an internal fixation operation for calcaneal collapse from a medical textbook, and then carry out the cutting, measuring, moving, and rotating of the 3D images via the software. Following the angle and length of the CAD system, the physician places the foot (calcaneus) image model to check each relevant part and to determine whether the foot is correctly placed on a weight-bearing plane in order to obtain the requisite information and results which shown in Fig. 1(b).

(3)Database module of clinical and planning cases (compiled databank) :

The planning cases of internal fixation operations for calcaneal collapse, as operative clinical cases, have been collected into a databank (database module) for further study and reference in Fig. 1(c). This planning system integrates CT and clinical experience for preoperative planning of clinical surgeons. By comparing the planned results to actual clinical results using related variables, the databank can become more helpful for the internal fixation operation of calcaneal collapse.

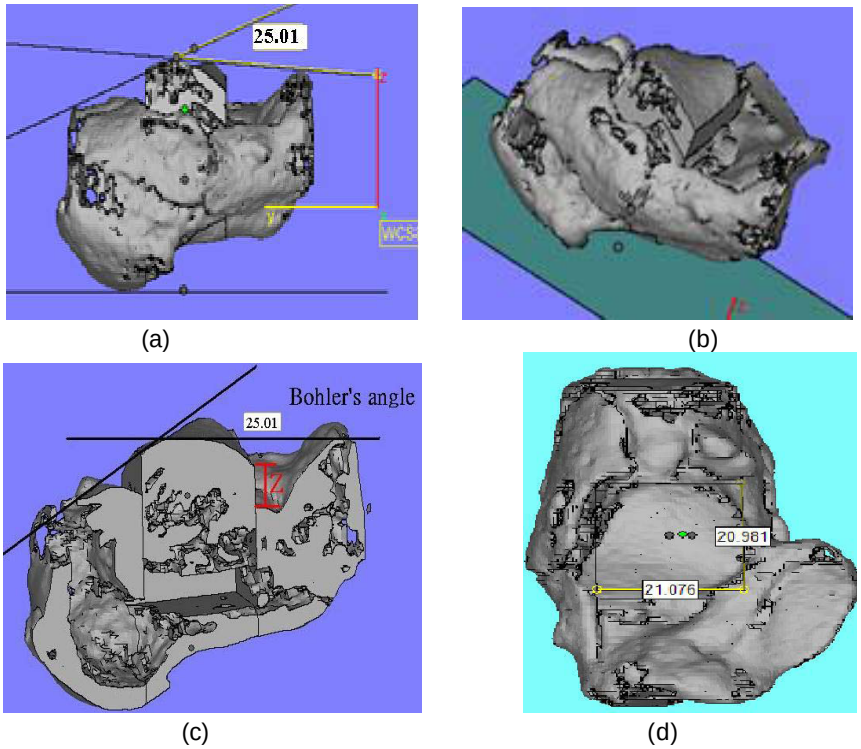
After completion of these 3 software modules, the basic platform of the preoperative planning and evaluation system was essentially complete. Altogether, the multimedia system integrates a 3D image editor, computer-aided design (CAD) software, and a compiled databank in the form of a 3D preoperative planning system for calcaneal fracture surgery. The final simulation system merged CT and clinical experience to enable surgeons to plan in a preoperative setting. Since adding new data can modify the system, including data obtained after surgical interventions, comparisons between pre-surgical simulation and results obtained by actual operative interventions can be made, and the databank can gradually become more and more useful.

3 RESULTS

In order to integrate different software functions the Autoplay Media Studio, such as Mimics, Magics, and Geomagic Studio have been performed in this study. And then, a 3D simulation system for the internal fixation operation of calcaneal collapse is consequently built. Integration of full-scale 3D image modules, computer-assisted planning modules, and a clinical case database for the computer aided surgery system developed for this study. In addition, this system has been used and verified by several clinical surgeon cases at the Department of Orthopedic Surgery, Kaohsiung Veterans General Hospital, Taiwan proof it was user friendly. The 3D imaging data and the deformed calcaneal data would be matched with the data from the planning software to allow immediate improvement of deformity correction and implant fixation in the preoperative simulation. This study presented a set of the full-scaled 3D computer-aided clinical planning system of calcaneal osteotomy surgery, which posses the function of clinical stimulation, regard as a preoperative simulation system. It not only includes the functions of simulating the calcaneus related correction, shifting, rotation and measurement, but also shows the full-scaled 3D digital model images of calcaneus provide users to

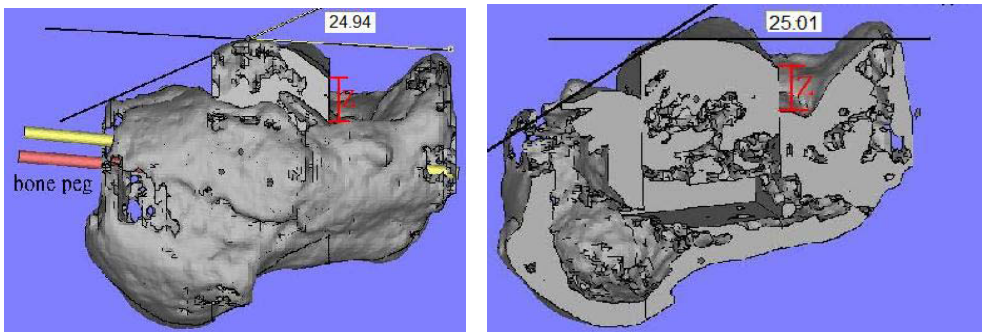
predict the surgical results in Fig. 2(a), (b), (c), (d), respectively. It is useful for patient's communication and information in the informed consent process.

The simulation information, offered by the system used in this study, included a sectioned image of a fractured calcaneus, complete with all references that a surgeon would require when handling this type of disorder, including Böhler's angle, location of the cortical screws, bone graft displacement, and so forth, as shown in Fig. 3(a), (b), (c), respectively.

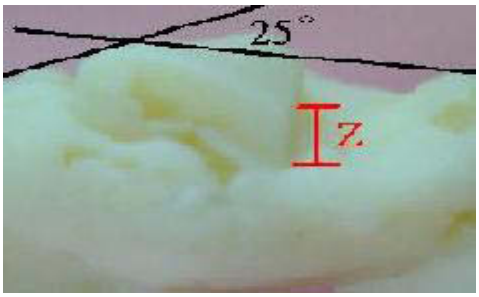


(a) (b) (c) (d)

Fig. 2: Simulation of calcaneal internal fixation operation (a) Böhler's angle (25°), (b) Top-View, (c) Proposed operation site, (d) Side-View.



(a) (b)



(c)

Fig. 3: Clinical preoperative simulation of calcaneal internal fixation operation (a) Original foot angle, (b) Proposed operation site, (c) RP sample.

In our environment, as the surgeon removes each voxel of bone, the simulator determines whether this voxel would be visible to a physician at the time of removal. Post-simulated 3D models of the calcaneus are then reconstructed by using the rapid-prototyping (RP) machine shown in Fig. 3(c) to validate the reliability of the data.

The drilling site, exit point, direction and length of the fixation screws are simulated on the full-scaled 3D image by the standard software illustrated in Fig. 3. This paper presents a calcaneal preoperative planning module under 3D full-sized computerized environment and lets users to manipulate the systems easily, and make the surgery simulating more practicable and friendly. Under the computer-aided planning modulus, we can easily achieve all aspects of preoperative simulation and the possible reconstruction. This modulus with its tremendous potential is a useful communicational tool between surgeons and patients.

Another goal of our simulation environment is let surgeons to avoid damaging critical structures when using the drill or cortical screw. One of the most important ways to minimize the risk in bone surgery is only to remove the bone within the line of sight. A saucerizing drilling technique (removing the bone to create a saucer-shaped cavity on the bone surface) allows the surgeon to avoid damaging vulnerable structures adjacent to the bone surface, using subtle visual cues that indicate their locations. During or after a virtual procedure, a user can visualize the visibility or invisibility of every voxel removed to explore the overall safety of the technique and find specific problem areas.

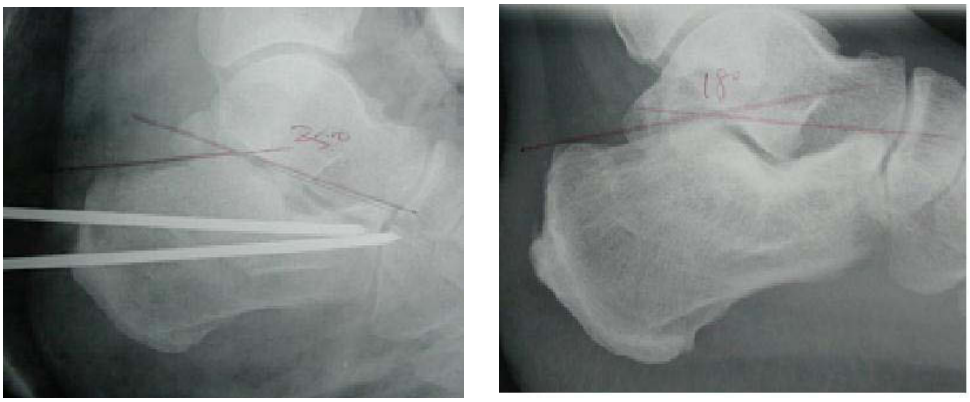
4 DISCUSSIONS

The treatment of deformed calcaneus has to be tailored not only to the correction of individual deformity but also to the functional demand, comorbidities and compliance of the patient. The experienced surgeon is usually able to foresee the surgical process and its subsequent prognosis with accuracy. Up to the present day, this form of empirical simulation surgery has become more popular and constantly been updated. Previously it is common for the surgeons to do their preoperative simulation with a 2D tracing of the procedure on some flexible material such as gauze, X-ray film, tracing paper as a preliminary step before performing the actual surgery; in essence, computerized 3D simulation effectively eliminates these tedious and often imprecise manual drawing and instead provides the optimal surgical planning with the aid of a computer. By using this simulation system to perform surgery for the calcaneal internal fixation surgery, highly accurate data, such as Böhler's angle, location of implants, volume of bone graft or displacement of bone block etc., can be obtained

as parts of the preoperative simulation; hence the surgical mishaps during actual surgery could be lessened.

Foot and ankle surgery up to date is characterized by the use of sophisticated computerized preoperative and postoperative diagnostic and simulation procedures. However, with the special-integrated CAD system animation is added to the on-screen simulation, and sections of the bone allocated as if in the actual operation, thus the simulation results are previewed. This system establishes a useful preoperative evaluation model by computer-aided technique for calcaneal internal fixation surgery of collapse calcaneus which often has comminuted articular surface deformation. This planning system not only allows the users to have a full-sized 3D preoperative simulation for reference purpose, but also can improve the accuracy in simulating the joint reduction and body height restoration by providing the 3D sectional images. Furthermore, since the planning process is mainly computerized, repeatable simulations could decrease expenditure in medical resources.

The clinical case for calcaneal fracture internal fixation surgery is shown in Fig. 4. Böhler's angle was successfully reconstructed during surgery as shown in Fig. 4 (a). The postoperative course was favorable without complication. The patient was able to ambulate in standard shoes with full weight-bearing 1 year postoperatively. Calcaneal collapse at about 29 weeks after surgery was due to the supporting structure of calcaneal not having enough strength in Fig. 4 (b). The undertaken work presents an alternative planning system for calcaneal fracture surgery to increase the sustainability of the calcaneus. The surgical planning in this study used an internal fixation operation to restore Böhler's angle of calcaneal fracture and fix the fractured part with a bone peg. The planning information offered in this study, besides a sectional image of the calcaneal fracture for reference for the surgeon, along with parameters of surgery planning (Böhler's angle and location of cortical screw and bone graft), allows the surgeon to engage in a planning experience with useful images and data to operate.



(a) (b)

Fig. 4: Clinical case of subtalar mini-open approach (internal fixation operation) (a) Internal reconstructed Böhler's angle (25°), (b) 29 weeks after surgery (Böhler's angle 18°).

In this study, a thorough inspection of the entire structures of a calcaneus is possible because of the innovatory technology of the computer assisted environment (full-scaled 3D image editor, better image quality, etc.). However, identification of the exact location and size of the bony fragments can still be problematic even for the experienced surgeons during their preoperative planning. Our 3D

computer-assisted reconstructive modules provide the surgeons a useful tool to overcome problems preoperatively, and hence obtain a better surgical outcome.

The characteristic of this simulating system depends on the function units that combine different software promptly and share the same data format easily. The integrated software function in computer-aided technology makes planning and carrying out systematically. The development a 3D preoperative simulation system of the calcaneal internal fixation surgery in this study can makes the credibility and feasibility of preoperative simulation system to improve further.

5 CONCLUSIONS

The computer-aided simulation system is helpful in creating a complex 3D correction with the precise placement of bone block and fixating screws preoperatively, and to obtain a better clinical outcome postoperatively. This computer simulation system can contribute another filed as a teaching tool of the orthopedic residentsø training. The residents can be familiarized with calcaneal internal fixation surgery by ways of surgical simulations provided by the databank of clinical cases from this study. Computer aided surgery systems is maybe time-consuming for experienced surgeons that can perform operation accurately and easily. However, the preoperative simulation modules of the calcaneal fixation surgery developed in this study have unity function for users to be familiar with operating interface easily under computer-assisted environment.

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