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SURGERY PLANNING SIMULATION FOR CLOSED REDUCTION AND INTERNAL FIXATION

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Abstract: Careful planning of operations is critical to success of the closed reduction and internal fixation (CRIF) surgery to fix proximal femur fractures. This paper presents a novel surgery planning simulation for the CRIF. The developed simulation employs 3D femur model reconstructed from actual patient's CT data, and enables the user to make a plan on the model using 2D mouse. A projection scheme is developed to map a selected point on the monitor screen onto the 3D femur model. A centerline of the femur neck and cross section images are provided to help the user make optimal planning. The centerline of the femur neck is extracted by connecting two center points of cross sections selected by the surgeon. The cross section image is generated using intersection points between the femur model and a plane selected by the user. The simulation also displays post-operative appearance of the femur using 3D implants models.

1. INTRODUCTION

The proximal femur fracture is a major public health problem in the United States, and also in Korea (Johnell, 1997). Medical treatment for the fracture costs $8.68 billion in the United States each year (Ray, et al. 1997). The proximal femur fracture occurs commonly as a result of falls among elderly people whose bone is weakened by osteoporosis or other bone diseases. Occasionally, in younger people, high energy injuries such as car accidents cause the fracture. The fracture causes immobility, and patients often die of complications induced from the immobility. Mortality rate of the fracture reaches to 15% (Nather, et al. 1995).

Surgical operations are generally performed to fix the fracture. The most frequent operation is the closed reduction and internal fixation (CRIF) surgery. In the operation, a small incision is made to the outside of the thigh, and artificial implants are passed across the fracture under the guidance of fluoroscopy images obtained intra-operatively. Since only a small incision is made, there are many benefits for the CRIF surgery such as faster recovery time, reduced pain and fewer traumas compared to open surgery.

Accurate placement of the implants is essential to ensure secure fixation of the fractures. Wrongly positioned implants can lead to loose fixation, protrusion of the implant or additional fractures. It is difficult to determine the accurate placement during the operation because the surgical environment of the CRIF surgery has many limitations such as difference between hand and eye coordinates, and discrete and two dimensional fluoroscopy images. Preoperative planning is generally conducted to achieve accurate placement of the implants and to reduce the use of fluoroscopy.

Conventional planning of the CRIF surgery including determining insertion points, direction and size of the implants is conducted based on 2D X-ray images. The surgeon draws the insertion points and direction on the patient's X-ray image and determines the size by measuring dimension of the femur on the X-ray image. The conventional planning has several problems. The insertion points and directions are not precisely and concretely determined because the X-ray image can not represent a real femur completely. Also, the size of implant is inaccurate because one can not measure the exact dimension of the real femur using the X-ray image. And the surgeon can not confirm whether the planning is conducted correctly because post-operative appearance of the femur cannot be provided.

Computer-based simulation can be an alternative to alleviate the problems of the conventional planning method. Surgical planning using computer simulation has many advantages. It allows a surgeon to plan directly on the 3D model reconstructed from patient's computer tomography (CT) images. The surgeon can precisely inspect quantitative features of organs and bones, such as angles, distances and volumes. It enables the surgeon to confirm the post-operative appearance, and to check whether the planning is conducted correctly or not. The planned result can be transferred to the operating room directly. The planned results can be presented to the surgeon by superimposing on the intra-operative image. Due to these advantages, there have been many researches to

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develop simulations for surgical planning.

Bernhard Reitinger *et al.* (2005) developed Virtual Liver Surgery Planning (VLSP) system. The VLSP displays the liver model in 3D space using augmented reality techniques and allows a user to plan on the model using optically tracked pen and panel. H. Delingette *et al.* (1994) developed craniofacial surgery planning simulator. A user can cut the object by drawing a line using mouse and rearrange the cut object with a virtual hand which is tracked by electromagnetic sensors. Xia *et al.* (2001) developed an orthognathic surgery planning simulator. A user can cut the skull bone and reposition the subdivided bones using the 3D flying mouse. D. Testi *et al.* (2005) developed a surgery planning simulator for total hip replacement (THR). In this simulator, a user can position a prosthetic component and the simulator shows feasibility of the planned position, range of motion of the operated joint and limb shortening after joint reduction. O. Sourina *et al.* (2000) developed a simulator for planning of the proximal femur fracture surgery. The simulator displays a femur model on a monitor and a user can determine an insertion point, angle and size of screws using ordinary 2D mouse. The simulator shows post-operative appearance but it does not provide additional information necessary to increase accuracy of the planning.

2. SIMULATOION SYSTEM

The simulation system consists of a monitor, main processor and 2D mouse. The monitor shows a virtual model of the femur and a user can select insertion point, direction and size of the implant on the model using the mouse. The main processor receives the user's input through the mouse and computes selected insertion point, direction and additional information necessary for the planning. These results are passed to the monitor, and the monitor displays them to the user. Figure 1 shows a configuration of the simulation.

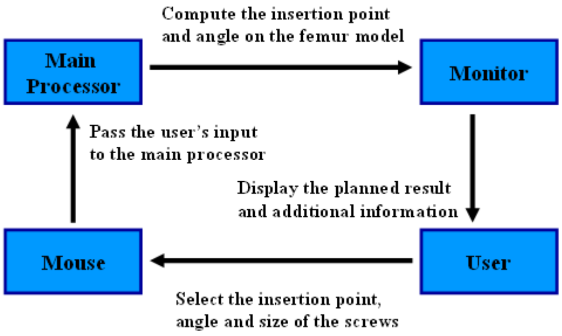
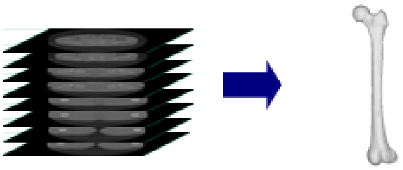


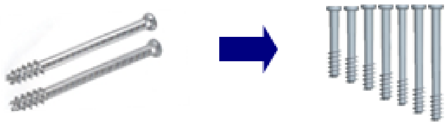
Figure 1 Configuration of the simulation

2.1 3D Model

The major drawback of the conventional planning is that the planning is conducted on the 2D X-ray images. The developed simulation employs 3D femur model which is reconstructed from patient's CT images as shown in Figure 2 (a). Femur part is segmented in each CT image using intensity value of the pixels. And the 3D femur model is constructed by connecting the segmented images. 3D models of the implants are also employed in the simulation. The implant models are generated using the solid modeling software (Pro-Engineer) according to actual dimension of the implants as shown in Figure 2 (b).



a. 3D model of the femur



b. 3D model of the implants

Figure 2 3D models of the femur and implants

2.2 Graphic user interface (GUI)

The GUI consists of three panes as shown in Figure 3: 3D view, cross section view and collection of buttons. The 3D view shows the 3D femur model. The user can rotate, translate, zoom in and zoom out the model in this view. The user can inspect anatomical feature of the femur closely through this pane. Any point on the 3D femur model can be selected as the insertion point by rotating the femur model. The post-operative appearance of the femur is displayed in this pane.

The cross section view shows cross sections of the femur model selected by the user. The user can confirm the relative position of the implants with the femur more precisely in this pane. The user can also adjust the position of the implant in the cross section. It enables the user to position the implant arbitrarily in the interesting cross section. The pain 3 shows several buttons which are used in extracting a centerline of the femur neck, selecting the size of the implant and the cross section.

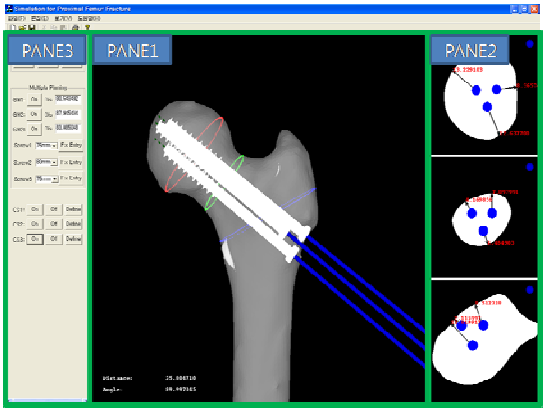


Figure 3 Graphic user interface of the simulation

3. USER INTERFACE

The user interface is essential part of the planning simulation and is designed according to the kind and the procedure of the target operation. For convenient use and practicality of the simulation, the user interface should be as simple as possible within the range of embodying the planning fidelity. For the CRIF surgery, the key of the planning is determining the insertion points and direction of the implants. This procedure can be carried out sufficiently using 2D mouse input.

The basic idea of selecting an insertion point using 2D mouse is projection. During the simulation, the femur model is displayed to the user through the monitor and the user clicks the mouse after placing the cursor on the desired insertion point. The selected point with 2D coordinates in the monitor frame is, then, projected on the corresponding point on the femur model.

Figure 4 shows the process of displaying a 3D model on the monitor using orthographic projection (Richard, et al. 2001). Every point of the model is projected on the monitor along the ray cast from the eye point Using this method reversely, a point selected by the mouse is projected onto the 3D femur model.

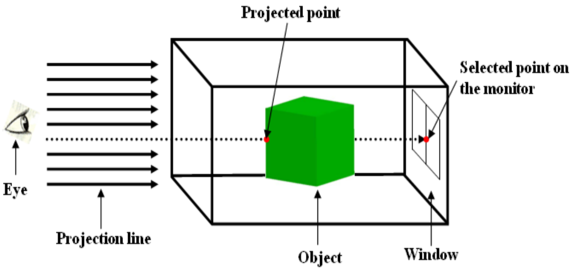


Figure 4 Orthographic projection

Locating an insertion point selected by the mouse requires finding intersection points between the femur model and the ray. The femur model is composed of 35,500 triangles, hence it is computationally expensive to inspect intersection between the ray and all the triangles of the femur model. The femur model should be organized into an optimal data structure to reduce the computational overhead.

The data structures to reduce the computational load of ray-object intersection can be broken down into two categories: spatial subdivision and bounding volume (Glassner, 1989).

The spatial subdivision technique partitions an interested space into sub-spaces and each of the sub-spaces has a list of objects which occupy the sub-space. It reduces the number of intersection test by limiting the test to the objects that occupy the sub spaces that the ray is passing through. There are several methods in the spatial subdivision techniques: octree (Gargantini, et al. 1993), binary space partitioning tree (Naylor, et al. 1990) and k-d tree (Samet, et al. 1989). The spatial subdivision technique is useful when many objects exist in the scene. This technique is, however, inappropriate in our problem because there is only one object in the scene.

The bounding volume technique encloses a complex object by simple bounding volumes such as spheres or boxes which are much easier to compute intersection. The methods used in this technique are largely divided into three according to a type of bounding volume: oriented bounding box (OBB) tree (Gottschalk, et al. 1996), axis aligned bounding box (AABB) tree (Gino, 1998) and sphere tree (Benitez, *et al*. 2005).

The AABB and sphere tree have an advantage that computational load of constructing the tree is smaller than the OBB tree. These trees are commonly used for deformable objects that need to update the tree in real time. The OBB tree has advantages that the number of operations necessary to find intersection point is smaller than the AABB or sphere tree because the bounding box fits the object tightly. For our problem where deformation of the model does not occur the OBB tree is more efficient than the AABB or sphere tree. Figure 5 shows the tight fitting process of OBB for the femur model.

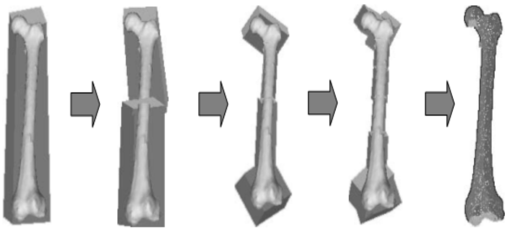


Figure 5 Tight fitting OBB of the femur model

Locating the intersection point in the hierarchical tree structure is performed by traversing the tree (Gottschalk, *et al*. 1996).

4. AID FOR OPTIMAL PLANNING

The simulation provides two functions to help the user plan optimally: displaying cross section images and centerline of the femur neck.

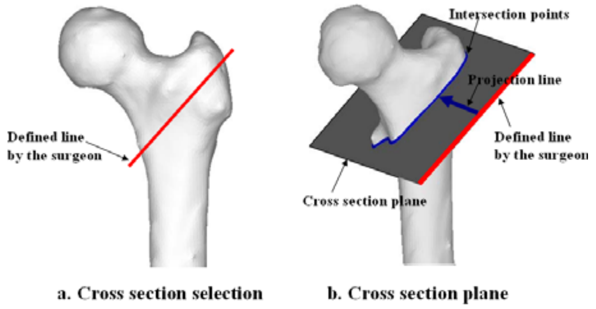
4.1 Cross section images

It is difficult to confirm relative position of the implants within the femur precisely in the 3D view because the surfaces of the 3D models are overlapped on the screen. The simulation provides function of displaying the cross section image to confirm the relative position of the implants accurately. Moreover, the user can adjust the position of the implants in the selected cross section. It helps the surgeon determine the position of the implants.

The cross section of the femur is computed as follows.

1. A cross section plane is selected by the user
2. Intersection points between the cross section plane and the femur model are computed.
3. The cross section image is generated by triangulating the intersection points.

The user determines the cross section of the femur by drawing a line on the monitor as shown in Figure 6 (a). If the line is determined, the selected cross section plane is defined by the selected line and the projection line as shown in Figure 6 (b). And the cross section of the femur can be obtained by the intersection points between the surface of the femur model and the selected cross section plane as shown in Figure 6 (b).



a. Cross section selection
b. Cross section plane

Figure 6 Cross section of the femur model

The intersection points are computed as follows.

1. Generate points at regular intervals on the line that is determined by the surgeon.
2. Cast rays parallel to the projection line from each point on the line.
3. Compute intersection points between each rays and the surface of the femur model.

Figure 7 shows the method of computing the intersection points.

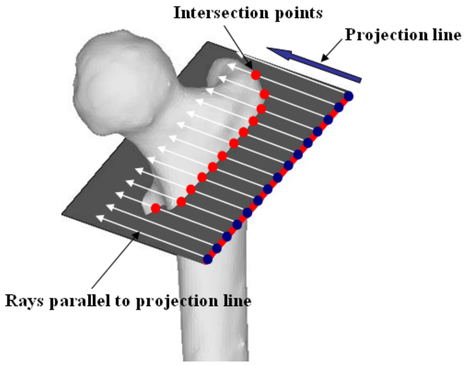


Figure 7 Computing intersection points

Although the intersection points can be obtained easily using this method, the intervals between neighboring points are not uniform. Intersection points are generated densely on the surface which is perpendicular to the projection line but the points on the surface parallel to the projection line are generated sparsely as shown in Figure 8.

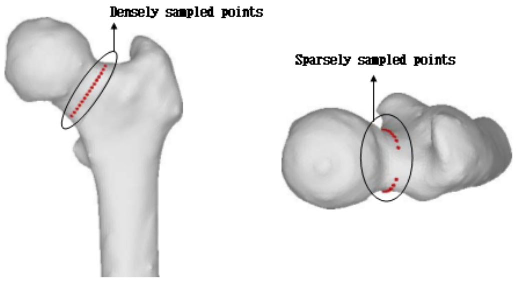
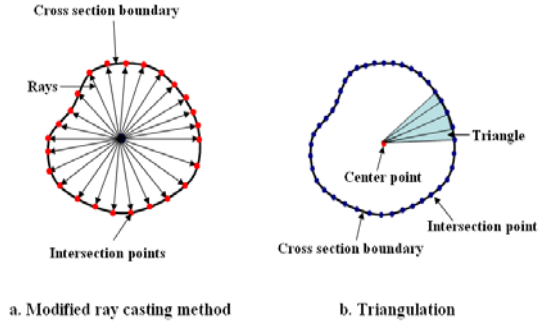


Figure 8 Non-uniformly sampled points

The intervals of neighboring points largely vary according to the angle between the surface of the femur model and the ray because all the rays are parallel in the above method. The method of ray-casting is modified to solve this problem.

First, the center point of the cross section is computed by averaging the obtained intersection points. Rays are, then, cast from the center point in radial direction as shown in Figure 9(a). The intersection points are recomputed using these rays. The cross section is generated by triangulating the intersection points. Each triangle is generated by connecting three points as shown in Figure 9(b).



a. Modified ray casting method
b. Triangulation

Figure 9 Modified ray-casting and cross-section computing

4.2 Centerline of the femur neck

The centerline of the femur neck is used as a reference line when the user determines the insertion point and direction of the implants. In the CRIF surgery, the surgeon should insert the screws passing through the cross section of the femur neck which is 3-4cm in diameter. To minimize weakening of the femur and to fix the fracture stably, the implants should be positioned uniformly around the centerline of the femur neck. The developed simulation shows the centerline of the femur neck to help the user determine the insertion point and direction easily and accurately.

Research on the centerline extraction has been conducted extensively and there are several algorithms developed for extracting the centerline: topological thinning (Ge, et al. 1999), distance mapping (Wan, et al. 2002) and voronoi diagram (Dey, et al. 2004; Foskey, et al. 2003). These centerline extraction algorithms are inappropriate to our problem. The centerline extracted from these algorithms only reflects the geometry of the complete model. The centerline of the femur neck applicable to the developed simulation should take the nature of the fracture into account. The centerline of the femur neck should pass through the center point of the critical cross section such as the cross section in the fractured region. Hence the centerline of the femur neck is computed as a line which connects the center points of two cross sections selected by the user as shown in Figure 10. The centerline of the femur neck is extracted automatically after the surgeon selects the two cross sections which are critical in the operation. The centerline is superimposed on the femur model during the simulation. The surgeon can locate the implants around the center points of the critical cross section by referring to the centerline of the femur neck.

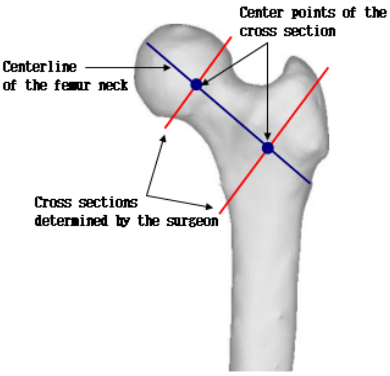


Figure 10 Centerline of the femur neck

5. CONCLUSION

A surgery planning simulation is developed for the CRIF. The developed simulation aims at enabling the user to make a more accurate plan for the CRIF that is performed most frequently for the proximal femur fracture. The simulation employs 3D femur model to determine accurately the insertion points and direction of the implants. The simulation employs an ordinary 2D mouse to interact with the femur model, and to make a surgery plan simply and intuitively. A projection scheme is used to enable the 2D interaction.

The simulation provides useful functions such as displaying centerline of the femur neck and cross section images to help the user make an accurate plan. The centerline of the femur neck is used as a reference line to determine the position of the implants. A semi-automatic method is developed to extract the centerline. The user can confirm the implant placement in the desired cross sections and adjust the placement in the displayed cross section. This improves accuracy of the plan.

Future research includes exporting and displaying the surgery plan onto the intra-operative fluoroscope images. This will help the surgeon carry out the procedure more accurately and eventually improve the outcome of the CRIF surgery.

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