Bone Fragment Repositioning Using Registration Methods

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The surgical intervention of complex bone fractures has to be planned very carefully, especially for such a complex bone as the pelvic ring. The computer aided surgical planning is done before the actual surgery takes place and its main purpose is to gather more information about the dislocation of the bone fragments and to arrange the surgical implants to be inserted. With the help of finite element analysis even the biomechanical stability of the whole plan can be predicted.

To create such a plan the following steps are performed (as described in [1]). First, the CT dataset of the patient is segmented, which enables us to treat the different bones and broken fragments separately. Next the surface of these bones is determined and presented in a 3D environment. Since the fragments may have moved during the fracture, it is essential to move and rotate them back to their original or healthy position. Without this repositioning step, no implants can be inserted, since the final locations of the fragments are unknown. Previous solutions to the fracture reduction problem included moving the fragments with the mouse, or a special 3D haptic device. The former is not intuitive to use since the mouse is only 2D, and the later is expensive and still requires learning.

In this paper we present a semiautomatic method for the repositioning problem. It is semiautomatic because the user has to select the corresponding surface pairs on two different fragments which belong to the same fracture by clicking on them with the mouse. For a simple fracture, where the healthy bone was split into two fragments, there is only one surface pair to select, but a complex case can have up to 8 or 10. Assuming we have collected all the surface pairs, our algorithm registers them one by one. The registration is basically a search for the three translational and the three rotational parameters to move and rotate one fragment to match the other. We formulated this search as a function minimalization problem where our cost function is the sum of the distances of all the points on the first surface to their nearest neighbors on the second surface. To reduce the 6-dimensional search space we included constraints on both the translational and rotational components: we permit only 2 cm movement and 20 degrees rotation. In fact, the dislocation can be much higher than the above mentioned value, but we start the process by translating the centroids together to cancel out the initial distance. The function optimization method we used was a Evolutionary Algorithm with a population size of 400 and lack of improvement served as stop condition.

The described method matched a single surface pair with high accuracy. Because the selection was made by hand, the user himself introduced minor errors besides previously present inaccuracies caused by improper segmentation or surface simplification. These errors accumulate if the number of dependent surfaces pairs is high, especially with models containing circles in their object graph. Therefore a global optimization is necessary to finalize the transformations. In this global optimization all surface pairs are considered simultaneously which means the dimensionality of the search space grew to $(n-1)*6$ for n bone fragments. The cost function was the same as above, but the constraints were stronger assuming there are only small corrections to make.

Using this method the fragment repositioning task can be done faster than with the mouse in particular for complicated cases. However human verification of the result is still required.

References

[1] Balázs Erdőhelyi, Endre Varga, and Attila Kuba. Surgical Planning Tool with Biomechanical Simulation. In *Proceedings of the International Conference on Computer Assisted Radiology and Surgery (CARS)*, volume 2 of International Journal of Computer Assisted Radiology and Surgery, pages S262-S263, 2007.