Preoperative planning program tool in treatment of articular fractures: Process of segmentation procedure

M. Tomazevic[1], D. Kreuh[2], A. Kristan[1], V. Puketa[1], M. Cimerman[1]

[1] Traumatology Department, University Clinical Centre, Ljubljana, Slovenia
[2] Ekliptik, l.t.d, Ljubljana, Slovenia

Abstract— **a developing computer program for preoperative planning of articular fractures is presented. The program consists of three closely integrated tools, the 3D viewing tools, the segmentation tools and the reduction and fixation simulating tools. Data from CT of a fracture in DICOM format are used. First the 3D model is made, and then segmentation is carried out, where each fracture segment is made as an individual object. In reduction each fracture segment can be moved in all three directions, can be rotated in all planes and its pivot point of rotation can be changed. After reduction fixation can be undertaken, either with plates that can be automatically contoured or with pre curved plates that are already in program database. The plan of automatically contoured plates can be drawn and printed out in 1:1 scale. The most important is that all the steps can be carried out on a personal computer by the surgeon who is doing the preoperative planning. This is the complete novelty since segmentation can be carried out by the surgeon. In that way all the fracture lines are studied in preoperative planning. The procedure is quick and easy. This is why we made segmentation in 20 consecutive cases that were admitted to our department of fresh articular fractures where CT was indicated and done that were admitted to our department. The steps needed in segmentation process were recorded and fractures were described whether there were luxation, multifragmentary or impaction fractures and classified according to AO classification. The presented computer program is an easily usable application which brings significant value and new opportunities in clinical practice, teaching and research.**

Keywords— **Preoperative, Planning, Articular, Fractures. Computer.**

I. Introduction

Because articular fractures extend into joint surfaces and because joint motion or loading may cause movement of the fracture fragments, intra-articular fractures can present challenging treatment problems. Most intra-articular fractures heal, but if the alignment and congruity of the joint surface is not restored, the joint may be unstable, and in some instances, especially if the fracture is not rigidly stabilized, healing may be delayed or nonunion may occur. However, prolonged immobilization of a joint with an intra-articular fracture frequently causes joint stiffness. For these reasons, surgeons usually attempt to reduce and securely fix unstable intra-articular fractures. This approach ideally restores joint alignment and congruity and allows at least some joint motion while the fracture heals. Unfortunately, restoring joint alignment, congruity and stability in patients with severe intra-articular fractures may require extensive surgical exposure that further compromises the blood supply to the fracture site. Even after reduction and adequate initial stabilization, intra-articular fractures may displace due to high transarticular forces, failure of the stabilization or collapse of the subchondral cancellous bone.[1]

A study of contact stress aberrations following imprecise reduction of experimental human cadaver tibial plateau fractures showed that generally peak local cartilage pressure increased with increasing joint incongruity (fracture fragment step-off), but the results varied among joints. In most specimens, cartilage pressure did not increase significantly until the fragment step-off exceeded 1.5 mm. When the step-off was increased to 3 mm, the peak cartilage pressure averaged 75% greater than normal [.2, 3]

Although the functional anatomy of the joints is well studied and 3D CT has much improved imaging, complete understanding of the fracture lines and fragments is still difficult. Another problem is the choice of correct operative approach. Reduction of bone fragments, which is usually very demanding, represents a key element for the normal post-operative biomechanical functions in articular fractures. Complete and precise control of the reduced fragments is also problematic, because visualization of whole fragments and the joint surface is often technically impossible. After reduction, the problem of fixation occurs. The plates must be precisely contoured in all three planes to fit an individual bone. Taking all this into account, it is obvious that strict preoperative planning is a crucial step in articular surgery. It is not therefore surprising that new technologies have been introduced in orthopedics and trauma to help the surgeon to plan and to perform operative procedures more precisely. Computer assisted orthopedic surgery (CAOS) has been developed as the application of computer based technology to assist the surgeon to improve the precision of the operative procedure.[4, 5, 6, 7] There are reports on the use of virtual planning in the resection of pelvic bone tumors, for individual modeling of prosthetic substitutes5 and maxillofacial surgery.[8, 9, 10] There were already described programs for planning of fractures treatment, but, because segmentation process was so demanding a group of people were involved in segmentation process.[5, 6] Together with computer engineers from Ekliptik l.t.d., we have developed an experimental computer program which enables performance of a complete procedure, from imaging, segmentation process and virtual operation of a fractured bone. The key element in segmentation process is, to know al the fracture lines, so the surgeon really studies the fracture. The purpose of virtual surgery is to perform all the steps of the ‘‘real’’ surgical procedure. We have been using this software in our institution first for dealing with acetabulum fractures, but because it was so useful and uncomplicated we started to use it also for all articular fractures. The segmentation process is a novelty that is why we studied which steps we need to do in different kind of fractures, so the fracture segmentation is done to the last fragment. We made segmentation on 20 consecutive cases of articular fractures that were admitted to our clinic and classified them according to AO classification.11

II. Materials and methods

EBS software enables complete preoperative planning of intraarticular fractures on the model acquired from real patient data. Data from CT in DICOM format are used. Slices of 3 mm or less are required. We used various thickness of slices, depending on the joint that was injured. The thinner they are the better is the resolution of the reconstruction model. Models for the simulation are produced semi automatically on PC with windows environment by the surgeon who is doing the preoperative planning. The first part of this process is determination of the area that you want to build the model from and of the threshold that specifies desired densities which define bones. Then the computer builds automatically an 3D model. The second part of segmentation process is divided in to two parts. Basic segmentation is where we clear the aquierd segment of artifacts and divide the bones, which are in close contact with the fractured bone. Fracture segmentation is where we divide fragments of the fractured bones. In segmentation process different tools can be used. Merge tool is used when we merge different segments in to one segment. Paint tool is used where the fracture line needs to be drawn if the computer does not find it. Fill hole tool can be used in the osteoporotic bone. Separate tool can be used where new objects needs to be done from the unconnected bones. Split tool is used where segmentation in done by positioning the seeding points on different fracture sites and the computer finds the fracture line in between. Cut tool is used where we cut thru the virtual bone, but there is no fracture line seen. This can be used in planning osteotomies, or in impaction fractures. After the segmentation process, each fracture fragment becomes a separate object. In the rendering process, each bony fragment can be colored. After this procedure, the simulation model is ready for use. The surgeon can start to perform the virtual operation Basic commands are made in a user friendly manner and the screen is similar to other programs run on regular pc computers in the Windows environment. The pelvis can be turned around in all directions during the virtual operation, so each step of the procedure can be studied in relation to the operative approach. Bone fragments can be moved and rotated in all three planes, and the pivot point can be changed so the reduction of the fracture can be performed and key bone fragmentsidentified. After reduction, fixation can be performed. The surgeon can chose the appropriate reconstruction plate and put it across the fracture. Contouring of the plate is performed automatically. The screws can be chosen and inserted into the plate or across the fracture. The length of the screws can be measured accurately. The direction of the screws can be controlled by making the bones more transparent. A special feature of the software is simulation of intraoperative C arm. In our study we recorded which steps were used in diffirent kind of fractures. We did not mesaure the time, because time is dependent on the learning curve and the operator. But it takes around 15 minutes for a suregeon with a few computes skills and with an average laptop PC. Later the segmentation process is shown step by step.

III. RESULTS

From twenty consecutive cases of articular fractures, there were five proximal humerus fractures, one distal humerus fracture, two proximal tibia fractures, one distal cruris fracture, three spine fractures, one pelvis fracture, four acetabulum fractures, one metacarpal fractures and one midfoot fracture.

In basic segmentation process only separate and split tool were used. In fracture segmentation process all tools except fill hole tool needed to be used. Most importantly paint tool needed to be used only once. Paint tool is the most time consuming tool. All other tools are semiautomatic and time sparring. It was needed in a compression spine fracture where the spine was already degenerative changed. The results are listed in table.(.Table 1)

Fracture site	AO clasification	Basic segmentation (number of tools needed)	Fracture segmentation (number of tools needed)
Proximal humerus	11 B1	1	3
Proximal humerus	11 C1	2	1
Proximal humerus	11 C1	2	1
Proximal humerus	11 C1	1	1
Proximal humerus	11 C2	2	1
Distal humerus	13 C3	2	3
Disral radius	23 B3	2	1
Proximal tibia	41 B2	2	3
Proximal tibia	41 C3	2	2
Distal cruris	43 C3	3	1
Spine	53 A1	2	4
Spine	53 A1	2	2
Spine	53 A2	2	2
Pelvis	61 B1	2	1
Acetabulum	62 A1	2	1
Acetabulum	62 A1	2	3
Acetabulum	62 B1	2	3
Acetabulum	62 B1	2	3
Metacarpal	74 C2	2	2
Midfoot	82 B2	2	4

Table1: Tools needed for segmentation in diffirent kind of fractures.

We can see that the most challenging are compression fractures. Because there are no fracture lines, only the bone is more dense than usual. In these cases either the use of paint tool or cut tool is necessary

The segmentation process of a proximal humerus fracture is shown step by step.

First data is loaded and the field of interest is chosen (fig.1)

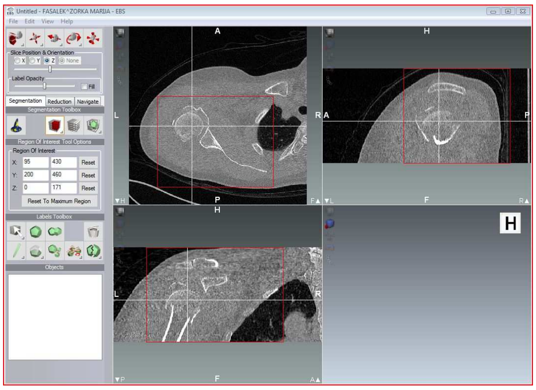

Fig. 1 : data is acquired from DICOM images

Then the 3D model is built automatically (fig.2)

Fig. 2 : 3D image

Using the separate tool the unconnected items are automatically segmented. The computer finds the lines between the fragments and unconected bones by him self.(fig.3)

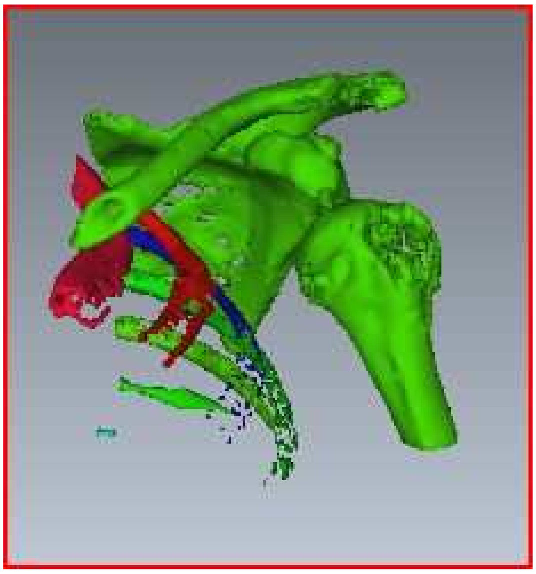

Fig. 3 : automatic segmentation

Then the virtual bones that are of no interest to us are subtracted by simply unmarking them. Than we start with the segmentation of bones that are in close contact with the fracture site. They are marked with seeding points and the virtual bones that are in close contact with the fracture site are separated (fig.4, 5). To get the better view and better working area it is useful to subtract the bones that are unbroken to solving the fracture segmentation and later reduction and virtual operation.

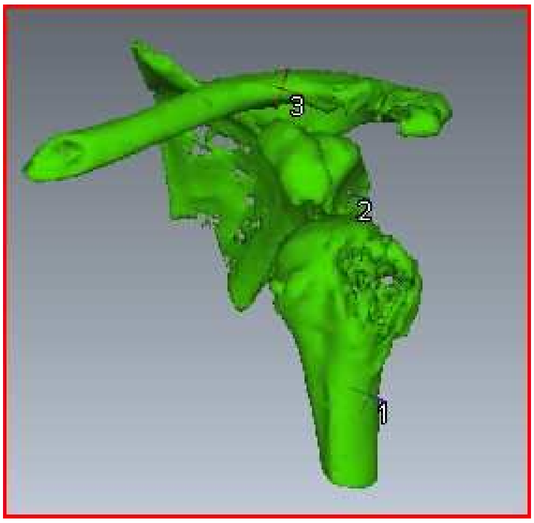

Fig. 4 : Setting the seeding points on the bones that are in close contact with the fractured bone.

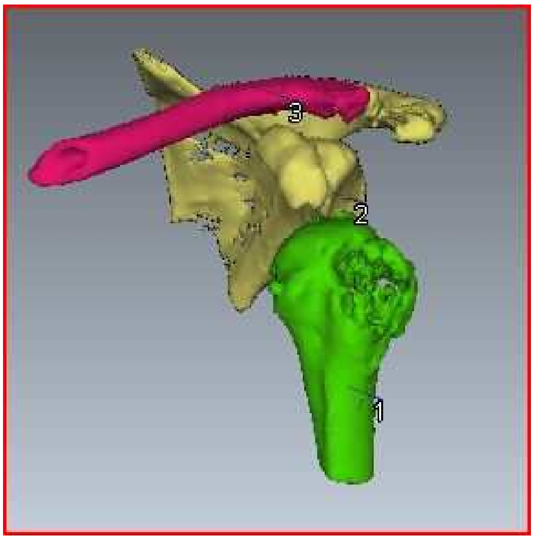

Fig. 5 : The semi automatic segmentation: clavicle, scapula and humerus are separated.

When we start working on a fractured bone, in our case proximal humerus it is useful to turn it around so we get the general idea of the fracture type and position. Than we again place seeding points on the fracture fragments and the computer fins the fracture segments by its own. And we can control them in all three planes on the CT images. When pleased with segmentation (fig.6), classification can be done and virtual surgery can proceed.

IV. CONCLUSION

Articular fractures are very demanding to treat that is why the preoperative planning is essential. There were programs before, where you could do the virtual operation, but to really know the fracture, surgeon must be involved in segmentation process. With EBS program the surgeon can completely prepare himself for the operation. The segmentation process is easy and can be done without any special computer skills. After segmentation, virtual reduction and fixation is done on the simulation model, the real operation seems like just another rehersal.

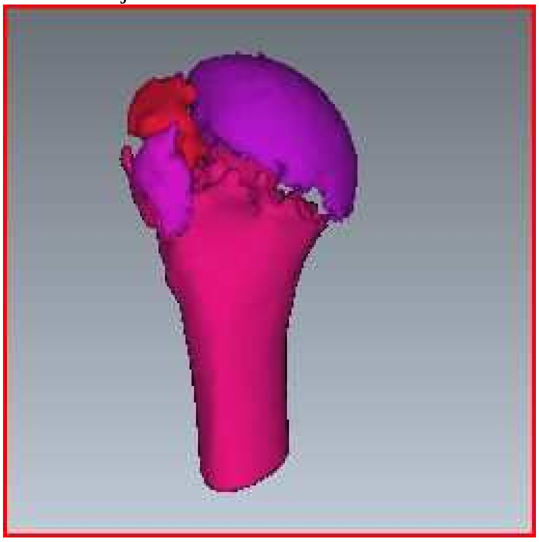

Fig. 6 : Segmented 11 C1 AO fracture

REFERENCES

1. Bucholz RW, Heckman JD, Court-Brown C (2006) Rockwood and Green’s Fractures in Adults. Lippincott Williams & Wilkins, London
2. Brown TD, Anderson DD, Neola JV, et al. Contact stress aberrations following imprecise reduction of simple tibial plateau fractures. J Orthop Res 1988; 6:851-862.
3. Trumble T, Allan CH, Miyano er al A preliminary study of joint surface changes after an intraarticular fracture: a sheep model of a tibia fracture with weight bearing after internal fixation.J Orthoph Trauma 2001 15:326-332
4. Nolte LP, Beutler T. Basics principles of CAOS. Injury 2004;35(Suppl 1):6—15.
5. Dahlen C, Zwipp H. Computer-assistierte OP-Planung: 3D Software fur de PC. Unfallchirurg 2001 104: 466-479
6. Cimerman M, Kristan A. Preoperative planning in pelvic and acetabular surgery:The value of advanced computurised planning modules. Injury 2007 38: 442-449
7. Citak M, Gardner MJ, Kendoff J et al. Virtual 3D planning of Acetabular fracture reduction. J Ortoph Res 2008 26 547-552
8. Gellrich NC, Schramm A, Hammer B, et al. Computer-assisted secondary reconstruction of unilateral posttraumatic orbital deformity. Plast Reconstr Surg 2002;110(6):1417—29.
9. Langlotz F, Bachler R, Berlemann U, et al. Computer assistance for pelvic osteotomies. Clin Orthop Relat Res 1998;354:92—102.
10. Marchetti C, Bianchi A, Bassi M, et al. Mathematical modeling and numerical simulation in maxillo-facial virtual surgery (VISU). J Craniofac Surg 2006;17(4):661—7.
11. Rüedi TP, Buckley RE, Moran CG, (2007) AO Principles of Fracture management Thieme Verlag Stuttgart