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Original article

Does semi-automatic bone-fragment segmentation improve the reproducibility of the Letournel acetabular fracture classification?

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ABSTRACT

Background: The Letournel classification of acetabular fracture shows poor reproducibility in inexperienced observers, despite the introduction of 3D imaging. We therefore developed a method of semi-automatic segmentation based on CT data. The present prospective study aimed to assess: (1) whether semi-automatic bone-fragment segmentation increased the rate of correct classification; (2) if so, in which fracture types; and (3) feasibility using the open-source itksnap 3.0 software package without incurring extra cost for users.
Hypothesis: Semi-automatic segmentation of acetabular fractures significantly increases the rate of correct classification by orthopedic surgery residents.
Methods: Twelve orthopedic surgery residents classified 23 acetabular fractures. Six used conventional 3D reconstructions provided by the center's radiology department (conventional group) and 6 others used reconstructions obtained by semi-automatic segmentation using the open-source itksnap 3.0 software package (segmentation group). Bone fragments were identified by specific colors. Correct classification rates were compared between groups on Chi^2 test. Assessment was repeated 2 weeks later, to determine intra-observer reproducibility.
Results: Correct classification rates were significantly higher in the "segmentation" group: 114/138 (83%) versus 71/138 (52%); $P < 0.0001$. The difference was greater for simple (36/36 (100%) versus 17/36 (47%); $P < 0.0001$) than complex fractures (79/102 (77%) versus 54/102 (53%); $P = 0.0004$). Mean segmentation time per fracture was 27 ± 3 min [range, 21–35 min]. The segmentation group showed excellent intra-observer correlation coefficients, overall (ICC = 0.88), and for simple (ICC = 0.92) and complex fractures (ICC = 0.84).
Conclusion: Semi-automatic segmentation, identifying the various bone fragments, was effective in increasing the rate of correct acetabular fracture classification on the Letournel system by orthopedic surgery residents. It may be considered for routine use in education and training.
Level of evidence: III: prospective case-control study of a diagnostic procedure.

1. Introduction

In 1961, Emile Letournel published a classification of acetabular fractures based on the 3 standard X-ray views (AP, ¾ alar and ¾ obturator) and intraoperative data. Description of the anterior and posterior columns with mental 3D representation of the various fracture types distinguishes 10 types of fracture [1–4]. If it is to be useful, a classification needs to have good inter- and intra-observer reproducibility. Considering the diversity of fracture types in acetabular traumatology, most studies reported acceptable reproducibility using only standard X-rays for expert but not for inexperienced surgeons. Reproducibility seems to be improved by using CT images [5]. Correct classification rates range from 30% to 76% according to the surgeon's experience [4,5]. The contribution of 3D reconstructions is controversial. Some authors reported improved reproducibility and better understanding of fracture types [6,7]. Correct classification rates range from 52% to 65% for users with little experience. The limitations comprise the quality of certain 3D reconstructions, depending on CT-scan power. Fracture lines can be difficult to assess due to problems of resolution and/or

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Table 1
Main epidemiological characteristics of the series and fracture type distribution on the Letournel classification [2,3].

Characteristics	n = 23
Age (years)	41.8 ± 15.6
Gender (%)	
Male	20 (87%)
Female	3 (13%)
Lesion mechanism (%)	
Road accident	10 (43%)
Sports accident	10 (43%)
Work accident	3 (13%)
Fracture type	
Simple	6 (26%)
Posterior wall	2 (9%)
Posterior column	1 (4%)
Anterior wall	0 (0%)
Anterior column	3 (13%)
Transverse	0 (0%)
Complex	17 (74%)
Posterior column + posterior wall	1 (4%)
Transverse + posterior wall	5 (22%)
"T"	3 (13%)
Anterior column + posterior hemitransverse	4 (17%)
2-column	4 (17%)

loss of precision in converting pixels to voxels. The fact that these reconstructions are frozen images that cannot be freely mobilized by the user, except for some Picture Archiving and Communication System (PACS) receivers, is another drawback. In addition, the angle of view is determined by the radiologist. Despite precise protocols for 3D reconstruction and CT slice angles, some bone fragments may be difficult to identify. In semi-automatic segmentation, on the other hand, each fragment is identified by a specific color; moreover, the segmented images can be moved freely, enabling the user to locate regions of specific interest for the Letournel classification [8].

This segmentation technique, however, has not to our knowledge been assessed, and we therefore conducted a prospective study, to determine:

- whether semi-automatic bone-fragment segmentation increased the rate of correct classification;
- for which fracture types it is most effective;
- feasibility using the open-source itksnap 3.0 software package without incurring extra cost for users [9].

The study hypothesis was that semi-automatic segmentation of acetabular fractures significantly increases the rate of correct classification by orthopedic surgery residents.

2. Materials and methods

2.1. Patients

The study received institutional review board approval. Medical files were included for all patients operated on between January and December 2014: i.e., 30 patients. Twenty-three acetabular fractures had analyzable high-resolution CT-scans (minimum inter-slice distance, 2 mm; matrix, 512 × 512; slice thickness, 1.2–1.6 mm), with axial, coronal, sagittal and 3D reconstruction. Fracture type classification correlated with intraoperative findings (Table 1). Seven fractures (2 posterior wall, 3 anterior column with posterior hemitransverse fracture, and 3 of both columns) were excluded for lack of 3D reconstruction, leaving 23 cases for analysis. Table 1 shows the main characteristics of the series. The 23 patients had unilateral fractures: 3 female, 20 male; mean age, 41.8 ± 15.6 years (range, 20–65 years). Ten involved road accidents, 10 sports accidents (skiing or climbing), and 3 work accidents.

2.2. Description of method

The Letournel classification was shown to 12 volunteer orthopedic surgery residents without specific knowledge of acetabular surgery. They were in their first or second year of residency. The sex ratio was 2 females to 10 males. The open-source itksnap 3.0 software package (Yushkevich PA, Pennsylvania, and Gerig G, Utah: http://www.itksnap.org/), was used to segment bone fragments by Hounsfield thresholding, region growing and manual finishing [9]. Segmentation was performed by the first author (MB). After importing DICOM images into the software, regions of interest were selected by bone-density thresholds so as to segment only bone structures. Once these structures were identified, the software automatically performed segmentation. A specific color was attributed to each fragment (Fig. 1). Manual finishing separated fragments in comminutive fractures, using the software tools. The software allows free 3D movement of fragment models but, for the study, only exo- and endo-pelvic screen-shots were used, taken by the first author so each fragment would be displayed least once.

Six volunteer residents (1 female, 5 males) classified the 23 fractures based on 3D reconstructions made by the radiology department (conventional group). Fractures were presented in random order, for a maximum 2 minutes. Participants were told that each of the 10 Letournel types might be presented several times or not at all. Six other volunteer residents (1 female, 5 males) classified the same 23 fractures based on 3D reconstructions made by segmentation (segmentation group) (Figs. 2 and 3). The segmentation group repeated the exercise 2 weeks later, with fractures presented in a different random order, to asses intra-observer reproducibility.

2.3. Assessment method

Each participant classified 23 fractures: i.e., 138 fractures per group, 276 fractures in all. Data were collected prospectively and analyzed.

2.4. Statistics

Correct classification rates were compared between groups on Chi^2 or Fisher F test, according to sample size. Alpha risk was set at 5%. Power was calculated a posteriori:

- compared to the conventional group (23 × 6 = 138 proposed classifications, 52% of which were correct), 80% power and 5% alpha risk required at least 23% greater correct classification in the segmentation group;
- with 83% correct classification in the segmentation group (i.e., 31% improvement on the conventional performance), 138 observations were enough.

For non-parametric tests, the software automatically implemented the Fisher test. Correct classification rates were also compared between simple and complex fractures. And finally, the most frequently misclassified fracture types were analyzed. Reproducibility was assessed by intra-class correlation coefficient, following Landis and Koch [10]. Analyses used StatView 5.5 software (SAS Institute, Cary, NC, USA).