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Evaluation of Pelvic Volume Modification in "Open Book" Fractures Using a Three-Dimensional Model

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Abstract

Background: The modification of the pelvic volume strongly influences the blood loss in "open book" fractures. Assessment of the degree of the changes helps in further management of the trauma patient.

Aim: The aim of this study was to create a three-dimensional pelvic model for the measurement of pelvic size. Methods: Using computer software we created three-dimensional models of the pelvis, based on CT images of 21 patients. To simulate an "open book" pelvic fracture we generated 2, 4, 6, 8 and 10 cm pubic disjunctions on the virtual model. In each modification we measured the pelvic diameters and we calculated the pelvic volume. The mathematical model used for calculation was the truncated elliptical cone.

Results: The mean pelvic volume was 1005.97 cm^3. The transverse diameter increased significantly at 2 cm of pubic disjunction (p=0.0228). At 6 cm pubic disjunction significant modifications were noticed in promonto-suprapubic (p=0.0057) and biischiadic (p=0.0221) diameters. The pelvic volume increases significantly at only 4 cm pubic disjunction (p=0.0442). At 10 cm disjunction an increase of over 50% of the original volume occurred.

Conclusion: By measuring the pubic disjunction on CT image we can appreciate the pelvic volume increase. CT scan with bone visualization may be useful in previewing the magnitude of the hemorrhage in victims of blunt traumatic injuries associated with pelvic fracture, but further *in vivo* studies may be necessary.

Keywords

Pelvic fractures; Retroperitoneal hematoma; CT scan; Three-dimensional model

Introduction

In an "open book" pelvic ring fracture, the pubic symphysis diastasis and/or horizontal pubic branch fracture is associated with the disruption of the sacroiliac joint. The antero-posterior compression fractures type II and III (Young and Burgess Classification system) usually occurs after the impact of high-intensity energy with antero-posterior orientation, resulting in the opening of the pelvis around his craniocaudal axis. There is a direct relationship between the high mortality rate of patients and bleeding resulting from the injury [1]. In these unstable pelvic fractures the diameters of the pelvic ring increase, leading to an increased pelvic volume. The most important consequence of these geometric changes is the increase of blood loss in the retroperitoneal space [2].

The purpose of the study was to create a three-dimensional model of the pelvis and simulate an "open book" fracture for the evaluation of the pelvic volume modifications.

Materials and Methods

In this prospective study 21 CT scans were used (sex ratio 14:7 women:men, mean age 55 year), from patients who underwent routine diagnostic CT examination. None of these patients presented injuries involving the pelvic ring. A three-dimensional image of the pelvic ring was reconstructed based on CT scan images, using InVesalius 3.0 computer software (Figure 1) [3]. Cristarum distance (distance between the most prominent points of the iliac crest) was measured to further calibration purposes. The three-dimensional model of the pelvis was created using MeshLab software [4]. All elements except the bone structures were removed. The resulting three-dimensional model of the pelvis was constructed of 34.000 nodes and 60.000 facets (Figures 1 and 2).

Measurements of pelvic diameters and subsequent handling of the model was completed with Google SketchUp 8 software [5]. First the calibration to real size was performed with the previously measured bicristal distance.

To estimate the volume of the bony pelvis a mathematical representation of a truncated cone with elliptical, symmetrical bases was used. For calculations the area of the superior circle, the area of the inferior circle and the height of the truncated cone were considered. The measuring endpoints were set up. Highlighting them helps proper determination of distances in the same position after "open book" fracture simulation (Figure 3). The input parameters were measured as follows: a-representing half of the anatomical transverse diameter; b representing half of the promonto-suprapubic diameter; a'-representing half of the biischiadic diameter; b' was calculated with the following formula $b' = \frac{a.b}{a'}$ due to the symmetry of the bases; h-representing the height of the truncated cone, measured between the midpoint of promonto-suprapubic diameter and center of biischiadic distance (Figure 4). The formula for the volume of a truncated elliptical cone is as follows:

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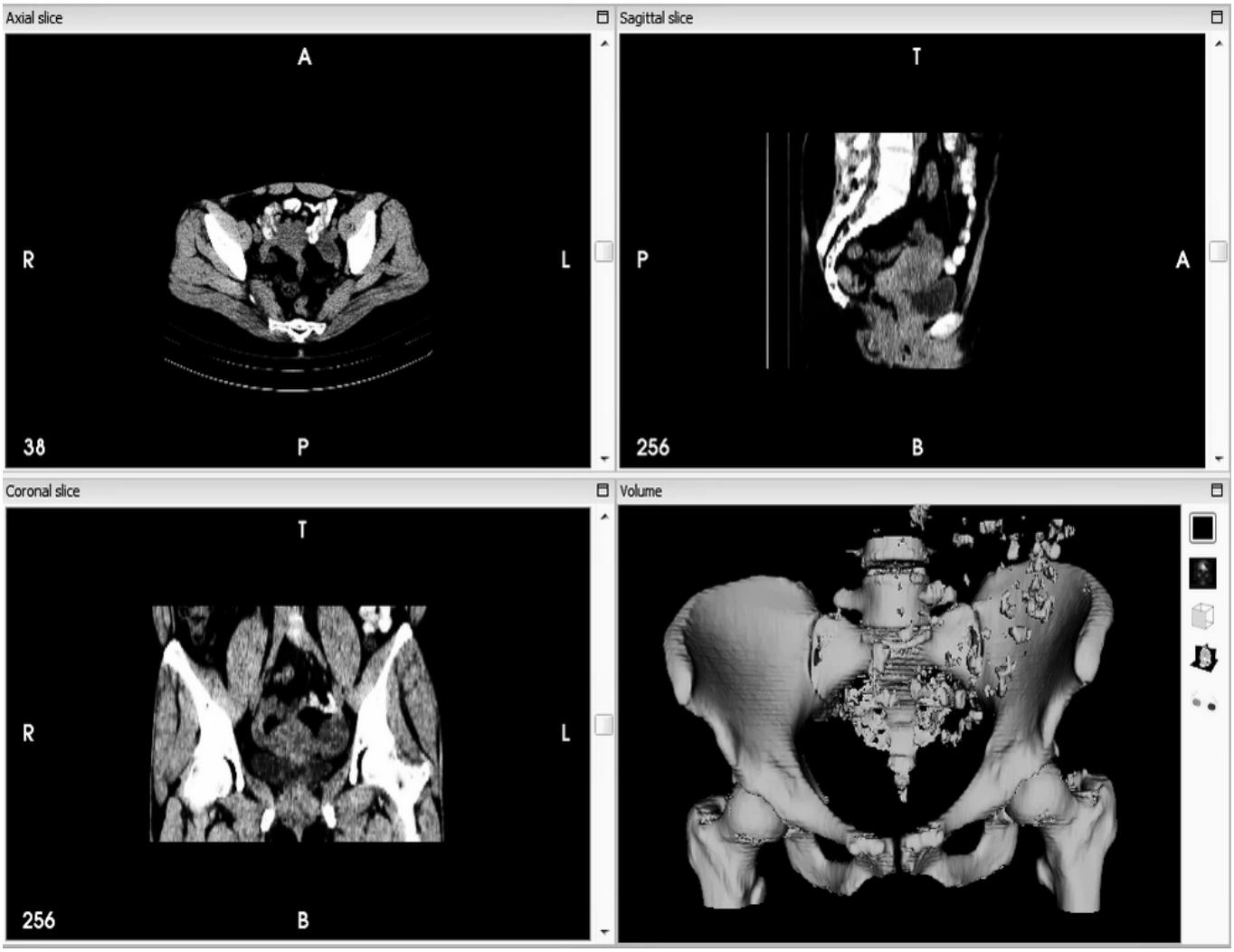

Figure 1: The pelvic bone structures reconstruction with In Vesalius 3.

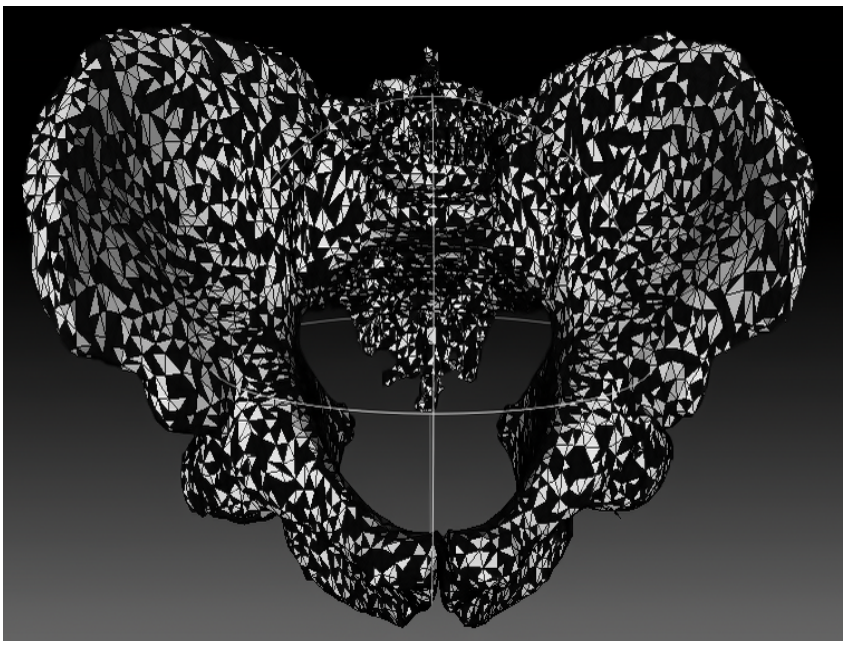

Figure 2: The three-dimensional model of the pelvis in Meshlab.

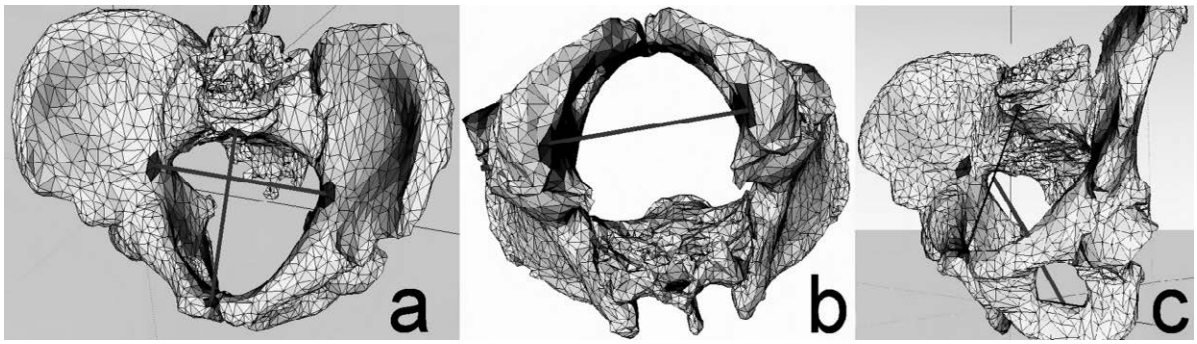

Figure 3: The reference points of the truncated cone with elliptical bases: a) superior diameters. b) inferior diameter. c) height.

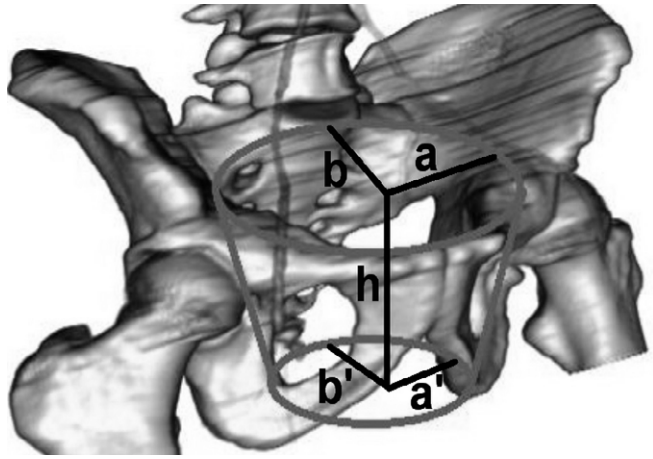

Figure 4: The mathematical model used in determining the pelvic volume.

$$V = \frac{\pi \times h}{3} \times \frac{\left(a^2 \times b - a'^2 \times b'\right)}{a - a'}$$

The fracture simulation was performed in multiple steps. The right hemipelvis was selected as a separate component of the three-dimensional model, by gathering all vertices and facets belonging to it in a single geometric entity. This part can be mobilized independently. The rotation axis of the right hemipelvis started from the inferior point of the right sacroiliac joint (Figures 3-5).

The superior point, next to the symphysis on each of the superior pubic bone branches, was used as a benchmark. By rotating the right hemi pelvis around its axis (Figure 6), the pelvic ring was opened to 2, 4, 6, 8 and 10 cm distances. After each modification the diameters were remeasured and the pelvic volume was calculated. Statistical analysis of results was performed with the GraphPad Prism 5 software using Mann Whitney non-parametric test considering statistically significant the value of $p<0.05$ (Figure 6).

Results

The pelvic volume ranged from 514.94 to 1482.96 cm^3 (1005.97 ± 266.4 cm^3, CI 95%). Significant differences were found in the pelvic volume of males and females (average of 730.1 and 1144 cm^3, respectively, $p<0.0001$). By processing the "open book" fracture simulation the transverse diameter of the pelvis increased significantly starting at 2 cm pubic disjunction ($p=0.0228$). The promonto-suprapubic diameter and the biischiadic diameter increased significantly at 6 cm disjunction ($p=0.0057$ and $p=0.0221$, respectively). The augmentation of the pelvic volume after 4 cm pubic disjunction was 168.4 cm^3 ($p=0.0442$) with an increase of over 50% of the original volume at 10 cm disjunction (Figure 7).

Discussion

High energy trauma is required for a pelvic fracture to appear. It occurs usually in association with other injuries in polytrauma patients. In "open book" pelvic fractures one can find the diastases of the pubic symphysis and/or pubic branch fracture associated with rupture of the sacroiliac joint. In most cases multidirectional instability appears. Due to the proximity of numerous blood vessels, the most important consequence of this type of fracture is potentially lethal bleeding [6].

There are few studies that evaluate the correlation between the type of pelvic fracture and the level of bleeding. In pelvic fractures caused by anteroposterior compression the necessity of blood products is greater [7,8]. The lesion of major vessels (common, internal or external iliac artery or vein) or smaller branches (superior gluteal vessels, internal pudendal or iliolumbar vessel) may occur. According to anatomical studies performed by Yiming, the most vulnerable vessel in case of sacroiliac joint rupture is the iliolumbar pedicle, due to its transverse position [1,9].

Retroperitoneal hematoma is of venous source in 90% of cases. The pressure in the retroperitoneal space may be sufficient to compress and stop the bleeding [10,11].

Studies targeting the determination of pelvic volume changes in pelvic fractures were performed on cadavers. After complete evisceration, the pelvic volume was measured by filling it with water. Baqué recorded an average volume of 872.5 cm^3. Experimental fractures were performed by direct rupture of the pubic symphysis and each sacroiliac joint, recording a 20.8% pelvic volume increase at 5 cm pubic disjunction [1].

For assessment of the pelvic volume Stover used several geometric shapes: sphere, cylinder and semi-elliptical sphere. He considered the semi-elliptical sphere model to be most appropriate [12]. In our study, which focuses on the modifications of the bony pelvis, the formula of the truncated cone with elliptical and symmetrical bases was used.

The most important moment in the simulation was to establish the rotation point of the fractured pelvic structure. The rotation point was considered the lowest point of the sacroiliac joint projected on the floor of the three-dimensional space in which the pelvic model was placed. This mobilization was allowed by the rupture of sacroiliac joint.

In our study we recorded 16.73% and 28.71% pelvic volume increase at 4 and 6 cm pubic disjunction, respectively. Our results correlate with those obtained in studies on cadavers. [1]

Performing biomechanical studies, Sigg found that the retroperitoneal hematoma, when associated with an intact pelvis, increases the retroperitoneal pressure with 5 ± 3 mmHg, 27 ± 13 mmHg and 96 ± 37 mmHg with volumes of 0.5 L, 1.0 L and 1.5 L, respectively. Induced "open book" fracture decreases the retroperitoneal pressure significantly compared with an intact pelvis.

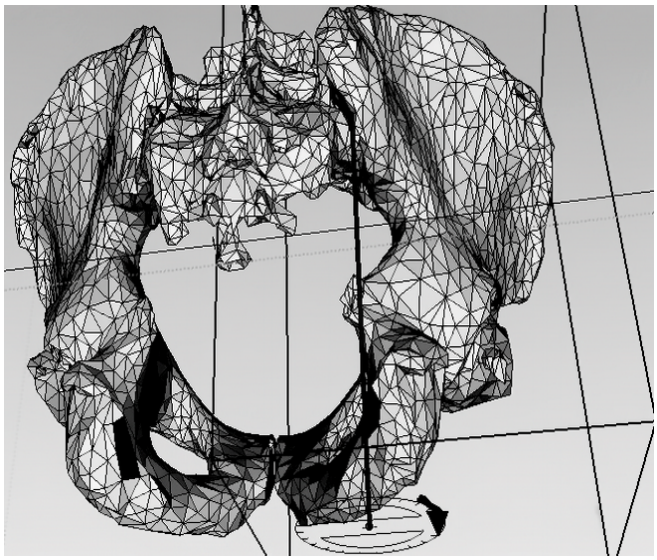

Figure 5: The rotation point of the right hemipelvis.

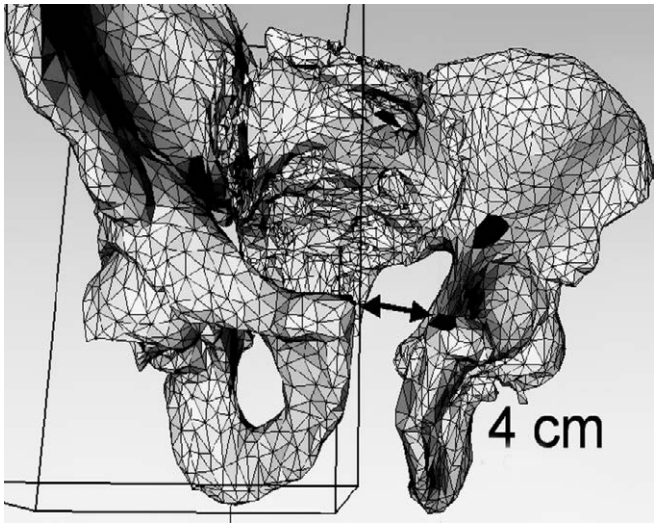

Figure 6: Simulation of the "open book" pelvic fracture with 4 cm pubic disjunction.

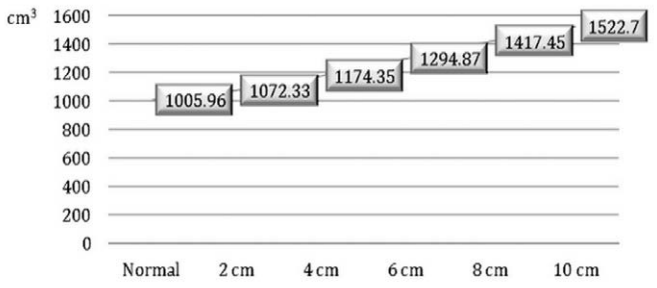

Figure 7: The variation of the pelvic volume in "open book" pelvic fracture.

In the absence of a retroperitoneal hematoma the reduction of the partially stable or unstable pelvis does not increase the retroperitoneal pressure significantly. Only in the presence of a 1.5 L hematoma appears significant increase in pressure once reducing a partially stable (6.7 mmHg) or unstable pelvis (7.4 mmHg). A local retroperitoneal hematoma can cause a sufficient increase in pressure to stop a venous bleeding [13].

Ghanayem concluded that the abdominal wall ensures stability for the pelvic ring. Laparotomy destabilizes "open book" fracture by increasing the volume of the pelvis and can lead to the re-expansion of the retroperitoneal hematoma by simple decompression [14]. This leads to higher blood loss and delayed tampon effect.

Conclusion

Our study certifies that the measurements based on computed tomography images implemented on a three-dimensional model correlates with reality and can be used in medical practice. The 4 cm pubic disjunction causes a significant increase of the pelvic volume. The 10 cm pubic disjunction appears to increase the pelvic volume with over 50%. The CT scan with bone visualization may be useful in previewing the magnitude of pelvic volume changes and can influence further management of the trauma patient.

Conflict of Interest and Acknowledgement

The Authors declare that there is no conflict of interest in this paper. Informed consent was obtained from all individual participants included in the study. Authors would like to thank engineer Máthé Sándor for his valuable contribution in the development of the three-dimensional model.

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