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3D-DIC in the service of orthopaedic surgery: Comparative assessment of fixation techniques for acetabular fractures

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A B S T R A C T

Three dimensional Digital Image Correlation (3D-DIC) is used in the present study in combination with traditional clip gauges to assess the efficiency of osteosynthesis techniques widely applied to fixate acetabular fractures. Thirty-five cadaveric semi-pelvises were artificially fractured and fixated with the aid of various combinations of either simple or locking fixation plates and screws. The fractures simulate a variation of the acetabular fractures known as “T-type”. The fixated constructs were properly supported to simulate single-leg stance. Quasi-static loading under displacement-control mode was monotonically imposed until one out of two predefined failure criteria (related either to the load attained or the displacement induced) was satisfied. It was proved that 3D-DIC, besides its advantages related to the full-field description of the displacement field, is an extremely valuable recording tool for the needs of the present protocol since it permits post-mortem evaluation of the relative displacement and relative sliding of the fixated parts, relieved from the influence of rigid body displacement and rotation. Proper elaboration of the data provided by the 3D-DIC system, implemented on the basis of an alternative assessing criterion, permitted a “fair” comparison between the fixation techniques, in terms of the response of all three independent fractures forming the specific variation of the T-type fracture. It was concluded that suitable combination of simple and locking reconstruction plates offers increased stability of the fixated semi-pelvises, compared to the other fixation techniques studied.

1. Introduction

The human pelvis supports the spine during the stance phase as well as during various complicated motions (walking, running, jumping, etc.) and transfers various types of loads exerted on the upper part of the body to the lower limbs. At the same moment it protects a series of important and very delicate organs, while for the female body it forms, also, the “bone tube” through which the embryo passes during the vaginal delivery. Although there are quite a few anatomic differences between male and female pelvises the main characteristics are common for both genders: The pelvis consists of two semi-pelvises, each one of which is divided into three parts, i.e. the Ilium, the Ischium and the Pubic bone (Fig. 1a and b) and it is characterized by two columns denoted as posterior and anterior (Fig. 1c). During the very first period of human life the

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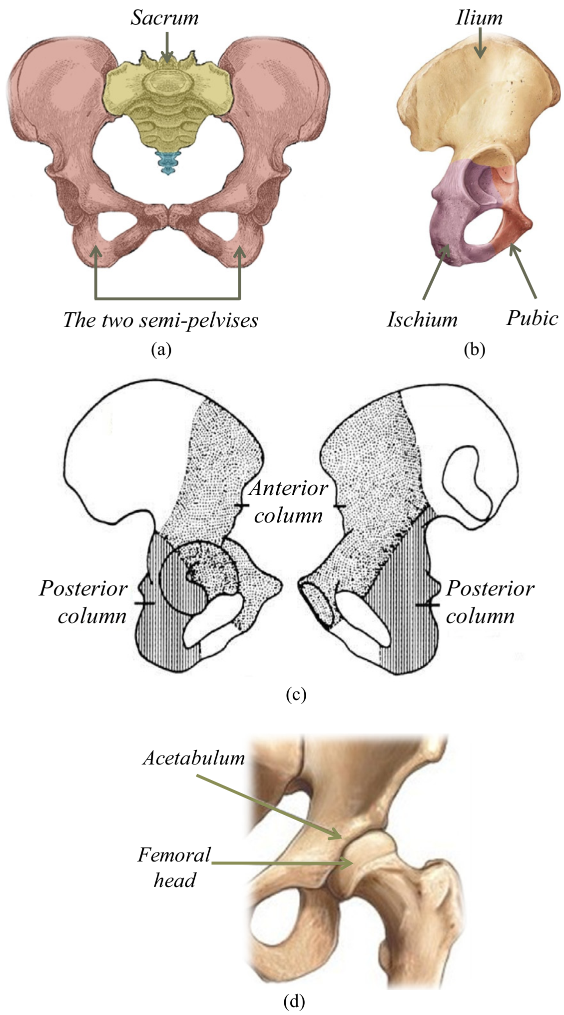

Fig. 1. Schematic representation of: (a) The pelvic ring, (b) the three parts of each semi-pelvis, (c) the posterior and anterior columns and (d) the hip joint.

three parts of the semi-pelvis are independent. Gradually, as the human skeleton becomes mature, they are joined together, forming a semi-spherical "cavity" known as acetabulum. This cavity "hosts" the head of the femur forming one of the strongest joints of the human body (Fig. 1d). The two semi-pelvises are joined together along the pubic symphysis and also they are joined to the sacrum forming the pelvic ring (Fig. 1a).

The pelvic ring is an essential element for the equilibrium of the human body. In fact the center of mass of the human body is located within the pelvic ring. In addition the pelvic ring is the intersection "point" of the lines of action of the forces exerted by the upper part of the body and the reactions exerted by the two femurs. The magnitude of the forces exerted on the pelvic ring is difficult to be accurately quantified, however it is estimated that the compressive ones may attain values equal to about 5.5 kN while the shear ones may reach values equal to about 1.2 kN, depending of course on the kind of human activity (walking, running, standing up, sitting down, stair climbing, etc.). It is mentioned characteristically that even during normal walking the magnitude of the forces exerted on the pelvic ring may exceed four times the weight of the body. The vectorial representation of the forces exerted on the pelvis, as well as the spatial distribution of the components of the stress field developed due to the action of these forces, is an extremely complicated task that concerns Biomechanics from its very first steps of development. The specific task is well beyond the scope of the present study. For the reader interested in the specific topic some relatively recent studies (of either experimental or numerical or hybrid nature) are mentioned here (only indicatively), like the ones by Rydell et al. [1], Crownshield et al. [2], Oonishi et al. [3], Bergman et al. [4–6], Dalstra et al. [7,8], Anderson et al. [9], Philips et al. [10], Shim et al. [11], Clarke et al. [12], Ghosh et al. [13] and Kourkoulis and Kyriakou [14].

From an engineering point of view the pelvis is an extremely sophisticated layered structure, of extremely complicated geometry. Its thin external layer (cortical bone) carries the major part of the forces exerted on the pelvis while the internal one (trabecular bone) is more or less load-free. In this way the pelvis, despite its volume, remains a relatively light structure

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