Predictive criteria for the development of thoracolombar posttraumatic kyphosis, based on 3D and finite elements models

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Secondary posttraumatic deformity is a relatively common complication following the thoracolumbar fractures treatment, be it surgical or conservative. Often asymptomatic, it may also involve pain and normal spinal balance alteration, disturbing daily life activity and general wellbeing.

Amongst the causes associated to this complication, the most frequently mentioned in the literature are the vertebral fracture level, the type of surgical treatment and the fracture severity. From a biomechanical standpoint, it is considered that the level of strain on each vertebra varies according to the super-adjacent weight and the force arm which are specific to the vertebral position on the spine. This qualifies the vertebral level as a potential predictive and explanatory factor for posttraumatic deformity. Moreover, most surgeons identify the thoracolumbar junction (T12-L1) as the most often affected segment.

Regarding the surgical procedure, posterior short segment fixation (PSSF) stands out as the most frequent approach. Along with multiple advantages, it presents the important detriment of unsatisfactory support for the damaged anterior column. Biomechanical research indicates that the PSSF device ensures only 40-70% of the rigidity of intact spine. Thus, the fractures treated with PSSF are frequently followed by loss of correction (LOC) or the deterioration of instrumentation.

Thirdly, once fractured, the vertebral body loses its biomechanical function of supporting the supra adjacent body segment. The support capacity may, hence, decrease proportionally to the degree of vertebral body fragmentation.

Considering the aforementioned theoretical premises, the doctoral research followed two main stages. The first involved a statistical approach to assessing the predictive function of the three hypothetical factors as well as their significance.

To this end, the first analysis considered a database of 175 patients with single level T11-L3 fractures. Correlation tests and linear regressions were performed, where the regressand is the difference between the post-surgery and the last follow-up (at least one year post-operative) kyphotic angles (LOC) and the regressor is the fractured vertebra level.

A second study was conducted on a lot of 586 patients with single level T10-L5 thoracolumbar fractures, which had been surgically treated with posterior short segment fixation (PSSF), PSSF with intermediate screws inserted at the fracture level and, respectively, PSSF with kyphoplasty. The three statistical subgroups were compared with ANOVA test against the “loss of correction” parameter.

Another batch of 287 patients data was the object of the third analysis. The statistical units were patients with single level T11-L5 fractures operated on with three different procedures: posterior short segment fixation, posterior monosegmental short segment fixation and anterior approach. We built and tested simple and multiple linear regression models, where the explained variable is the final (one year post-surgical follow-up) kyphotic angle and the explanatory variables are, either alternatively or simultaneously, the operation type, the fractured vertebra level and pre-operative kyphotic angle. The last variable was chosen as a proxy for the degree of the vertebral body fragmentation, or, in other words, the severity of the fracture.

Following these analyses, we have been able to draw several conclusions, which served as the starting point for the second research stage.

Firstly, it is apparent that the level of biomechanical stress that is laid on the vertebrae is, indeed, conditional on the position they hold on the vertebral spine. Thus, the secondary deformation affecting the fractured thoracolumbar spine, treated either conservatively or surgically, follows distinct patterns that have been depicted through best fit correlation equations specific to the position of the fractured vertebra on the column. Nevertheless, our research also presents statistically non-significant differences between the measured angles.

Furthermore, we have noticed that the operative procedures that rebuild and provide support to the anterior fractured column – such as, for example, posterior short segment fixation with kyphoplasty – are followed by the smallest level of correction loss.

In addition, the multifactorial regression models suggest that, even if some of the theoretical assumptions are validated, they explain at most 45% of the variation in the last follow-up kyphosis angle, while the other 55 percentage points may be explained by other factors not considered in our research, such as the movement type, body weight or bone density. The maximum explanatory power is associated with a regression model where the input variables were high pre-operative kyphotic angle, a thoracolumbar junction level of the fracture and monosegmental posterior short segment fixation.

The statistical approach indicates the preoperative kyphotic angle of the fractured vertebral body as the most relevant among the three potential predictive factors. Therefore, our research has further concerned particularly this element and the capacity of the fractured vertebral body to sustain super-adjacent structures.

The second phase of the doctoral research involved the 3D reconstruction of a real case of conservatively treated L1 fracture, based on the CT scan. Using the method of finite elements, the evolution of the fractured vertebral body was simulated, taking into consideration the phenomena and forces acting on the fracture in the daily life. We also simulated hypothetical situations by varying several parameters of the real case.

Three other distinct studies were conducted in this stage. The first one consisted of the construction of the 3D model based on the real medical data. The material properties of the modeled anatomic elements were predefined, according to the patient's age and weight. Subsequently, the model was subject to the mechanical forces associated to immobilization with a three-point thoracolumbar orthosis. We also simulated the case of the patient temporarily suspending immobilization that involves different stressing forces.

The second study simulated three hypothetical cases for the same fracture - (a) young overweight patient; (b) old patient, of normal weight; (c) old and overweight patient – in order to assess if weight and age are predictive factors for the level of kyphotic angulation of the fractured vertebral body.

The third study aimed to objectivise the changes in the flexion axis of the super-adjacent body and to identify the possible associated consequences on ligament apparatus and spine stability.

Simulating, with the finite elements method, the evolution of a real fracture case has showed that the secondary angulation of the fractured vertebral body is not the result of the pure axial compression force, but its association with the flexion movement. This observation is in accordance with the statistic result that indicated the thoracolumbar junction as the most affected segment, this being the most solicited area of the spine in flexion movement. Other factors, such as the body weight or age do not seem to a have significant impact on the final outcome, as long as the bone stock is of appropriate quality/

The association between high weight and low bone resistance (yet not osteoporotic) synergetically accentuate the angulation of the fractured vertebral body.

The simulation exercise highlighted a phenomenon not mentioned before in the literature: when the flexion involves one intact and one fractured vertebral body, the instantaneous centre of flexion is posterior shifted and this biomechanical change may bring forth, in the medium or long run, the deterioration of the posterior ligament apparatus with late secondary instability of the segment. This observation needs further research for validation.

Acknowledgement

This paper is partly supported by the Sectorial operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU 80641.