Significant roentgenographic parameters for evaluating the flexibility of acute thoracolumbar burst fractures

An in vitro study

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Summary. Plain lateral radiographs in a neutral position were studied in ten acute thoracolumbar burst fractures produced by high speed impact on three vertebrae human cadaveric spine segments. Six linear geometric parameters were measured on each film. The ratio of each value in the neutral injured to the intact condition was correlated linearly with the motion parameters obtained from post-traumatic three-dimensional flexibility data (neutral zone NZ; range of motion ROM). Anterior unit height (vertebra + adjacent discs) had the highest correlation with the neutral zone and flexibility in all directions, especially flexion-extension (NZ, $R^2 = 0.93$; flexion ROM, $R^2 = 0.86$; extension ROM, $R^2 = 0.79$) lateral bending (NZ, $R^2 = 0.83$; ROM, $R^2 = 0.90$) and right axial rotation (NZ, $R^2 = 0.53$; ROM, $R^2 = 0.86$). The deformation ratio (average height to depth) correlated most with the neutral zone in left axial rotation ($R^2 = 0.91$) and right lateral bending ($R^2 = 0.92$). Due to the high correlations obtained, these parameters should be evaluated in clinical situations to assess their effectiveness in predicting the instability of burst fractures. Ultimately, prospective clinical studies are required to verify their clinical utility.

Résumé. Les radiographies latérales en position neutre de dix fractures thoracolombaires aiguës comminutives provoquées par un impact à haute vitesse sur trois colonnes vertébrales de cadavres humains ont été étudiées. Six paramètres géométriques linéaires ont été mesurés sur chaque film.

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Le rapport entre les valeurs des conditions neutres après l'impact et des conditions avant l'impact a été mis en corrélation avec les paramètres de mouvement (zone neutre, NZ; proportion du mouvement, ROM) obtenus à partir des données post-traumatiques de flexibilité tridimensionnelles. L'unité de hauteur antérieure (vertèbre plus disque adjacent) eut la plus haute corrélation avec la flexibilité en flexion-extension (NZ, $R^2 = 0.93$; flexion ROM, $R^2 = 0.86$; extension ROM, $R^2 = 0.79$), courbure latérale (NZ, $R^2 = 0.83$; ROM, $R^2 = 0.90$) et la rotation axiale à droite (NZ, $R^2 = 0.53$; ROM, $R^2 = 0.86$). Le rapport de déformation (moyenne de la hauteur par rapport à la profondeur) correspond plus avec NZ lors de la rotation axiale à gauche ($R^2 = 0.91$) et lors de la courbure latérale droite ($R^2 = 0.92$). Vu les fortes corrélations obtenues, ces paramètres devraient être évalués en clinique pour évaluer leur efficacité dans la prédiction de l'instabilité des fractures comminutives. Finalement, des études cliniques prospectives sont nécessaires pour vérifier leur utilité clinique.

Introduction

Holdsworth described vertebral burst fractures in 1970 and considered that they were due to explosion of the body caused by fracture of the end plate and intrusion of the disc [11]. He regarded this as a stable fracture because of the intact posterior ligament complex.

However, CT scanning has shown that many burst fractures had disruption of the posterior ele-

ments, such as laminar fractures or apophyseal joint separation, and therefore were considered unstable [10, 12, 13, 15, 18]. Increasing evidence of progressive or post-traumatic kyphosis and neurological deficits has required further evaluation of their stability [3, 16, 17, 26].

The idea of the three column spine was introduced to evaluate post-traumatic instability [6]. Other studies have suggested that various geometric measurements on lateral radiographs represent the stability of the fracture [17, 27, 29]. McAfee et al. considered that a decrease of 50% or more of vertebral body height seen on lateral radiographs indicated instability, but they did not describe their method of measurement [18]. Willen et al. used anterior, central and posterior compression of the fractured vertebra to analyse instability and evaluate their patients [27]. They considered that a compression ratio of the anterior column exceeding 50% was a predictor for complications. The relationship between acute instability and radiographic parameters has not been based on objective data.

In these studies, only the changes in the vertebral body were investigated, although it is now established that the intervertebral disc/end plate unit is damaged in burst fractures. Such injuries affect spinal flexibility and stability [14], so that if the disc geometry is not included in the assessment, less than optimal stability would be predicted.

The relation between the stability of acute burst fractures and the CT fracture pattern has been established [19, 22], but plain lateral radiographs are the simplest and most practical method of assessment and provide the whole profile of the body-disc unit.

The goal of the present study was to determine whether a relationship exists between various geometric measurements on lateral radiographs and the acute flexibility of thoracolumbar burst fractures, and to find out whether the *in vitro* study provides parameters which can be used clinically.

Material and methods

Preparation of specimens

Twelve human cadaveric spines, without a history of injury, were frozen at -20°C until tested. The average age was 51 years (range 19 to 70 years) with an equal number of men and women. The three-vertebra segment specimens (ten from T11 to L1 and two from T12 to L2) were dissected free of nonligamentous soft tissues. The upper and lower vertebrae were mounted in polyester resin casts with their geometric centres aligned vertically.

The trauma apparatus [21]

This consisted of a mass falling through a Plexiglas tube 1.6 m high. The mass struck an impounder which was guided by linear bearings to slide vertically. The impounder rested on the top surface of the superior vertebral mounting. The initial impact mass was 8.3 kg in 8 cases and 4.3 kg in 4. If this did not produce a burst fracture, an additional 2 kg was added until a fracture occurred.

The burst fracture was defined as a fracture of both anterior and posterior walls of the vertebral body and was verified by CT scanning.

Flexibility test

Before and after the trauma, multidirectional flexibility testing was performed using a stereophotogrammetric method [21]. Pure moments of flexion, extension, bilateral axial torque and bilateral lateral bending, and the forces of tension and compression were applied individually to the top vertebral mount. Each moment and force was applied in three equal steps to maximum values of 7.5 Nm and 300 N respectively. Each load was cycled three times and three-dimensional motion measurements were taken on the third load cycle after 30 s of creep. The motions given here are Euler angles of the top vertebra with respect to the bottom vertebra of a three-vertebra segment.

For each load application, there were 6 motion components, 3 Euler angles and 3 translations. We report only 8 main motions, eg. flexion rotation due to flexion moment, and axial

Fig. 1. Diagram showing the linear parameters used to describe the geometry of burst fractures: AVH, anterior vertebral height; PVH, posterior vertebral height; VD, vertebral diameter; AUH, anterior unit height; PUH, posterior unit height. The deformation ratio (DR) was defined as $2VD/(AVH+PVH)$

translation due to tension. For each load motion curve, 2 parameters were computed, the neutral zone (NZ) and the range of motion (ROM). The NZ is the residual motion at the beginning of the third load cycle and the ROM is the displacement at maximum load. As there were 8 loads, the total number of parameters measured was 8 NZ and 8 ROM.

Radiographic analysis

Before and after the fractures occurred, lateral radiographs were taken in neutral posture with a scale in the midsagittal plane for calibration. This posture was created by the application of a small flexion moment which was produced by an anteriorly directed force (39N) above the centre of rotation. This was designed to simulate the clinical conditions of acute thoracolumbar burst fractures. The reason for this neutral posture has been described [14].

Geometric parameters

For each specimen, 6 linear parameters were measured: anterior vertebral height (AVH), posterior vertebral height (PVH), vertebral diameter (VD), anterior unit height (AUH), posterior unit height (PUH) and deformation ratio (DR) in the intact and injured specimens (Fig. 1). Each parameter was defined as follows:

- AVH: the perpendicular distance between the anterosuperior edge and the line parallel to the inferior end plate of the fractured vertebra.
- PVH: the perpendicular distance between the posterosuperior edge and the line parallel to the inferior end plate of the fractured vertebra.
- VD: the largest width of the fractured vertebra in the sagittal plane.
- AUH: the distance between the anteroinferior edge of the vertebra above and the line parallel to the superior end plate of the lower vertebra below, including the disc spaces above and below.
- PUH: the distance between the posteroinferior edge of the vertebra above and the line parallel to the superior end plate of the lower vertebra below, including the disc spaces above and below.
- DR: the ratio of VD to the average of AVH and PVH (not shown in Fig. 1).

Correlations

The ratio of each geometric parameter from the injured to the intact was correlated with each of the 16 motion parameters from the three dimensional flexibility tests. A simple pairwise Pearson correlation analysis was performed.

Results

Ten burst fractures were produced in twelve specimens based on CT evaluation. All the correlation coefficients and the statistical significance between the geometric and motion parameters are listed in Table 1. The results are summarised below; some of the relationships are illustrated in graphs showing both the individual data points and the linear regression line.

Flexion-extension

The AUH was the geometric parameter which correlated most with flexion-extension motion. Highly significant correlations were observed for each of the motion parameters NZ ($R^2 = 0.93$), flexion ROM ($R^2 = 0.86$) and extension ROM ($R^2 = 0.79$). The corresponding linear regression lines are plotted for each of these motion parameters (Fig. 2). The other 5 geometric parameters also had significant correlations with the NZ and the flexion-extension ROM ($P < 0.05$). The AVH and PVH showed the lowest correlations with the NZ and ROM, although they were statistically significant.

Lateral bending

Under both right and left lateral bending moments, the DR correlated most highly with both NZ

Fig. 2. Relationship between flexion-extension NZ, flexion and extension ROM, and the anterior unit height (AUH). The least-squares linear regression lines are drawn through each set of data points

Fig. 3. Relationship between the right and left lateral bending NZ and the deformation ratio (DR). The least-squares linear regression lines are drawn through each set of data points

Table 1. Simple pairwise correlation coefficients (R^2) between the geometric parameters measured on lateral radiographs and the motion parameters determined from the three-dimensional flexibility test. The statistical significance of the relationships are identified as follows: * for $P < 0.05$ and ** for $P < 0.0001$. Note that for convenience we have added a coordinate system as follows: Positive x, y and z directions are respectively left, superior and anterior. M and F stand for moment and force, respectively

	AVH	PVH	VD	DR	AUH	PUH
Flexion (+Mx)						
NZ	0.60**	0.37*	0.77**	0.76**	0.93**	0.75**
ROM	0.48*	0.23*	0.55*	0.52*	0.86**	0.60**
Extension (-Mx)						
NZ	0.60**	0.37*	0.77**	0.76**	0.93**	0.75**
ROM	0.58**	0.32*	0.65**	0.67**	0.79**	0.64**
Right lateral bending (+Mz)						
NZ	0.63**	0.65**	0.87**	0.92**	0.82**	0.84**
ROM	0.63**	0.54*	0.80**	0.83**	0.90**	0.79**
Left lateral bending (-Mz)						
NZ	0.60**	0.61**	0.88**	0.89**	0.84**	0.83**
ROM	0.45*	0.37*	0.86**	0.68**	0.91**	0.74**
Left axial rotation (+My)						
NZ	0.57**	0.69**	0.67**	0.91**	0.51*	0.68**
ROM	0.62**	0.56**	0.80**	0.91**	0.75**	0.75**
Right axial rotation (-My)						
NZ	0.16	0.06	0.50*	0.21*	0.53*	0.24*
ROM	0.55*	0.32*	0.77**	0.69**	0.86**	0.62**
Tension (+Fy)						
NZ	0.16	0.03	0.04	0.04	0.13	0.02
ROM	0.64**	0.46*	0.65**	0.72**	0.83**	0.62**
Compression (-Fy)						
NZ	0.21*	0.17	0.77**	0.49*	0.64**	0.56**
ROM	0.05	0.04	0.47*	0.19	0.52*	0.43*

parameters ($R^2 = 0.89$ and 0.92 , $P < 0.0001$) (Fig. 3). The VD, AUH and PUH all correlated highly ($P < 0.0001$) with the NZ in lateral bending. These 4 geometric parameters also correlated most highly with lateral bending ROM, each being

statistically significant. The AUH had the highest correlations with the ROM ($R^2 = 0.90$, 0.91 for right and left lateral bending).

Axial torque

The DR correlated best with both motion parameters NZ and ROM (both $R^2 = 0.91$) in left axial torque. These correlations for DR were much weaker for right axial torque, indicating some asymmetry of the burst fractures. In right axial torque, the highest correlations with both NZ and ROM were with AUH geometric parameters (NZ: $R^2 = 0.53$, $P < 0.05$; ROM: $R^2 = 0.86$, $P < 0.0001$).

Tension-compression

Under axial tension forces, none of the geometric parameters had a significant correlation with axial translation NZ. In contrast, all 6 geometric parameters had significant correlations with ROM, the highest being with AUH ($R^2 = 0.83$, $P < 0.0001$).

Fig. 4. Relationship between the tension and compression ROM and the anterior unit height (AUH). The least-squares linear regression lines are drawn through each set of data points

In axial compression, only the PVH did not correlate with the NZ parameter. The VD, AUH and PUH parameters had significant correlation with axial translation ROM (Fig. 4).

Discussion

Instability has been said to be an indication for operation in thoracolumbar fractures [6, 27]. Judgement of instability has been based on retrospective studies of the pathological anatomy of these fractures [6, 18, 28, 29] or on clinical reviews of the outcome [25]. Various criteria have been proposed, for example a decrease in vertebral height of more than 50% [5, 17], an anterior compression over 50% [27], and a kyphotic angle greater than 35° [24] or 15° [9]. None of these are based on objective data, partly because of the inherent variability of retrospective studies, the timing of mobilisation, the methods of reduction and the patients' cooperation.

The in vivo loads producing these burst fractures have been thought to be axial compression with or without flexion moments [6]. After fracture, an anteriorly eccentric compression may force the vertebra into kyphosis [12, 17]. The radiographic geometry of the neutral position in our specimens had similar values to those found in clinical studies, including the anterior and posterior vertebral heights, and the angle of the local kyphosis [8, 9, 14, 17, 24, 27, 29]. Measuring the orientation of the specimen under a flexion moment in the neutral position is therefore justified.

Although burst fractures have associated disc and end plate injuries, most of the clinical parameters indicating post-traumatic instability have been based on the bony deformity, such as AVH and PVH [9, 27]. The vertebral body contributes 40% of post-traumatic motion [14], so it seems reasonable to include the two adjacent discs when determining more comprehensive geometric parameters. We found that AUH and PUH, which include the disc heights, showed greater correlation than AVH and PVH in the evaluation of instability. Therefore, by including intervertebral disc heights, the anterior and posterior unit heights become more effective predictors of spinal instability.

In axial rotation and lateral bending, the deformation ratio parameter (DR) had high correlations with the neutral zone parameters, and is determined by changes in vertical compression and horizontal expansion. Its influence on changes of the neutral zone were obvious and its linear positive correlations were the highest of the instability

parameters, so it may be the best choice for clinical use. Although the neutral zone is a meaningful parameter in the kinematics of the spine, it has not been used clinically [20]. Perhaps some of the measurements which showed high correlations to the neutral zone could be useful clinically to make an indirect evaluation.

CT has many advantages in detecting displaced fractures of the posterior wall and any free bony fragments in the spinal canal. Our in vitro study has shown that plain lateral radiographs, correctly measured, are able to evaluate acute instability of thoracolumbar burst fractures. Further prospective clinical studies are needed for evaluation.

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