The Magnitude of Angular and Translational Displacement of Dens Fractures is Dependent on the Sagittal Alignment of the Cervical Spine rather than the Force of Injury

Sabina R Blizzard, BA, Bala Krishnamoorthy, PhD, Matthew Shinseki, BS, Marcel Betsch, MD, Jung Yoo, MD

Oregon Health & Science University
Department of Orthopaedics and Rehabilitation
3181 SW Sam Jackson Park Road, Mail stop OP31
Portland, OR 97239
Fax: (503) 346-6844
Telephone: (503) 494-6406

Sabina R Blizzard, BA, blizzars@ohsu.edu
Bala Krishnamoorthy, PhD, bkrishna@math.wsu.edu
Matthew Shinseki, BS, matt.shinseki@gmail.com
Marcel Betsch, MD, marcel.betsch@gmx.de
Jung Yoo, MD yooj@ohsu.edu (Corresponding author)

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Abstract

Object: Although it is generally believed that the magnitude of dens fracture displacement is proportional to the amount of force applied to the cervical spine during injury, the factors responsible for displacement have not been studied. Our aim was to determine factors which contribute to horizontal and angular displacement of dens fractures.

Methods: In this retrospective review, angular and horizontal displacements of the fractured dens in 57 patients were measured. Cervical lordosis was measured between C2 and T1. C3-4, C4-5, C5-6, and C6-7 disc inclination angles were measured. Antero-posterior sagittal balance was assessed by comparing the sagittal position of the C2 body to the C7 body. Subjects were grouped based on mechanism of fracture: motor vehicle accident, ground level fall, and higher falls. Data were analyzed using Pearson correlations, independent t-tests, and support vector regression to construct predictive models that determine factors contributing to the angular and horizontal displacements.

Results: The mean horizontal displacement of the fractured dens was not significantly different among groups. However, the dens in those with ground level falls had a significantly greater mean fracture angle compared to the higher energy trauma groups ($p=0.01$). There were positive correlations between angular displacement and C5-6 disc space inclination angle ($r=0.67$, $p<0.01$) and C6-7 disc space inclination angle ($r=0.61$, $p<0.01$). There were positive correlations between horizontal displacement and C6-7 inclination angle ($r= 0.4$, $p<0.01$) and sagittal alignment ($r=0.32$, $p<0.01$). The predictive model using all variables demonstrated that angular fracture displacement was dependent only on C5-6 disc space inclination angle. Horizontal displacement was dependent only on C6-7 inclination angle and antero-posterior sagittal balance.

Conclusions: Disc space inclination angles of the lower cervical spine and the cervical sagittal balance most contribute to the magnitude of angular and horizontal displacement of the dens after fracture.

Level of Evidence: III

Key words: Angular displacement, Cervical spine, Dens fracture, Fracture displacement, Horizontal displacement, Odontoid fracture, Trauma.

Introduction

Cervical spine fractures are among the most serious spinal fractures, since they are associated with a high rate of morbidity and mortality[2,14-16,20,26]. The epidemiology of these fractures appears to be quite distinct from other cervical fractures, as their incidence has a uniquely bimodal age distribution, affecting young active males and elderly patients of both genders. In fact, second cervical vertebra (C2) fractures are the most commonly fractured cervical vertebrae in elderly patients[19,23-9], and have a high reported incidence of associated mortality[14,16-18]. A recent study demonstrated that the rate of cervical vertebral fractures in the elderly population is increasing faster than the population growth[29].

Dens fractures require unique treatment strategies because of the distinctive anatomy and function of the dens. Conservative treatments have high rates of failure due to malunion and nonunion, therefore surgical treatment is often necessary. Unfortunately, surgical treatment often requires fusion across the atlanto-axial segment, depriving the patient of approximately 60% axial rotational motion of the cervical spine[10].

Despite the prevalence of dens fractures and their increasing consequence to the overall health of the population, there is a paucity of research addressing the factors that influence the healing potential. Existing literature demonstrates that age, displacement, and angulation are the factors that significantly influence the healing of dens fractures[3,9,13,21,22,24]. It is believed that the magnitude of displacement and angulation are positively correlated to the magnitude of the force applied to the cervical spine at the time of injury. However, there is no literature to support this belief. Our specific aims were (1) to determine if the horizontal displacement or angle of the fractured dens was dependent on patient gender, age, or mechanism of injury (low, moderate, or high energy trauma); and (2) to determine which *combination* of variables (age, gender, cervical lordosis, cervical vertebral inclination angles, or sagittal balance), as opposed to the individual variables considered in isolation, best predicts dens fracture displacement and angulation. In particular, we are *not* analyzing subsets of data, e.g., for just old subjects or just type II patients. Our goal is to explore the *interactions* of all variables including age, gender, mechanism, etc., over the entire dataset. The outcome of these analyses should allow clinicians to be more cognizant of the factors that will lead to failure of treatment.

Materials and Methods

The study was performed with Institutional Review Board approval. We conducted a retrospective review of adult patients who were admitted to our level one trauma center between 1/1/2008 and 12/31/2013. As part of our routine protocol, these trauma patients received a cervical CT scan in lieu of plain radiographs. Patients who sustained a dens fracture and obtained a CT scan on the day of injury were included in the study. We obtained age, sex, fracture type and the mechanism of injury from the medical records. The Anderson and D'Alonzo classification system for identifying dens fracture type was used[1]. The mechanism of injury was classified as motor vehicle accident (MVA), fall from height (HF) or a ground level fall (GLF). Oncologic cases were excluded. Sagittal reconstructions of CT scan images were used to obtain the following measurements which were made independently by two authors:

Fracture horizontal displacement: Measurements were made from the anterior margin of the proximal C2 body to the anterior margin of the inferior fractured dens for anteriorly displaced fractures (Figure 1, measurement A), and from the posterior margin of the proximal C2 body to the posterior margin of the fractured dens for posteriorly displaced fractures (Figure 1, measurement B). We assigned anteriorly displaced fractures a negative value to correspond with their translation in the negative x-axis, and a posterior displacement with a positive value.

Fracture angulation: Measurements were made by drawing one line through the midsection of the vertebral body and a second line through the midsection of the dens fragment on sagittal reconstruction CT images. The angle subtended by these two lines represented the degree of fracture angulation. We defined a posterior angulation as a positive value (Figure 1, measurement C) and an anterior angulation as a negative value (Figure 1, measurement D).

Cervical lordosis: Measurements were made using the Cobb angle method[8]. A line was drawn parallel to the inferior endplate of C2 and the superior endplate of C7Lordosis angle was defined as a positive value and the kyphosis angle was defined as a negative value.

Antero-posterior sagittal balance: Two parallel vertical lines were drawn on the sagittal image: one from the middle of the C2 inferior endplate and one from the middle of the C7 inferior endplate. The distance between these perpendicular lines was defined as the antero-posterior sagittal balance, and represents the anterior position of C2 relative to C7 (Figure 2).

Inclination angle: We defined the inclination angle as the sagittal angle of the disc space in relation to the long axis of the vertebral body. This is analogous to measuring sacral inclination angle of lumbosacral junction[7]. Two lines were drawn: one through the middle of the disc space and one perpendicular to the CT table. The resulting angle represented the caudally directed angulation of the disc space (Figure 3).

Statistical Analysis

The magnitude of fracture displacement and degree of fracture angulation were compared with age, cervical lordosis, inclination angle at every disc level from C3-4 to C7-T1, and sagittal balance using Pearson correlations. Mean differences of degree of fracture angulation or magnitude of fracture displacement were compared between the sexes and among the mechanisms of injury using analysis of variance of the means, with $p<0.05$ considered statistically significant.

Support Vector Regression Model

We employed support vector regression (SVR)[6] for function estimation within 10-fold cross validation[4] to build and test models for predicting fracture angulation and fracture displacement. The SVR framework is a state-of-the-art method for robust regression, and has several advantages over simple linear regression. SVR has seen increased use in many subfields of medicine, including surgery[1,5,11,25,28]. In particular, a variety of linear and nonlinear functional forms, or kernels, can be tested to obtain the best fit in SVR, as opposed to the single linear function available for linear regression. Furthermore, many ranges of values could be tested for the parameters defining each functional form. The framework also allows one to seamlessly employ continuous variables (age, inclination angles, etc.) along with categorical variables (sex, mechanism, fracture type, etc.) in a model. At the same time, building the model using cross validation (where 9 out of 10 parts, or folds, of the data are used to build each candidate model, which is then tested on the unused remaining fold) avoids overfitting. Such models are thus guaranteed to be more robust when used on fresh data, than models built using the entire data set.

The performance of each model was evaluated by computing the root mean squared deviation (RMSD) between the actual and predicted values of fracture angulation or displacement (lower value indicates better fit), and the Pearson correlation coefficient (r) between these two sets of values (higher r indicates better fit). We tested each variable individually, and then tested all input variables together, as well as several subsets of all variables. Of all these choices of groups of variables, we identified the most predictive model, i.e., the overall best model (smallest RMSD, equivalently highest r). To compare individual variables to the group of variables giving the overall best model, we report the p-value for testing whether the performance of the variable in question was statistically significantly worse than that of the overall best model. A p-value of <.05 means the variable alone is not statistically more predictive of fracture angulation and displacement than the best model.

Results

Sixty-five patients were admitted to our institution's trauma center with dens fractures in the 5-year time period. Eight patients were excluded who experienced unusual fracture mechanisms such as sports-related injury and assault, as the energy of injury in these cases could not clearly be categorized. The 57 remaining patients had radiographic imaging and medical records available for this study. Thirty (52.6%) were male and 27 (47.4%) female. Patient age ranged from 19 to 97 years (63.1 ± 24.9 years for males and 74.7 ± 14.3 years for females). Type II dens fractures were diagnosed in 38 (66.6 %) of the cases. Type III fractures were diagnosed in the remaining 19 cases. Dens fractures occurred from a motor vehicle accident in 19 cases, from a high level fall in 4 cases, and from a ground level fall in 34 cases.

The interrater reliability (concordance) between reviewer measurements was assessed; correlation coefficients ranged from 0.91 to 0.98, indicating strong agreement between reviewers. There were no significant differences between males and females in the degree of dens fracture angulation

($p>0.05$) and the magnitude of dens fracture displacement ($p>0.05$). The age of those who sustained fracture due to ground level falls was significantly greater than from higher-energy trauma ($p<0.05$). The mean absolute horizontal dens fracture displacements were not significantly different among the fracture mechanism groups ($p>0.05$). There was, however, a significant difference in mean absolute fracture angle between ground level falls and high level falls, and between ground level falls and motor vehicle accidents ($p =0.01$) (Table 1).

We found positive Pearson's correlations between horizontal displacement and both C6-7-disc inclination angle ($r=0.40$, $p<0.01$) and sagittal alignment ($r=0.32$, $p<0.01$).

While the initial statistical analysis described above identified possible differences based on mechanism of injury, a more comprehensive predictive analysis as described below revealed that mechanism is not significantly predictive when other variables are included in the consideration.

Support Vector Regression Model

The details of the best predictive models for fracture angulation using individual as well as groups of variables are given in Table 2. Using all ten variables (sex, age, C3-4, C4-5, C5-6, C6-7 inclination angles, C2-7 lordosis, antero-posterior sagittal balance, fracture mechanism, and fracture type) produced the most predictive model, with the smallest RMSD of 9.41 and largest r value of 0.76. However, this model was not significantly more predictive than the model using C5-6 inclination angle alone ($p=0.12$). Therefore, C5-6 inclination angle alone is statistically as predictive of the degree of fracture angulation as the model using all significant variables together. In particular, although the C6-7 disc space inclination angle in isolation predicts the fracture angle well, the C6-7 measurement did not contribute statistically significantly to the performance of the best predictive model when C5-6 inclination angle is included in the model.

The details of the best predictive models for horizontal fracture displacement using individual as well as groups of variables are given in Table 3. Among the individual variables, C3-4 inclination angle, C4-5 inclination angle, C5-6 inclination angle, C6-7 inclination angle, sagittal balance, mechanism, and fracture type were strongly predictive of fracture displacement. A Gaussian model combining these seven variables was the most predictive, with RMSD=3.02 and r=0.62. Similar to the fracture angulation data, the combined model was not statistically significantly more predictive than the best models using any of the 7 individual variables listed above. At the same time, the overall best model was also not statistically significantly more predictive than the best model using just the two variables C6-7 angle and sagittal balance (r =0.55, p=0.34). Hence these two variables together contributed more to the overall best predictive model, while the other variables did not contribute significantly to the model.

Discussion

It is believed that the level of traumatic energy correlates with the magnitude of translational and angular displacement of a fractured bone. However, our results suggest that such a direct correlation between traumatic energy and the displacement of dens fractures may not exist. In fact, the final displacement of the fracture appears to be inversely related to the presumed energy level. The greatest angulation of the fracture was seen with ground level falls, followed by falls from height; the least displacement of the fracture was seen with motor vehicle accidents. This suggests that dens displacement after fracture is related to factors independent of the force applied to the dens at the time of the injury.

We employed the state-of-the-art framework of support vector regression (SVR) to derive the predictive model, which is designed to compare *all* statistically relevant independent variables and derive the fewest number of independent variables that can predict the effect (angulation or displacement) as well as contribute to the model that includes all statistically correlated variables. We did not analyze subsets of data separately for groups, e.g., old or male subjects, but analyzed the entire data set together. In particular, although there is a strong correlation between angular displacement and C6-7 disc space inclination angle (r=0.59), this correlation is significantly lower (p=0.03) than the correlation between angular displacement and the group of all variables. At the same time, the latter correlation is *not* significantly higher (p=0.12) than the correlation between C5-6 inclination angle and angular displacement. In other words, C6-7 measurement did not contribute to the model when C5-6 inclination angle was included. This is because the inclination angle of C5-6 and C6-7 are not independent of each other and the addition of both does not contribute as much to the modeling as the C5-6 measurement alone. Modeling therefore eliminated many independent variables that are correlated with one another and used only the variables that are significantly independent of each other.

Our results demonstrate that the two factors contributing most to the displacement models are antero-posterior sagittal balance and lower cervical disc inclination angles. These two measurements are created by the position of the cervical spine relative to the rest of the torso. While the patient is lying on the CT table in a supine position, a cervical spine with greater inclination angle at the lower cervical disc space (i.e. more flexed at the lower cervical spine) obtains extension through the fracture itself, resulting in greater angulation at the fracture site. If the resting position of the C2 body is much more protracted to the C7 body than to the head, the head is more likely to be suspended from the table. In such patients, posterior translation of the fracture would result from a posteriorly directed force of gravity.

It is readily understandable that the angular positioning of the lower cervical spine will contribute to the angular displacement of the upper cervical fracture. However, translational displacement of the dens appears to be more complex. The resulting translational displacement is correlated to both sagittal balance between C2 and C7 and the inclination angle of the lower cervical spine. However, like the angular displacement, factors such as sex, age, and mechanism did not contribute to the risk model when lower cervical inclination angle and the sagittal balance were included in the model. This observation is significant when one considers the default notion that young and old subjects would exhibit different behavior in this context. Therefore, it is interesting that although our data set included both young and old patients, our robust statistical modeling did not find a significant correlation between age and the predicted variables when other significant factors were also included.

Although there appears to be higher displacement with lower energy trauma, this finding is due to a relationship between the covariables. Older patients are more likely to sustain a dens fracture from a fall (lower energy mechanism) and have greater sagittal imbalance and greater flexed posture of the lower cervical spine. When these two variables were included in the model, the mechanism of injury did not contribute to the magnitude of displacement.

Sagittal balance may impact healing potential and therefore clinical outcome. Our findings suggest that challenges in reduction of dens fractures associated with older patients may be associated with cervical spine anatomy interfering with maintenance of proper alignment when the patient is in the supine position thus decreasing stability and fracture surface contact. Therefore, understanding the position of preinjury posture and restoring alignment may improve their healing potential.

There are several weaknesses of the study. The influence of bone mineral density was not assessed, although it has been generally accepted that low bone density is a major contributing factor to vertebral fracture risk[12,27]. Due to the retrospective nature of the study, bone mineral density measurements were not available for a large number of our patients. Another limitation is that there is no independent confirmation that the patient is absolutely horizontal and the head rested on the backboard. However, we assumed that this was the case as this was the protocol and there is no documentation of deviation from the protocol. Finally, this is an analysis of retrospective single institution data with relatively small sample size. However, the statistical relationship between the independent variables (sagittal alignment of subaxial spine) and dependent variables (translational and angular displacement) are strong and the methodology outlined in this study can be easily applied to any retrospective or prospectively collected data for cross validation.

We believe that this is the first study to demonstrate that the most important factor in dens displacement is the sagittal alignment of the subaxial spine. This information may be valuable to surgeons as they incorporate subaxial cervical alignment into their treatment strategies for dens fracture patients.

Conclusion

Our study demonstrates that sagittal alignment of the lower cervical spine contributes significantly to the angular and translational displacement of the dens after fracture. Treatment strategies need to focus not just on the deformity at the fracture site but also on the overall alignment of the cervical spine.

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Figure Captions

Figure 1: CT scans of dens fracture displacement. Arrows indicate the position where the measurement (in mm) was made for anteriorly displaced fractures (A) and posteriorly displaced fractures (B). Dens fracture angle was measured as a posterior fracture (C) or anterior fracture (D) by connecting two lines: one drawn through the mid-portion of vertebral body and one drawn through the mid-portion of the fracture fragment.

Figure 2: The cervical antero-posterior sagittal balance was measured as the forward translation of C2; vertical lines were drawn from the midpoints of inferior endplates of C2 and the inferior endplate of C7. The arrow depicts the horizontal distance (mm) measured between the two lines. This distance represents the relative sagittal balance.

Figure 3: Sagittal disc space inclination was measured as the angle between intersecting lines made by the line bisecting the disc space and the line drawn parallel to the CT table.

Table 1. Characteristics of dens fracture cases studied in our dataset. The last row lists the *p*-values showing whether the mean displacement and angulation values were significantly different between the three subgroups of subjects according to mechanism (see the….

Mechanism	N	%Male	%Female	Age ± SD	|Horizontal Disp| ± SD (mm)	|Fx Angle| ± SD (degrees)
MVA	19	58	42	50.3 ± 23.5	2.6 ± 2.6	8.5 ± 8.7
HF	4	50	50	64.8 ± 19.0	2.0 ± 2.1	7.5 ± 2.3
GLF	34	41	59	80.3 ± 7.5	2.7 ± 2.9	18.8 ± 14.0
p-value					> 0.05	0.01

Table 2. Predictive models for fracture angulation.

Variables used	Model	RMSD	*r*	*p*
Individual Variables				
Sex	Linear	14.36	−0.27	0.00
Age	Sigmoid	13.39	0.34	0.00
C3-4 Inclination	Sigmoid	11.31	0.61	0.05
C4-5 Inclination	Sigmoid	11.51	0.59	0.03
C5-6 Inclination	**Sigmoid**	**10.70**	**0.66**	**0.12**
C6-7 Inclination	Sigmoid	11.60	0.59	0.03
C2-7 Lordosis	Gaussian	13.86	0.24	0.00
Antero- Posterior Sagittal Balance	Sigmoid	12.72	0.44	0.00
Mechanism	Gaussian	13.38	0.38	0.00
Fracture Type	Sigmoid	13.27	0.39	0.00
Subsets of Variables				
C34, C45, C56, C67	Polynomial (d=4)	9.53	0.75	0.42
All 10 variables	**Polynomial (d=4)**	**9.41**	**0.76**	-

Table 3. Predictive models for fracture horizontal displacement.

Variables Used	Model	RMSD	*r*	*p*
Individual Variables				
Sex	Gaussian	3.79	0.22	0.00
Age	Linear	3.57	0.35	0.03
C3-4 Inclination	Sigmoid	3.46	0.42	0.08
C4-5 Inclination	Sigmoid	3.44	0.42	0.08
C5-6 Inclination	Sigmoid	3.51	0.43	0.10
C6-7 Inclination	**Gaussian**	**3.33**	**0.48**	**0.18**
Lordosis C2-7	Linear	3.58	0.33	0.02
Sagittal Balance	**Gaussian**	**3.38**	**0.48**	**0.16**
Mechanism	Gaussian	3.54	0.39	0.06
Fracture Type	Sigmoid	3.60	0.44	0.10
Subsets of Variables				
All 10 Variables	Gaussian	3.04	0.60	0.49
C6-7, Sagittal Balance	Gaussian	3.17	0.55	0.34
Inclination angles (C3-4, C4-5, C5-6, C6-7), Sagittal Balance, Mechanism, Fracture Type	**Gaussian**	**3.02**	**0.62**	**-**

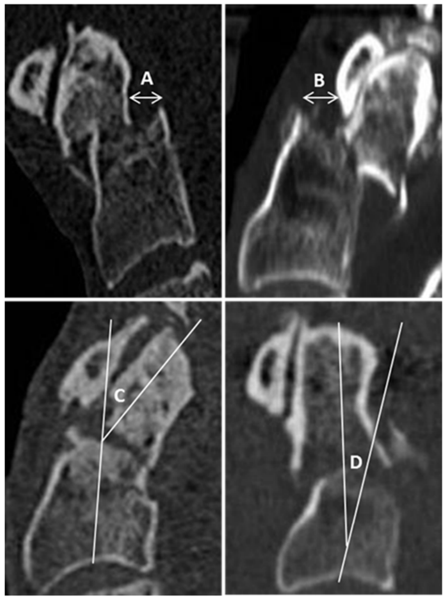
A
B
C
D

Fig. 2

Fig. 3