A retrospective study was made of 173 cases of acute cervical spine injury with halo vest management to compare initial injury features with outcome. The object was to determine whether a mathematical model could be developed enabling a prediction to be made at the time of the initial assessment as to the probability of success or failure of conservative management using the halo vest alone, and thus perhaps avoid lengthy, unsuccessful treatment.

Patients with facet joint dislocation were found to form a distinct subgroup of the injury population. Of the 70 patients in this subgroup, 44% achieved stability with the halo vest alone, but half of these had a "poor anatomical result." No mathematical model or associated injury features could be found to assist in the outcome prediction in this subgroup. Of the 103 patients without facet joint dislocation, 70% achieved stability with the vest alone and over 75% of these had a "good anatomical result." A useful model of outcome prediction was found for this subgroup by logistic regression analysis; the two most important predictors in the model were the amount of subluxation and the degree of angulation in the sagittal plane.

KEY WORDS • cervical spine • spinal injury • halo vest immobilization • prognosis model

Since James first reported on the use of a halo apparatus in the management of cervical spine fractures in 1960, a debate has continued in the neurosurgical and orthopedic literature on the role of this device in the early management of lower cervical spine injuries (C3-7). Although use of the vest has been shown to provide many advantages and has led to wide acceptance, it has not entirely replaced the need for surgery to achieve stability.

Koch and Nickel evaluated the movement and compression-distraction forces at individual levels in patients wearing a halo apparatus and found motion averaging 31% of normal, due to "snaking" or the "clothes-line" effect. White, et al., made a biomechanical analysis of stability in cadaver cervical spines and demonstrated that destruction or loss of function of all of the anterior or posterior elements, horizontal displacement of greater than 3.5 mm, or more than 11° of angulation rendered the cervical spine unstable. To date, no similar study has been undertaken in the clinical situation with specific measurement of traumatic injuries and subsequent spinal instability of patients managed in the halo vest. The purpose of this study was to determine whether a mathematical model could be developed to enable prediction at the time of the initial assessment as to the probability of success or failure with conservative management in the halo vest, based on specific measurements and features of the initial x-ray films.

Clinical Material and Methods

The study included 173 patients suffering cervical spine fracture from C-3 to C-7 inclusive, with and without cord injury. These patients were managed in the Spinal Cord Injury Unit at Sunnybrook Medical Centre. The philosophy of this unit has been to manage patients conservatively whenever possible, using closed reduction by traction and subsequent early mobilization in the halo vest apparatus. In general, reduction was attempted by the sequential addition of weights in 3- to 5-lb increments up to a maximum of 60 lbs. Once transferred to a vest, patients were quickly mobilized while being monitored frequently with radiographs. If there was no evidence of subluxation, the patients were followed up with routine clinical examinations and repeat radiographs at 4-weekly intervals prior to removal of the vest at 12 weeks postinjury. Stability at
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this time was checked with dynamic x-ray films in flexion and extension. If stable, the patients were then provided with a cervical collar to be worn for 1 month when walking. The patients then returned for follow-up review including repeat dynamic cervical spine x-ray films in flexion and extension.

Presentation Data
Initial plain x-ray films were available for all patients included in the study. Conventional tomograms were obtained for 132 patients and computerized tomography (CT) scans for 95 patients. A careful study and measurement of all plain x-ray films, conventional tomograms, and CT scans were performed by both authors to define the details of the injury. The features studied included: 1) the level of injury and the presence of secondary involvement of other adjacent and/or distant levels; 2) measurements of horizontal subluxation, expressed as a percentage of the width of the adjacent vertebral bodies; 3) the direction of subluxation: anterior or posterior; 4) measurements of degree of angulation made in the sagittal plane on the initial plain lateral x-ray films taken in the neutral position; 5) the presence of facet joint abnormalities such as dislocation or perching, partial subluxation, or widening of the joint space; 6) fracturing of individual elements of the vertebrae at the primary (most severely injured) site and any secondary levels involved; 7) widening of the interspinous space; and 8) the presence of premorbid pathological changes.

Other data obtained included the patient’s age and the weight required to achieve closed reduction of the injury. The neurological grade according to Frankel, et al., and the Sunnybrook Medical Centre’s scales was determined on admission, at discharge from the hospital, and at the final follow-up examination.

Treatment Outcome Measurement
Treatment outcome was classified into one of six groups. Group 1: Surgery was required for spinal cord or radicular decompression (“neurological deterioration”). Group 2: Surgery was required for failure to achieve satisfactory closed reduction (“failure to reduce”). Group 3: Surgery was required for “slip in halo vest” with inability to maintain adequate closed reduction. Group 4: Surgery was required for instability following removal of the halo vest (“late instability”). Group 5: No surgery was required, but only a “poor anatomical result” (subluxation ≥ 20% of width of vertebral body; angulation ≥ 15°; and/or persistent perched or dislocated facet joint) was achieved. Figures 1 and 2 show examples of poor and borderline-poor anatomical results. Group 6: No surgery was required and a “good anatomical result” (subluxation < 20%, angulation < 15°, and reduction of facet joint dislocations) was achieved. Figure 3 shows an example of a borderline-good anatomical result.

Statistical Analysis
Statistical analysis was performed by logistic regression. Attempts to fit a logistic regression model were
made using stepwise and forced analysis of all and of selected variables. Analysis of the contribution of various injury features to the prediction of probability of outcome was performed on all the patients as a group and on the following two subgroups: 1) patients with facet joint dislocations, both unilateral and bilateral; and 2) patients without facet joint dislocations.

Fracture features were analyzed with regard to outcome in several subgroups. The role of fracture of a particular element (such as pedicle), irrespective of the presence of fracture of another element, was examined.

### Results

#### Patient and Injury Data

The 173 patients studied ranged in age from 13 to 83 years (mean ± standard deviation: 31.5 ± 13.7 years). There were 131 males and 42 females. Forty-three patients had an acute complete spinal cord injury, 56 had evidence of incomplete spinal cord or radicular injury, and 65 had no neurological deficit (Table 1). Figure 4 presents the level of injuries. Single injury levels were present in 82% of patients, with 15% having injury at a second distinct level and 2% with injury at three levels. Preinjury pathological changes were evident in 22 patients: three had evidence of ankylosing spondylitis; three had severe degenerative changes; 15 had mild to moderate degenerative osteoarthritic changes; and one had the Klippel-Feil syndrome.

#### Outcome

The major subgroups for analysis included patients with either uni- or bilateral facet joint dislocation or without dislocations.

**Entire Group.** Of the 173 patients, 102 (59.2%) were managed conservatively in a halo vest and 71 (41.8%) underwent surgery. Figure 5 presents the details of these two groups. The following variables were analyzed by logistic regression: age, subluxation, angulation, facet dislocation, fracture of vertebral bodies, fractures of facets, fracture of pedicles, fracture of laminae, fracture...
Patients With Facet Joint Dislocation. Of the 70 patients with facet dislocation, 38 had unilateral and 32 bilateral facet dislocation. There was no significant difference in stability outcome between those with unilateral and bilateral dislocation, but there was a statistically significant difference (chi-square = 16.7, p < 0.001) between patients with and without facet joint dislocation. Figure 6 shows the details of this subgroup of patients.

Attempts to fit a logistic regression model forcing the number of facets dislocated, angulation, number of associated fractures, and weight required to achieve closed reduction as predictors of a "good anatomical result" (without any surgery) failed to produce a statistically significant model (chi-square = 8.69, p = 0.07, R = 0.101).

Patients Without Facet Joint Dislocation. The group of 103 patients without facet joint dislocation was analyzed separately (Fig. 7). Fitting a logistic regression model with subluxation, angulation, and number of columns fractured as predictors of "good anatomical result" (without surgery) failed to produce a statistically significant model (chi-square = 55.4 with 3 df and p < 0.001).

In this model, the coefficients associated with subluxation alone on outcome can be seen in Fig. 8 left, and on angulation alone in Fig. 8 right.

Although the number of columns fractured contributed to the logistic regression model, its associated
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FIG. 8. Surface charts showing further instability in patients managed in the halo vest with increased subluxation (left) and the effects of angulation (right). Sx = symptoms.

FIG. 9. Histogram showing the effect of increased numbers of column fractures on instability and outcome in patients without facet joint dislocation. Sx = symptoms.

Discussion

The fact that failure of immobilization of spinal injuries can occur in a halo vest is well known. Such failures in the vest presumably occur as a result of the residual mobility that occurs at individual segments of the cervical spine in the presence of an unstable spine. Nevertheless, in spite of such movements in the vest, many patients with unstable spinal injuries go on to heal with the aid of this orthosis, which enjoys wide popularity and use. The many advantages of management in the halo vest over conservative management using prolonged bed rest in traction have been discussed in the literature.

The Logistic Regression Model

Initially, all individuals studied were included in the logistic regression analysis. The model had a significant p value (p = 0.001), but the R value was only 0.411 and the sensitivity and specificity were 81.4% and 75.4%, respectively. This model did not appear to offer a predictive power much better than the expected clinical judgment. Therefore, we subdivided the patient population into two groups: those with and those without facet joint dislocation. Both simple chi-squared analysis as well as our initial model showed significant differences in outcomes between these two groups.

Patients With Facet Joint Dislocation

The clinical relevance of persistent dislocation of facet joints is not known. If we ignore return of correct anatomical alignment and look only at the questions of clinical stability (as determined by patient symptoms and flexion/extension radiographs), then 44% of the group with facet dislocation achieved stability with conservative management in the halo vest. Furthermore, if we exclude the 16 patients who underwent surgery for failure to achieve closed reduction, then 56% (of 54 patients) achieved stability with halo vest treatment alone.

We were unable to identify any features of the initial injury which could be used in the prediction of probability of outcome beyond the simple presence or absence of facet joint dislocation. Specifically, neither the number of facets dislocated, the presence of associated fractures (including facet fractures), nor the degree of angulation in the sagittal plane could be significantly correlated with outcome. At the onset, it was our clinical impression that greater weight required for reduction correlated with greater stability once reduced. While the mean weight required to achieve closed reduction was higher in the "good anatomical result" group (30.9 lbs) than in the "poor outcome" group (24.8 lbs), the standard deviations (up to 22 lbs) were too high to make this of use in prediction. Other authors have also found no contribution from the factors of age, sex, numbers of facets dislocated, or level of injury.

Patients Without Facet Joint Dislocation

The patients without facet joint dislocation showed a significantly different outcome from those with facet joint dislocation (p < 0.001), and hence this group was analyzed separately. The two injury features which were
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found to contribute most strongly to a model of outcome probability were angulation and subluxation. It is of note that White, et al., in their laboratory study of stability of cadaver cervical spines, described angulation and subluxation as two of the three key elements of instability. They stated that angulation in excess of 11° (when compared with adjacent segments) or subluxation in excess of 3.5 mm (allowing for magnification on clinical x-ray films) is associated with instability.

We measured subluxation as a percentage of the width of adjacent vertebral bodies to avoid the variability in magnification and it is evident that poor outcome increases markedly in patients with subluxation beyond the range of 12% to 15% (12% to 15% subluxation probably approximates well with 3.5 mm as described by White, et al., see Fig. 8 left). The direction of subluxation (anterior vs. posterior) did not independently appear to significantly affect outcome. With regard to angulation, the relationship between angulation and outcome appears more linear (Fig. 8 right). White, et al., stated that destruction of all anterior or posterior elements is the third key element of instability. They defined anterior elements as all bone and ligamentous structures anterior to the posterior longitudinal ligament (PLL) and posterior elements as those posterior to the PLL. Clinically, it is often not possible to tell whether ligaments have been damaged except by inference from subluxation and angulation. Indeed, some of the patients included in our group without facet dislocation would show major posterior ligamentous injury only on flexion films. Because flexion films were not performed routinely on all of the patients in the study for a variety of reasons, all measurements of subluxation and angulation were recorded from the initial films taken in the neutral position. We were, however, able to identify the presence or absence of fracturing of the various vertebral elements with the aid of CT and conventional tomography. Unfortunately, our series is too small to provide meaningful analysis of the influence on outcome of all of the many and varied combinations of fractures. Nevertheless, sufficient examples of fractures of each of the vertebral elements (when not studied separately) existed to demonstrate a lack of significant association with outcome prediction. To further increase our sample sizes, we grouped patients with fractures of the various columns and compared the outcomes of these groups. Figure 9 appears to show a progressive decline in good outcome as the number of fractured columns increased. Although contributing to the overall model significance, the coefficient associated with this variable was not statistically discernible from zero.

The logistic regression model for the prediction of probability of outcome in this group of patients presents good statistics using the variables: angulation, subluxation, and number of columns fractured. The p value was highly significant (p < 0.001) with a chi-squared value of 55.4. A traditional 2 × 2 diagnostic table is shown for this model in Table 4. As illustrated, the model provided 94.7% sensitivity (true-positive rate, 54 of 57) and 78.8% specificity (true-negative rate, 26 of 33), when a probability of p > 0.05 was taken to predict a “good” result and p < 0.5 to predict a “poor” result.

Conclusions

1. Patients with a facet joint dislocation must be regarded as a distinct population with outcome statistics quite different from those without such dislocations. Of this group, 44% achieved stability using conservative management in the halo vest without surgery, but almost half of these 44% (21.4% of the total) failed to retain “good” anatomical alignment. No statistically significant or useful model of outcome prediction could be found for this group. We were unable to find any associated injury features in these patients which added to prediction of anatomical outcome at the time of injury.

2. Of the patients without facet joint dislocation, 70% achieved stability with the halo vest alone and 75% of these achieved “good” anatomical alignment. The variables angulation and subluxation are the most significant contributors to this model. Subluxation in excess of 15% and angulation greater than 10° are associated with high probabilities of instability or poor anatomical outcome.

3. The number of patients exhibiting instability subsequent to removal of the halo vest (in which they had been managed exclusively) was small (2.9% of all patients). Patients whose vertebral alignment slipped in the vest tended to suffer this complication early in the course of their management.

4. “Good or poor anatomical alignment” is a radiological definition and its clinical importance is not yet clear. This is a subject of another study by the senior author.

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