Vertical translocation: the enigma of the disappearing atlantodens interval in patients with myelopathy and rheumatoid arthritis. Part I. Clinical, radiological, and neuropathological features


Departments of Surgical Neurology and Radiology, The National Hospital for Neurology and Neurosurgery, London, United Kingdom; and Department of Morbid Anatomy, London Hospital Medical College, London, United Kingdom

This statistical comparison between patients with cervical myelopathy secondary to horizontal atlantoaxial subluxation and those with vertical translocation is designed to elucidate the mechanisms responsible for cranial settling and the effect of translocation on the development of spinal cord compression.

In a 10-year study of a cohort of 256 patients, 186 suffered from myelopathy and 116 (62%) of these exhibited vertical translocation according to the Redlund-Johnell criteria. Vertical translocation occurred after a significantly longer period of disease than atlantoaxial subluxation ($p < 0.001$). Translocation was characterized clinically by a high cervical myelopathy with features of a cruciate paralysis present in 35% of individuals compared with 26% who exhibited horizontal atlantoaxial subluxation ($p = 0.29$), but there was a surprising paucity of cranial nerve problems. The patients with vertical translocation had a greater degree of neurological disability ($p = 0.002$) and poorer survival rates ($p = 0.04$).

Radiologically, vertical translocation was secondary to lateral mass collapse and associated with a progressive decrease in the atlantodens interval ([ADI], $r = 0.4$; $p < 0.001$) and pannus ($p = 0.003$). Thirty percent of patients exhibited an ADI of less than 5 mm. This phenomenon has been termed pseudostabilization. The authors’ studies emphasize that the ADI (frequently featured in the literature) is totally unreliable as an indicator of neuraxial compromise in the presence of vertical translocation.

**KEY WORDS** • basilar impression • cervical vertebra • cranial settling • rheumatoid arthritis • vertical translocation

**Clinical Material and Methods**

This was a prospective observational study, in the course of which 256 patients were recruited over a 10-year period (1983–1993). Of the total, 186 patients had myelopathy (Ranawat Classes II, IIIA, and IIIB)$^{35}$ and underwent spinal surgery (stabilization and decompression). This subgroup of patients forms the basis of this study. All of the patient data were collected prospectively and stored in a relational database system in five files (Demographic, Preoperative, Radiographic, Surgical, and Postoperative), which detail the clinical and radiological findings in each patient. Detailed autopsy reports were also available for eight patients with vertical translocation who died during the period of this study.$^{17}$

The two groups of patients with myelopathy, those with vertical translocation,$^{77}$ and those with horizontal atlantoaxial subluxation, were compared.

Patients were assessed by using several clinical grading/scoring systems, including the Ranawat classification for neurological grading (I–IIIIB),$^{35}$ the American Rheumatism Association functional grading system (Grades I–IV) developed by Steinbrocker, et al.,$^{39}$ and the Stanford Health Activity Questionnaire Disability Index. The degree of weakness was assessed using the Medical Research Council Grading system,$^{39}$ and spasticity was assessed using a four-point descriptive scale for both upper
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and lower limbs (none, moderate, severe, bilateral). The Ritchie index was used as an overall indicator of joint inflammation. All of the clinical data were recorded and collected prospectively by experienced spine research fellows.

Radiographic details were determined by means of plain cervical radiographs and computerized tomography (CT) myelography, which more recently has been complemented by magnetic resonance (MR) imaging. All radiological measurements were made on three occasions and the mean value was selected. The amount of pannus was graded by the radiologist (supplemented by information provided by the surgeon derived from findings at transoral surgery in 67 patients) into four groups: 1) none; 2) a small amount of fluid; 3) a moderate amount of fibrous tissue; and 4) exuberant, florid pannus. Interpretation of the radiological studies was completed under the supervision of the consultant neuroradiologist (J.S.).

Statistical Analysis

Statistical analysis was performed using parametric and nonparametric methods (Student’s t-test and one-way analysis of variance and the Mann–Whitney and Kruskal–Wallis tests). Categorical data were compared by using the chi-square test. Survival analysis was performed using the Kaplan–Meier method and differences in survival rates between the two groups were calculated using the log rank test (Mantel–Haenzsel test). Pearson’s correlation method was also used. To avoid type I errors, significance was only accepted at the p < 0.01 level for correlations and at the conventional level of p < 0.05 for the other analyses.

Results

Clinical Findings

A statistical comparison between those patients with horizontal atlantoaxial subluxation uncomplicated by vertical translocation and those with vertical translocation is presented in Table 1. There was no statistical difference between the groups with respect to age at onset of rheumatoid arthritis or of neurological presentation, duration of neurological symptoms, occipitocervical pain, or previous medication (steroids, azothioprine, gold). However, the patients with vertical translocation had had rheumatoid arthritis for an average of 6 years longer than those with horizontal atlantoaxial subluxation (95% confidence limits 2.9, 9.7).

There was a relative paucity of clinical symptoms or signs attributable to cranial nerve dysfunction. Dyspnea was twice as common in patients with vertical translocation as in those with horizontal atlantoaxial subluxation (p = 0.05). However, facial sensation (mainly affecting the ophthalmic and maxillary divisions of the trigeminal nerve) was more commonly impaired in those patients with horizontal atlantoaxial subluxation (p = 0.002).

Clinical Scoring Systems

The preoperative neurological grade, as assessed by the Ranawat classification, was significantly worse in the presence of vertical translocation (McRae, p = 0.002, Redlund-Johnell, p < 0.001). One-way analysis of variance revealed a stepwise increase in the degree of vertical translocation in conjunction with poorer Ranawat neurological classification (Fig. 1). A similar pattern was found for functional ability as assessed by the American Rheumatism Association grades (p < 0.01) and the Stanford Health Activity Questionnaire disability index (p < 0.003). There was no difference between general levels of joint inflammation as measured by the Ritchie index.

Survival Rates

The survival rates of the two groups (those with and
without vertical translocation) are illustrated in Fig. 2. There was a significant difference between those patients with horizontal atlantoaxial subluxation and those with vertical translocation; the latter exhibited poorer survival patterns (p = 0.04). A Cox regression model was constructed to examine the factors that might influence survival and revealed that age (p < 0.001) and the presence of vertical translocation (p = 0.04) were significant independent predictors of survival, but gender and the duration of the rheumatoid process had no effect.

Radiological Findings

Comparisons between the two groups of patients are summarized in Table 2. There was no significant difference observed between the two groups with respect to the anterior or posterior atlantodens interval (ADI), the length of the compressed segment, the extent of maximum compression (spinal cord diameter or spinal cord area), or the degree of angulation of the craniocervical junction (Wackenheim’s angle). However, the level of maximum compression of the neuraxis was significantly lower in patients with subluxation compared with those who had vertical translocation (p = 0.009), occurring on average 10.8 mm below the level of the foramen magnum.

There was an inverse log linear relationship (in millimeters) between the ADI and the degree of translocation of the odontoid peg through the foramen magnum (r = 0.4, p = 0.0001) (Fig. 3). The median ADI in those individuals with the “odontoid peg in the head” was 4 mm, whereas for those in whom there was no translocation of the odontoid process through the foramen magnum this value was 7 mm (p < 0.0001). Thirty percent of the patients with vertical translocation displayed an ADI less than 5 mm.

Lateral mass collapse was strongly associated with vertical translocation (p < 0.0001). For patients with lateral mass collapse, the mean level of the odontoid peg was 4 mm above the foramen magnum, whereas in those individuals with erosions of the atlantoaxial joint only, it was 1.6 mm. We have also observed that erosive changes to the lateral articular surface of the superior facet of the axis, by changing the inclination of this joint from horizontal to nearly vertical, were also associated with vertical translocation. This new vertical orientation allowed C-1 to slip down or settle onto the body of C-2. The wide base of the axis occupied the ring of the atlas and directly compromised the space available for the spinal cord, although the ADI was normal. The cervicomedullary junction was further deformed as the head and atlas tipped forward over the anterior aspect of the base of the axis (Fig. 4) with the cervicomedullary angle being reduced by 35˚, from 155˚ (normal) to 120˚.

Patients with no pannus or only a small amount of fluid were nearly twice as likely to have vertical translocation and to a significantly greater degree (p = 0.001). This descriptive scale was subjective and somewhat arbitrary; therefore, further information about the pannus was also obtained by direct measurements from the CT myelogram. The amount (in millimeters) of circumferential soft-tissue pannus surrounding the cord measured from the CT myelogram also correlated inversely, albeit weakly, with the degree of vertical translocation (r = 0.3; p = 0.001); that is, as the degree of vertical translocation increased the amount of pannus decreased.

Neuropathological Findings

Detailed neuropathological analysis was performed at autopsy in eight patients from this series who suffered vertical translocation (mean Redlund-Johnell value of 18.4 mm). All patients except one were female, with a mean age of 63.3 years. The cranial nerve nuclei were normal in three of four of the specimens obtained. Abnormalities were observed in two specimens: gliosis of the trigeminal nucleus in one and mild unilateral changes to the dorsal

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>Radiographic data obtained in 186 patients with myelopathy*</th>
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<tbody>
<tr>
<td>Factor</td>
<td>Vertical Translocation</td>
</tr>
<tr>
<td>no. of patients</td>
<td>116</td>
</tr>
<tr>
<td>ADI (mm)</td>
<td>5</td>
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<tr>
<td>craniocervical angle (°)</td>
<td>146</td>
</tr>
<tr>
<td>canal diameter (mm)</td>
<td>13.3</td>
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<tr>
<td>spinal cord diameter (mm)</td>
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</tr>
<tr>
<td>spinal cord area (mm²)</td>
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<tr>
<td>level of maximum cord compression relative to foramen magnum (mm)</td>
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</tr>
<tr>
<td>length of compressed cord (mm)</td>
<td>11.3</td>
</tr>
<tr>
<td>diameter of pannus (mm)</td>
<td>4.4</td>
</tr>
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<td>descriptive assessment of pannus</td>
<td>none/fluid</td>
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<tr>
<td></td>
<td>fibrous/florid</td>
</tr>
<tr>
<td>atlas</td>
<td>normal or erosions</td>
</tr>
<tr>
<td></td>
<td>lateral mass collapse axial normal or erosions</td>
</tr>
<tr>
<td></td>
<td>length of C-2 (mm)</td>
</tr>
<tr>
<td></td>
<td>McRae value (mm)</td>
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</table>

* NS = not significant.
motor nuclei of the vagus and hypoglossal nuclei in another. In all of the spinal cords, the arachnoid was thickened focally at points of compression. There was hyalinization of intramedullary arterioles and no vasculitis or evidence of thrombosis or ischemic lesions. At the site of severe compression the spinal cord was typically fragmented and necrotic, whereas at levels of less severe compression the disease was localized principally to the dorsal white matter and axonal disruption and edema were observed (Fig. 5). The cuneate fascicle was more commonly affected than the gracile fascicle. There was no significant anterior horn cell loss.

Discussion

Review of Literature

Traditionally, vertical translocation has been defined as the presence of the odontoid peg above McRae’s foramen magnum line (opisthion-exion). However, the foramen magnum line can be difficult to determine on plain radiographs, and polytomography was often required. McGregor’s method also enjoyed some popularity in the past; by definition the tip of the odontoid process should be at least 4.5 mm below the palatooccipital line (McGregor’s line). However, it is not always possible to obtain this measurement because of a combination of factors that include osteoporotic bone, the overlying mastoid processes, and erosion of the dens. The Redlund-Johnell method, which does not rely on the visualization of the tip of the dens or the identification of the foramen magnum, is a useful screening method that has found favor among recent investigators. There are numerous other craniometric methods used to assess the presence of vertical translocation, which include those of Fischgold and Metzger, Ranawat, et al., Kauppi, et al., Teigland, et al., Clark, et al., and Dvorak, et al. Most of these methods, like those of McRae and Barnum and McGregor, have been rendered redundant with the advent of modern neuroimaging.

There has been a growing interest, over the past decade, in the problem of vertical translocation of the rheumatoid spine. This started as an occasional case report, typically identifying rather severe cases, with what were perceived at that time as unusual presentations: hydrocephalus, vertebral artery compression, and dysphagia associated with medullary compression. As awareness of this condition grew, more detailed analyses of groups of patients were published, but because of the small size of those studies (fewer than a dozen cases per series) their findings, although important, were inevitably anecdotal.

The first serious attempts to unravel this condition were made by several investigators, notably Redlund-Johnell and Pettersson and later by Menezes and colleagues, who reported a remarkable surgical series of 45 cases in 1985. The significance of this latter study was that it was conducted in preimaging days by means of polytomography. Investigators in other radiological and surgical series commented on vertical translocation, but to a large degree their interest was just in passing, with no formal analyses of these patients being performed. Notable exceptions were Ranawat, et al., who devised a method of quantifying vertical translocation, and Weissman, et al., who highlighted the effect of atlantoaxial impaction on the development of myelopathy in 43 patients.
the region of the posterior horn.42 extends downward into the upper spinal cord segments in natal trigeminal nucleus is approximately 19 mm long and that is mediated by the spinal trigeminal system. The spi-

seen by examining the neuroanatomy of facial sensation alone. The reason behind this apparent paradox can be

tantly less than in patients with atlantoaxial subluxation, but this was significantly different from the population of patients with atlantoaxial subluxation alone (9%).18

Radiological Findings. Perhaps the most interesting radiological finding in this study is that of the progressive decrease in the ADI as the degree of vertical translocation increased. The relationship between the ADI and vertical translocation has not been defined before. Our very large group of patients has allowed us to perform a detailed analysis and, as might be expected, the relationship is complicated both statistically, with the degrees of freedom, and clinically, by variability of the disease. Although this appears as an inverse log linear relationship, it repre-
sents an oversimplification of the pathomechanical processes involved. This group of patients is highly select-
ed; therefore, all patients with early disease and a normal ADI with no vertical translocation have been excluded from our analysis because they would not be expected to develop spinal cord compression.

The ADI is used a great deal as an indicator of potential neurological problems. Many surgeons have suggested specific cutoff points for surgical intervention. The clear implication from the inverse relationship between the ADI and the degree of vertical translocation described in this study is that decisions based on the ADI as a major radiological determinant for surgical intervention are flawed when vertical translocation is present. This may help to explain the often-quoted poor correlation between the ADI and the development of neurological problems.2,7,25,33

Use of the posterior ADI, as suggested by Boden, et al.,3 although an improvement, only assesses one dimension of the problem. Vertical translocation must be considered, as should soft-tissue compression by pannus that cannot be visualized on plain radiographs.

In the literature, the diminishing ADI seen in vertical translocation has been termed “pseudostabilization,” with many believing that this represented an amelioration of the patient’s condition.25 Our findings, based on neurologi-
cal grading using the Ranawat classification19 and functional grading using the American Rheumatism Associa-
tion grading system,39 clearly show the fallibility of this notion. The increasing degree of vertical translocation is strongly associated with increasing degrees of disability. Moreover, poor survival is also related to the presence of vertical translocation.

However, the concept of pseudostabilization is not to-
tally erroneous, and one interesting epiphenomenon ob-
served is that with increasing degrees of vertical translo-
cation, which will reduce the mobility in the area, there is a significant decrease in the amount of pannus. This strongly echoes the observation made by Zygmunt, et al.,46 that the amount of periodontoid pannus decreases after surgical stabilization. In this case it is not instrumentation that brings about the decrease in mobility but the physical

Current Study

We believe that there are several important findings in this report on patients with myelopathy, rheumatoid arthritis, and vertical translocation.

Symptoms and Signs. Our study confirms that vertical translocation is a feature of end-stage disease.36,37 In our study cohort, translocation occurred following rheumatoid arthritis that had lasted 6 years longer than in the average patient with myelopathy and simple horizontal atlantoaxial subluxation. There was a relative paucity of specific neurological signs. However, despite the impressive cervicomedullary compression seen on neuroradiological studies and the appeal of ascribing specific clinical patterns to compression of the brainstem, we have found lit-
tle evidence of these. Certainly there are some patients with symptoms of bulbar dysfunction, but these are rela-
tively rare. Trigeminal involvement was found in 2% of patients with vertical translocation, but this was significa-

antly less than in patients with atlantoaxial subluxation alone. The reason behind this apparent paradox can be seen by examining the neuroanatomy of facial sensation that is mediated by the spinal trigeminal system. The spi-
nal trigeminal nucleus is approximately 19 mm long and extends downward into the upper spinal cord segments in the region of the posterior horn.42

Symptoms of dysphagia and dysarthria observed in this group of patients were not associated with overt lower cranial nerve palsies, and although it is possible that they were secondary to medullary or cranial nerve compression they could also be related to other causes.9 In the case of dysphagia, xerostomia or fixed flexion of the head on the neck are strong potential candidates, whereas cricoary-
tenoid arthritis is a possible cause for dysarthria. Night-

mares, which we believe were caused by cerebral hypoxia secondary to a reduced respiratory drive from compressed medullary respiratory centers, occurred in 12% of patients with vertical translocation, but this was not significa-

Figure 5. Photomicrograph of a myelin preparation revealing damage to the cuneate fascicle (left), which is markedly paler than the adjacent gracile fascicle. Woelche, original magnification × 400.
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constraint of the ring of the atlas as it slides down the axis. Depending on the angle of descent, there will be different degrees and directions of spinal cord compromise. The length of the odontoid process in patients with vertical translocation was significantly shorter than in those with horizontal atlantoaxial subluxation (p = 0.001), presumably because of a severe erosive phenomenon. This, together with the disappearing ADI and smaller amount of pannus, might reasonably be considered to be “protective” in terms of further neuraxial compression. However, these patients are more severely disabled than others. The possible explanation for this is discussed in the section titled Neuropathological and Neuroradiological Correlations.

Further insights into the pathomechanics of vertical translocation are afforded by the statistically significant observation that vertical translocation is associated with lateral mass collapse of C-1. This is the primary reason for the ascent of the odontoid peg, although destructive changes in C-2 and the occipital condyles are also important. Progressive destruction of the lateral masses of C-1 has previously been believed to be the cause of cranial settling, but earlier studies have lacked the numbers of patients needed to make this a concrete and statistically robust finding.12,16,30 Our study was able to confirm this previous hypothesis.

Neuropathological and Neuroradiological Correlations

The degree of spinal cord compression as assessed by the length of the compressed segment, the space available for the cord, and the subarachnoid and cord areas were not significantly different between the vertical translocation and horizontal atlantoaxial subluxation groups. The only radiographic difference between the two groups was the level of compression, which occurred at a slightly higher level in the vertical translocation group. Furthermore, the amount of pannus, the ADI, and even the length of the odontoid process decreased with increasing degrees of vertical translocation. How can these apparent paradoxes be reconciled with the increased neurological disability and mortality? We speculate that the nature of the compressive force is more likely to be osseous and fixed (and hence less “forgiving”) in vertical translocation compared with the uncomplicated case of a mobile, reducible horizontal atlantoaxial subluxation, in which the compression is intermittent and often produced by soft-tissue pannus. Our own serial studies antedating surgical intervention echo Redlund-Johnell’s work and show that horizontal atlantoaxial subluxation precedes vertical translocation.

Given the neuropathological considerations and the longer duration of disease, we surmise that there has been repetitive trauma associated with horizontal atlantoaxial subluxation. As the vertical translocation proceeds over the next 6 years or so, this anterior deforming mass causes shearing forces in the spinal cord stretched over it that result in damage to the dorsal columns. The mechanical process is identical to that proposed by Breig, et al.,4 in cervical spondylosis. We consider this process to be cumulative and irreversible, with profound implications on the timing of surgery.

Conclusions

We have observed that vertical translocation is a late phenomenon in the rheumatoid process. Patients presented with myelopathy only after rheumatoid arthritis had lasted an average of 25 years. There are relatively few symptoms or signs specific to vertical translocation. Vertical translocation is secondary to lateral mass collapse and is associated with a progressive decrease in the ADI and the degree of rheumatoid pannus. The degree of functional and neurological impairment is significantly more severe with vertical translocation compared with that of horizontal atlantoaxial subluxation.

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Manuscript received April 9, 1996. Accepted in final form July 8, 1997. Address reprint requests to: H. Alan Crockard, F.R.C.S., Department of Surgical Neurology, The National Hospital for Neurology and Neurosurgery, Queen Square, London, WC1N 3BG United Kingdom.