Original Article

# C1:C2 ratio is a potential tool assessing atlas fracture displacement and transverse ligament injury


## ABSTRACT

**Objectives:** The aim of this study was to determine the reliability of a C1:C2 ratio in a cohort of patients with atlas fractures. Second, we aimed to consider the utility of the C1:C2 ratio with regard to diagnosis of transverse ligament (TL) injury.

**Design:** This is a retrospective analysis.

**Methods:** Patients with atlas fractures in the Waikato region between 2008 and 2010 were identified retrospectively through clinical coding and collated radiology trauma database.

**Main Outcome Measurements:** The maximal width of C1 and C2 was measured using the first-taken trauma radiograph series. Combined overhang of lateral masses (Δmm) and a C1:C2 ratio was then calculated. Final ratio and atlanto-dens interval (ADI) were measured at the last clinical follow-up.

**Results:** A total of 24 patients with full radiographic records were included. Of these, five patients (21%) had TL injuries confirmed on computed tomography or magnetic resonance imaging. No patient with a ratio 1.15 had an intact TL, whereas a ratio of >1.10 captured 80% of TL injuries. The ratio ($P < 0.001$) and delta values ($P < 0.001$) were statistically significantly different between TL-injured and TL-intact cohorts. Two patients in the TL injury group demonstrated increased ADI on final follow-up with a ratio of >1.10.

**Conclusions:** A C1:C2 ratio >1.10 on plain radiographs showed a sensitivity of 80% in detecting atlas fractures with associated TL injury. All patients with a ratio of ≥1.15 had TL rupture subsequently confirmed by an advanced modality. A ratio calculation on radiographs is a potentially useful method of describing atlas lateral mass displacement.

**Level of evidence:** Level III


**Keywords:** Atlas fracture, C1:C2 ratio, cervical spine, fracture displacement, rule of Spence, trauma

## INTRODUCTION

Atlas fractures represent 3%–13% of cervical spine fractures.[1,2] Epidemiology often shows a bimodal distribution depending on the mechanism of injury.[3] The best known eponymously named Jefferson fracture has been defined as a bursting atlas fracture of all types including unilateral arch fracture, lateral mass fracture, and a combination of C1/C2 fractures.[4-6] Landells described three main fracture types depending on anatomical location, as follows: Type I: fractures involving either the posterior arch or anterior arch; Type II: fractures involving both anterior and posterior arches; and Type III: fracture of the lateral masses.[7] Atlas fractures can be defined as stable or unstable based on the inferred integrity of the transverse ligament (TL).[3,6-8] This consideration gave rise to further subclassification: Dickson described Type I as mid-portion TL injury or at insertion point of the tubercle, incapable of healing with external immobilization, and Type II involves fracture and avulsion of the tubercle of TL


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insertion – capable of healing with external immobilization alone.[9] Computed tomography (CT) and magnetic resonance imaging (MRI) further assist by demonstrating either avulsion of the TL insertion or an intrasubstance tear.[10]

Treatment may be nonoperative depending on pathoanatomy, and integrity of the TL is a key consideration.[11] Classically, injury to the TL has been detected by the "rule of Spence," which is defined as combined displacement of the C1 lateral masses on C2 articulations of ≥6.9 mm on open-mouth radiograph.[8] Given inherent magnification error, this has been adjusted to a combined displacement of ≥8.1 mm and considered diagnostic.[11,12] Studies, however, have suggested that the "rule of Spence" is in fact not sufficiently accurate to exclude TL injury or predict clinical outcome,[13,14] and that Dickman's classification is of greater value.[15]

Plain radiographs, although gradually being replaced by CT at many trauma centers, remain a common first-line investigation in cervical spine trauma along with radiographs of the chest and pelvis. However, it is important to note that in resource-scarce centers, immediate CT may not be available. While the combined lateral mass displacement has been well evaluated as an absolute measure, this is prone to error due to variability in calibration.[12] A ratio avoids errors that may be caused by calibration or magnification and is therefore applicable to the individual no matter what the calibration of the imaging is. A C1:C2 ratio has only once before been suggested in the management of C1 fractures, indicating that a proportion is more accurate than raw distance; however, it was described without further consideration.[16]

The first aim of this study was to determine the reliability of a C1:C2 ratio in a cohort of patients diagnosed with atlas fractures. Second, we aimed to consider the utility of the C1:C2 ratio with regard to the diagnosis of TL integrity. We hypothesize that using a ratio is useful in eliminating the issue of magnification and calibration and is a reliable first-line method, especially when immediate advanced imaging is not feasible.

## METHODS

Local approval was obtained for retrospective analysis of this cohort. The authors have no conflicts of interest for disclosure.

Patients with a history of traumatic atlas fracture were identified from the hospital's clinical coding over an 8-year period (2009–2017, inclusive of both years). The start date of collection coincided with the introduction of digital radiographic records, allowing for access to full radiographic records. Hospital's coding was cross-referenced with trauma CT cervical spine series, and reports were viewed during this period to find additional patients with atlas fractures otherwise not identified via clinical coding. Patients treated by the orthopedic spinal service for a C1 fracture aged over 18 years were included. Only those with full radiographic records (plain radiographs, CT ± MRI, where indicated) were included in the study.

Patient demographics were retrospectively gathered through clinical notes. Information included patients' age, gender, mechanism of injury, injury severity, neurologic status, and treatment. Fractures were classified as Landells Types I, II, or III as previously described. The diagnosis of TL rupture was made either by CT demonstrating an avulsed osseous fragment (Dickman Type II) or by MRI in those cases where there was significant lateral mass overhang of C1 on C2, suggestive of intrasubstance tear without evidence of TL avulsion fracture on CT (Dickman Type I).

The maximal width of C1 and C2 was measured as demonstrated in Figures 1 and 2. All measures were performed on the Philips IntelliSpace Picture Archiving and Communication System using the first-taken trauma radiograph series. Where multiple open-mouth views were taken, the senior author determined which was of better quality and therefore included it for measuring between all observers and analyses. Measures were taken by three individuals including one junior orthopedic resident, one senior orthopedic resident, and one fellowship-trained spine surgeon. Measurements were performed a minimum of 2 weeks apart, and the order of radiographs was randomly reordered for the second analysis. Final radiographs for comparison were measured at the last clinical follow-up in

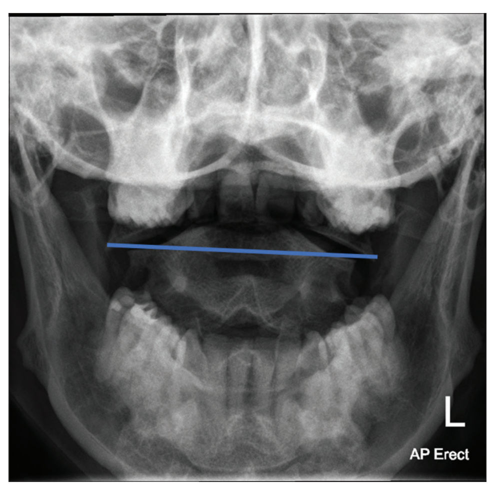


Figure 1: Measurement of the C1 lateral mass distance

which appropriate imaging was available. Measurements at final follow-up included the maximal width of C1 and C2 and atlanto-dens interval (ADI) on lateral radiographs at neutral, flexion, and extension.

Data analysis was performed using ExcelSTAT (Addinsoft Paris, France 1993). Inter- and intraclass coefficients were measured using Cronbach's $\alpha$. Mean values and their standard deviations (SDs) were reported for the entire cohort, the TL ruptured cohort, and the TL intact cohort. Positive predictive value (PPV), negative predictive value (NPV), sensitivity, and specificity were calculated in the standard fashion – three different diagnostic values were selected for testing. Unpaired *t*-tests were used for subgroup analysis.

## RESULTS

A total of 24 patients with complete radiographic records were included. The mean age was 59.1 years (SD: 26.1), and there were 14 males (58%). Mechanisms of injury included mechanical falls, motor vehicle accidents, and sporting injuries. Nearly 30% of patients suffered an isolated atlas injury, whereas 70% suffered other associated spinal injuries. One patient underwent posterior stabilization, and the remainder were treated nonoperatively. Of these, five patients (21%) had TL injuries confirmed on CT or MRI showing either TL avulsion fracture[4] at the site of attachment or intrasubstance tear on MRI.[1] The mean age of these patients was 53.2 years (SD: 20.8).

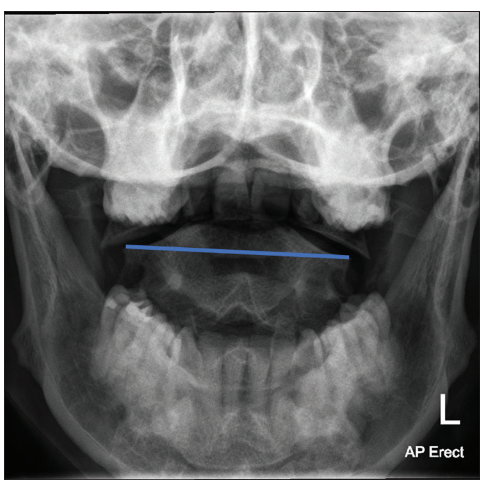


Figure 2: Measurement of the C2 lateral mass distance

The interclass coefficient between assessors was 0.983 (0.969 and 0.991). Intraclass coefficients for each assessor were 0.967, 0.968, and 0.858, suggesting excellent reliability between assessors and good-to-excellent intraobserver reliability. The mean values for the cohort of C1 width and C2 width, the respective ratio, and delta values are shown in Table 1. The C1 width ($P = 0.165$) and C2 width ($P = 0.705$) were not statistically significantly different between TL-injured and TL-intact cohorts, whereas the ratio ($P < 0.001$) and delta values ($P < 0.001$) were statistically significant. PPV, NPV, sensitivity, and specificity results are shown in Table 2 according to three different potential cutoff values for diagnosis.

Nineteen patients were followed up for a mean of 139 days (SD: 152). No follow-up findings were available for patients discharged to a regional center posttrauma. Two patients (40%) in the TL-injury group had an ADI of >3 mm, but none in the non-TL injury group. The above two patients were treated in a halo jacket and both had a ratio of >1.10.

## DISCUSSION

The aim of this study was to determine the utility of the C1:C2 ratio in the management of atlas fractures, with a focus on ability to detect TL rupture. We found that the measure is reproducible across levels of experience and therefore suitable for use by a variety of clinicians. Based on simple calculations, a key finding is that if the C1:C2 ratio is >1.12, then one can be certain that the TL is compromised.

Atlas fractures have long been recognized to be commonly associated with other injuries of the cervical spine[7] and associated rupture of the TL, with resultant instability allowing forward subluxation of the atlas on the axis.[8] Goel *et al*. recently discussed lateral displacement of the facets of atlas in relation of facets of axis in patients with bifid arches of atlas and their relation to atlantoaxial instability.[17] Even if alar ligaments are intact, this is insufficient to prevent fatal cord injury or delayed myelopathy.[8] Multiple other soft-tissue stabilizers including the capsular ligaments, alar ligaments, apical ligaments, anterior longitudinal ligaments, and tectorial membranes assist the TL in providing cervical stability. This research adds an additional method to assess the status of

**Table 1: Columns of average measured values of C1 width and C2 width in mm and ratio of C1:C2 and C1-C2 width in mm**

| | C1 width (mm) | C2 width (mm) | Ratio C1:C2 | Delta C1:C2 width (mm) |
|---|---|---|---|---|
| Average of the entire cohort | 63.9±6.9 | 60.5±6.1 | 1.06±0.06 | 3.4±3.8 |
| Average TL rupture | 67.7±7.1 | 59.6±5.1 | 1.13±0.07 | 8.1±4.1 |
| Average TL intact | 62.9±6.5 | 60.8±6.3 | 1.04±0.04 | 2.1±2.5 |

Rows showing the average of all patients, patients with transverse ligament rupture and intact transverse ligament. TL - Transverse ligament

**Table 2: Positive predictive value, negative predictive value, sensitivity, and specificity according to three selected cutoff values and the well-described absolute values**

| | PPV (%) | NPV (%) | Sensitivity (%) | Specificity (%) |
|---|---|---|---|---|
| Ratio >1.08 | 57 | 94 | 80 | 84 |
| Ratio ≥1.10 | 67 | 94 | 80 | 89 |
| Ratio >1.12 | 100 | 90 | 60 | 100 |
| Delta ≥6.9 mm | 100 | 90 | 60 | 100 |
| Delta ≥8.1 mm | 100 | 90 | 60 | 100 |

PPV - Positive predictive value; NPV - Negative predictive value

TL, with a 67% likelihood of rupture if the ratio is at least 1.10 and 100% likelihood of rupture if the ratio is >1.12.

Previously, the ratio was briefly described by Perez-Orribo *et al*. comparing CT with MRI measurements of the TL integrity.[16] The authors obtained the atlas lateral mass spread and the C1:C2 ratio was calculated as the coefficient between atlas lateral diameter and axis lateral diameter. They suggested the integrity of the TL using a proportion may be more accurate than using an absolute distance. However, the ratio has not been further investigated.

Compared to the well-defined absolute measure of 8.1 mm used to detect potential TL injury, a ratio of 1.12 as a cutoff value had the same sensitivity and specificity. Lowering the ratio resulted in improved sensitivity to detect those fractures with associated TL injury. Notably, the sensitivity and specificity were the same irrespective of the absolute value used – a consequence of a small cohort study and a weakness we acknowledge. It is worth noting also that none of the selected ratios provided 100% sensitivity due to one patient with a TL injury, and a ratio of 1.03 and delta 1.6 mm <20% of the cohort had a ratio lower than this.

The ADI, the distance between the C1 anterior arch and odontoid process on lateral radiograph, is also commonly used in assessing TL injuries. This was demonstrated by Oda *el al*., with all nonfunctional TL having ADI values >3 mm, indicative of instability at the C1/2 articulation.[18] Cadaveric studies have also suggested accuracy of neutral-to-flexion ADI at assessing TL impairment.[16] From our cohort, only 19 patients were followed up until discharge from clinic and two had an increase in ADI – none of our patients with an initial ratio of <1.10 demonstrated an increase in ADI at follow-up in flexion radiographs. A further consideration in the applicability of the C1:C2 ratio is its use in the follow-up of patients with atlas fractures – we see that the ratio measured on the first assessment did not change throughout the study for any of the 19 out of 24 patients during the last clinical follow-up, and there was no indication of instability by any other radiographic finding.

We acknowledge that our study has weaknesses. First, this is a retrospective study and inherent to this is that we rely on the accuracy of clinical documentation and that we rely on the treating clinicians' decision-making with regard to obtaining advanced imaging modalities. As already alluded to, 24 is a small sample size and a larger cohort study would add strength to the findings – prospective analysis of the C1:C2 ratio will help clarify its exact role. Major trauma centers in the developed world have easy access to immediate advanced imaging in the form of CT or MRI; however, this may be less so in resource-poor areas. Therefore, we feel that an accurate plain radiological image would be of benefit in such situations.

## CONCLUSIONS

Utilizing a C1:C2 ratio is a reliable first-line method to define the magnitude of lateral mass displacement and predict injury to the TL. This is especially useful if advanced imaging is not immediately available. Further studies will assist in providing validation of the ratio as a tool for detecting TL injuries associated with atlas fractures.

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Nil.

### Conflicts of interest

There are no conflicts of interest.

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