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Original article

C1 fracture: Analysis of consolidation and complications rates in a prospective multicenter series

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ABSTRACT

Introduction: Three types of C1 fracture have been described, according to location: type 1 (anterior or posterior arc), type 2 (Jefferson: anterior and posterior arc), and type 3 (lateral mass). Stability depends on transverse ligament integrity. The main aim of the present study was to analyze complications and consolidation rates according to fracture type, age and treatment.
Material and methods: The French Society of Spinal Surgery (SFCR) performed a multicenter prospective study on C1-C2 trauma. All patients with recent fracture diagnosed on CT were included. Consolidation on CT was studied at 3 months and 1 year. Medical, neurologic, infectious and mechanical complications were inventoried using the KEOPS data-base.
Results: Sixty-three of the 417 patients (15.1%) had C1 fracture: type 1 (33.3%), type 2 (38.1%), or type 3 (28.6%). The transverse ligament was intact in 53.9% of cases. Treatment was non-operative in 63.5% of cases, surgical in 27.0%, and surgical after failure of non-operative treatment in 9.5%. There were 8 medical complications, more frequently in patients aged >70 years, following surgery ($p < 0.0001$). The consolidation rate was 84.2% with non-operative treatment, 100% for primary surgery, and 33.3% for secondary surgery ($p = 0.002$). There were 10 cases of non-union, in 4.8% of type 1, 13.6% of type 2 and 33.3% of type 3 fractures ($p = 0.001$).
Conclusion: Medical complications showed association with age and with type of treatment. Non-operative treatment was suited to types 1, 2 and 3 with minimal displacement and intact transverse ligament. C1-C2 fusion was suited to displaced unstable type 2 fracture. Displaced type 3 fracture incurred risk of non-union. Early surgery may be recommended.
Level of evidence: III.

1. Introduction

Atlas (C1) fracture was first described by Jefferson in 1927 [1]. Epidemiology was analyzed by Matthiessen [2]. There is male predominance of 1.3:1. Mean age is 60.5 years, with 2 peaks, at 24 and

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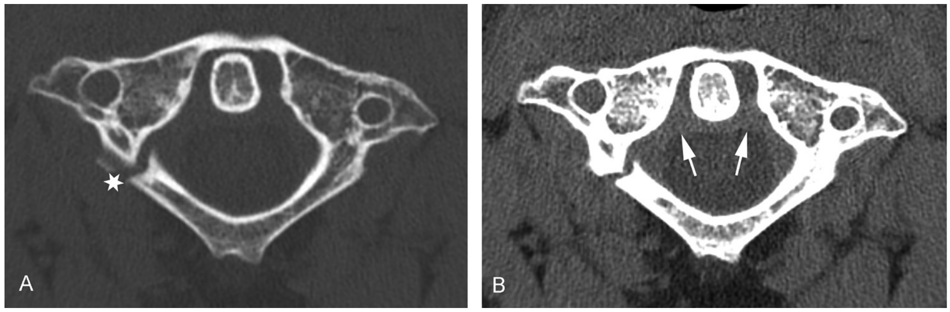

Fig. 1. Type 1 fracture with (A) isolated posterior arc involvement (star) on CT bone window axial slice, and (B) intact transverse ligament (arrows) on soft tissue window axial slice.

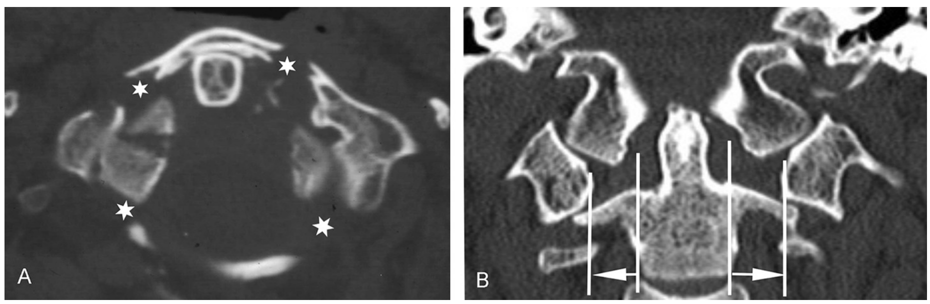

Fig. 2. Type 2 (Jefferson) fracture with (A) anterior and posterior arc involvement at 4 points (stars) on CT axial slice, and (B) coronal slice showing lateral subluxation of the lateral masses: Spence's rule predicts transverse ligament tear if the sum of C1 translations with respect to C2 (arrows) exceeds 7 mm.

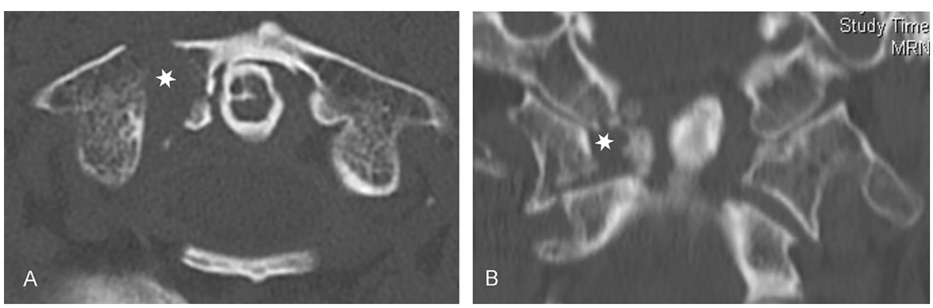

Fig. 3. Type 3 fracture with isolated lateral mass involvement (star) on (A) axial and (B) coronal CT slices.

82 years. High-energy road accidents are the most frequent cause in young patients; in elderly osteoporotic patients, low falls are often implicated. In 19% of cases, there is associated axis (C2) fracture. C1 fractures are classified in 3 types [3,4]. Type 1 (Fig. 1) is isolated anterior or posterior arc fracture (31–45%); type 2 (Fig. 2), known as "Jefferson's fracture", is fracture of both anterior and posterior arcs (37–50%); type 3 (Fig. 3) shows a fracture line through the lateral masses (13–37%).

The atlas lies at the level of the brainstem. Severe displacement in C1 fracture incurs potentially life-threatening neurologic risk. Transverse ligament tear induces occipito-atlanto-axial instability, which can be assessed by indirect signs on X-ray or CT: Spence's rule is the best-known means [5], associating tear with >7 mm C1 lateral mass lateralization with respect to the C2 lateral masses in the coronal plane (Fig. 2B), or atlas-odontoid distance >5 mm in the sagittal plane. The tear is well visualized on CT in case of bone avulsion at the insertion (Fig. 4B). Dickman et al. [6–8] described corresponding signs on MRI, which is the gold-standard examination in suspected ligament involvement (Fig. 4A).

In stable C1 fracture, 8–12 weeks' immobilization by Philadelphia Minerva brace, or more rarely by halo-vest, is recommended. Surgery is indicated for unstable fracture [9,10]. Surgical posterior fixation generally uses C1-C2 screwing following Harms and Melcher [11] (Fig. 5) or, more rarely, occipito-cervical internal fixation. Surgical indications are unclear in displaced lateral mass fracture with intact transverse ligament: there is a risk of malpositioned non-union when the C0-C1 and C1-C2 joint surfaces are subluxated, and both operative and non-operative strategies are considered.

The aim of the present study was to assess primary treatments for C1 fracture, and complications and consolidation rates according to type of fracture, type of treatment and patient age.

2. Material and methods

2.1. Study and patients

A prospective observational multicenter study of C1-C2 trauma was conducted for the French Society of Spinal Surgery (SFCR). The study was approved by the Strasbourg University Hospital review board.

The University Hospital Centers of Lyon, Strasbourg, Bordeaux, Marseille, Nice, Montpellier, Nîmes, Besançon, Grenoble, Lille and Dijon provided data. All patients with recent C1 or C2 fracture diagnosed on CT were included. MRI was required in case of suspected ligament involvement. Old trauma and patients without primary

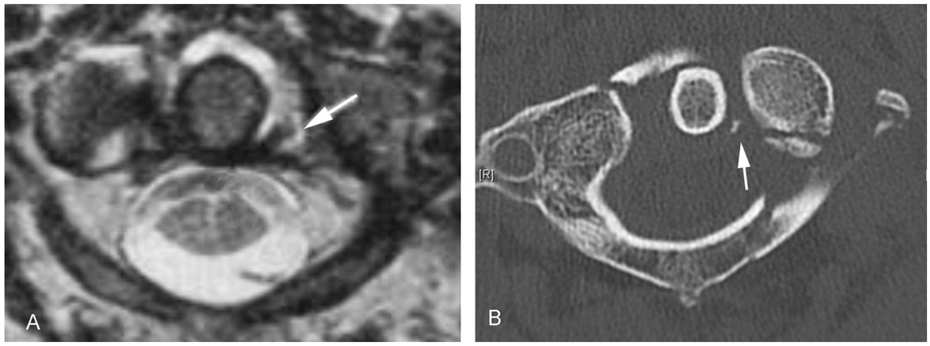

Fig. 4. Transverse ligament tear (arrow) (A) on MRI axial slice and (B) transverse ligament avulsion (arrow) on CT bone window axial slice.

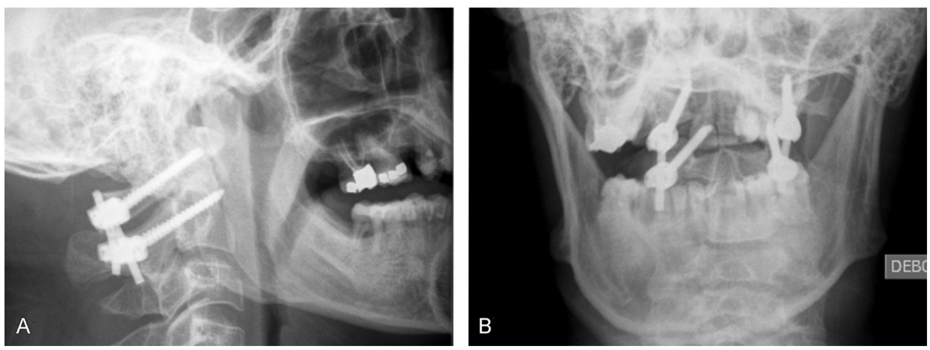

Fig. 5. Posterior C1-C2 internal fixation and fusion (Harms technique) with screwing of C1 lateral masses and C2 pedicles: (A) postoperative lateral and (B) AP radiographs.

CT were excluded. Patients with C1 fracture were extracted from the overall data-base for the study.

2.2. Analysis parameters

The shared KEOPS data-base (SMAIO, Lyon, France) was used for collection of data recorded at admission and at each consultation. Follow-up was prospective, at 6 weeks, 3 months, 6 months and 1 year. The following items were recorded:

- epidemiology: age, gender, American Society of Anesthesiologists (ASA) comorbidity score;
- fracture: level (C1), associated fractures, classification and transverse ligament involvement (intact or torn);
- treatment: non-operative (Minerva brace and surveillance), surgical (type, fixation level, bone graft, postoperative immobilization), or secondary surgery;
- complications: medical (pneumopathy, cardiac decompensation, deep venous thrombosis, bed-sores, postoperative delirium), neurologic, infectious or mechanical.

CT was performed at 3 months in non-operative cases, with control CT at 1 year in case of incomplete consolidation. CT was performed at 1 year in surgical cases. Consolidation was assessed on coronal, axial and sagittal bone window on 0.6–0.8 mm slices, and classified as “complete” for no visible fracture line, “incomplete” for partial residual line, or “non-union”.

2.3. Statistical analysis

Statistical analysis used SAS v9.3 software (SAS Institute Inc., NC, USA). A descriptive analysis was made. Qualitative variables were compared on chi^2 or Fisher exact test as appropriate. Complications and consolidation were assessed according to age (</>70 years), type of treatment (operative/non-operative) and fracture type (1 to 3). The significance threshold was set at 5%.

3. Results

3.1. Epidemiological data

Sixty-three of the 417 patients in the C1-C2 trauma data-base (15.1%) had C1 fracture: 35 male (55.6%), 28 female (44.4%); mean age, 60.5 years (range, 16–95 years) with 29 (46.0%) aged $\leq$70 years. Twenty patients (31.7%) had isolated spinal trauma, 27 (42.8%) associated cranial trauma, and 16 (25.4%) multiple trauma. Causes in the 29 patients aged $\leq$70 years comprised: 25 road accidents (86.2%), 2 sports accidents (6.9%) and 2 high falls (6.9%). In the 34 patients aged >70 years, causes comprised: 24 body-height falls (70.6%), 5 road accidents (14.7%), 4 domestic accidents (11.8%), and 1 aggression (2.9%). Table 1 shows comorbidities and ASA scores.

3.2. Fracture types

C1 fractures were type 1 in 21 patients (33.3%), type 2 in 23 (38.1%) and type 3 in 19 (28.6%). The transverse ligament was intact in 34 patients (53.9%) on visualization of axial CT slices through soft tissue and according to Spence’s rule. Ligament tear was secondarily confirmed on MRI in 12 patients (19.0%) with type 2 fracture. In type 3 fracture, mean displacement at the lateral masses was 2.4 mm (range, 0–12 mm).

3.3. Treatments

Non-operative treatment alone was applied in 40 patients (63.5%), including 36 by Philadelphia Minerva brace; the other 4 had a foam-rubber cervical collar; no halo-vests were used. Distribution was equivalent between stable type 1 to 3. Surgery was performed in 17 patients (27.0%). The technique of choice was posterior C1-C2

Table 1
Distribution of American Society of Anesthesiologists (ASA) scores and comorbidities according to age.

	Patients ≤70 years $n=29$	Patients >70 years $n=34$
ASA score		
ASA I	10 (34.5%)	3 (8.8%)
ASA II	12 (41.4%)	12 (35.3%)
ASA III	6 (20.7%)	14 (41.2%)
ASA IV	1 (3.4%)	5 (14.7%)
Comorbidities		
Cardiac	9 (31.0%)	18 (52.9%)
High blood pressure	10 (34.5%)	25 (73.5%)
Vascular	4 (13.8%)	14 (41.2%)
Diabetes	8 (27.6%)	9 (26.5%)
Respiratory	3 (10.3%)	8 (23.5%)
Neuro-cognitive	1 (3.4%)	8 (23.5%)
Gastro-intestinal	2 (6.9%)	3 (8.8%)
Hepatic and alcoholism	2 (6.9%)	1 (2.9%)
Kidney failure	2 (6.9%)	12 (35.3%)
Oncologic	3 (10.3%)	4 (11.8%)

screwing. Fractures were predominantly type 2. In 6 patients with associated C2 fracture, complementary odontoid screwing was performed. In 6 patients (9.5%), surgery was performed in second line after non-operative treatment, for consolidation delay on CT at 3 months; these were type 3 fractures with intact transverse ligament; displacement on initial CT exceeded 2 mm in each case.

3.4. Complications

Overall mortality was 3.2%, with 2 early deaths in patients aged >70 years, ASA IV, treated non-operatively. Medical, neurologic, infectious and mechanical complications are shown in Table 2. The rate of medical complications increased with age: 2/29 patients aged ≤70 years (6.9%) versus 9/34 patients aged >70 years (26.5%) ($p<0.0001$). They were more frequent following surgery: primary in 5/17 patients (29.4%) and secondary in 4/6 patients (66.7%), versus 2/40 patients (5.0%) treated non-operatively ($p<0.0001$). They showed no association with fracture type. Two of the 63 surgical patients (3.2%) showed initial Frankel C tetraparesia, recovering to Frankel B and A respectively. There were no postoperative infections. Mechanical complications comprised non-union and internal fixation material loosening: 1 lateral mass screw through C0-C1, one C1 screw with medial cortical breach; they concerned 3/17 patients with primary surgery (17.6%), 4/6 with secondary surgery (66.7%), and 5/40 (12.5%) with non-operative treatment ($p<0.001$).

3.5. Consolidation

Bone consolidation was analyzed on CT in the 61 surviving patients. At 1 year, it was complete in 45 patients (73.7%) and partial in 6 (9.8%), with non-union in 10 (16.4%). It was complete or partial in 32/38 patients treated non-operatively (84.2%), 17/17 (100%) with primary surgery, and 2/6 (33.3%) with secondary surgery ($p=0.002$). By fracture type, non-union concerned 1/21 (4.8%) type 1, 3/22 (13.6%) type 2 and 6/18 (33.3%) type 3 ($p=0.001$) fractures. Consolidation was not associated with age: 25/29 (86.2%) in patients aged ≤70 years and 26/32 (81.3%) in patients aged >70 years ($p=0.99$).

4. Discussion

C1 fractures account for 2% of spinal fractures, with male predominance [2,3,12–14]. According to Panjabi et al. [15], young patients are often high-energy road accident victims, whereas elderly patients more often sustain low-energy trauma to osteoporotic bone. According to Koller et al. [16], axial compression underlies atlas fracture. In the present series, epidemiology and trauma causes were comparable to those reported in the literature [2,3,12–14]. In all, 46.1% of patients had transverse ligament tear on CT and in some cases on MRI. Three signs predominate on MRI: hypersignal on gradient echo, ligament discontinuity, and insertion site bleeding [17].

Non-operative management depends on fracture type: it is indicated in case of only slight displacement with intact transverse ligament. Ryken et al. [10], Kontautas et al. [18] and Landells et al. [3] recommend 8–12 weeks' immobilization by rigid cervical Minerva brace. Delcourt et al. [19] reported halo-vest immobilization, but with high rates of skin complications and swallowing and respiratory disorder in geriatric populations [20,21]; halo-vests were not used in the present series. Philadelphia Minerva collars seem suited to stable fractures with little displacement.

In case of transverse ligament involvement or severely displaced fracture, surgery is indicated, with several options: C1-C2 fixation is indicated in most cases, with occipito-cervical fusion reserved for the most complex. No studies have demonstrated superiority for any particular technique in terms of mechanical stability or consolidation [12,22–25]. The main drawback is restricted motion in axial rotation of the superior cervical spine, which takes place between C1 and C2 [9]. The various C1-C2 fixation techniques were studied by Stulik et al. [22]. The Harms-Melcher technique [11] has the advantage of lesser risk of vertebral artery injury, as the C2 screw can be used like a short isthmic screw [24,26,27]. This internal fixation technique seems to be the current gold-standard [22,23] and was the surgical technique of choice in the present series. Parker et al. [25] recommend inter-spinal fusion, but this is not feasible if the posterior arc is fractured. Occipito-cervical fixation may be indicated in case of C0-C1 joint subluxation.

Medical complications mainly concerned elderly patients managed surgically, in agreement with Ryken et al. [10]. Early mortality was 2.7% for Derman et al. [12], comparable to the present rate of 3.2%. Mitchell et al. [13] reported a rate of 0.7% before 65 years of age, versus 11.8% after. Daentzer and Flörkemeier [21] showed that mortality and the general complications rate increased with age.

Table 2
Complications according to type of treatment.

Complications	Non-operative $n=40$	Primary surgery $n=17$	Secondary surgery $n=6$
Death	2 (5.0%)	0 (0%)	0 (0%)
Medical			
Pneumopathy	1 (2.5%)	2 (11.8%)	2 (33.3%)
Cardiac	0 (0%)	0 (0%)	2 (33.3%)
Thrombosis	0 (0%)	1 (5.9%)	0 (0%)
Delirium	0 (0%)	2 (11.8%)	0 (0%)
Bed-sores	1 (2.5%)	0 (0%)	0 (0%)
Neurologic	0 (0%)	2 (11.8%)	0 (0%)
Infection	0 (0%)	0 (0%)	0 (0%)
Mechanical			
Internal fixation	–	1 (5.9%)	1 (16.7%)
Non-union	5 (12.5%)	2 (11.8%)	3 (50.0%)

Horn et al. [20] reported >20% mortality with halo-vest immobilization in the elderly. Dysphagia (14.3%) and respiratory problems (9.5%) are among the most frequent general complications after non-operative treatment [20]. Intraoperatively, Stulik et al. [22] found vertebral artery lesion rates of 3.7–8.2%, and Lall et al. [24] reported rates of 1.3–4.1%. There were no vertebral artery lesions in the present series using the Harms-Melcher technique [11]. Complications specific to posterior internal fixation are few [12,24]. For Parker et al. [25], rates of malpositioning and cortical breach by C2 pedicle screws were around 7%. Mechanical complications related to screw malpositioning are rare, with rates of 5.4–6.1% [22,25].

Bone consolidation rates reported by Ryken et al. [10] and Stulik et al. [22] ranged between 90% and 100% according to fracture type and treatment. Landells and van Peteghem [3] reported on non-union in displaced fracture managed by Minerva brace. Horn et al. [20] reported a non-union rate of 23.8% with halo-vest treatment. Results in the literature are difficult to compare, as radiologic assessment methods differ. In the present series, non-operative treatment for stable fracture gave 84.2% consolidation. C1-C2 fusion would guarantee 100% consolidation if implemented in first-line. Type 3 fracture is problematic in case of significant displacement with respect to the lateral mass. It is underestimated, incurring risk of non-union, even in fusion performed for delayed consolidation. Hein et al. [28] stressed the problem of some type 2 (Jefferson) and type 3 fractures treated non-operatively: in case of C0-C1 and C1-C2 joint facet incongruence, non-union risk is high and lesions may remain unstable; 5 of their 8 patients underwent secondary surgery. The present study confirmed these findings: first-line surgery is preferable in case of severe lateral mass displacement, even with intact transverse ligament.

The present multicenter study by the French Society of Spinal Surgery comprised a large series of C1 fractures. It confirmed the literature data, but did not shed any new light on treatment.

5. Conclusion

Medical complications rates increased with age after surgery. Consolidation depended on type of fracture and treatment. Non-operative treatment was suited for type 1, 2 and 3 fracture with slight displacement and intact transverse ligament. C1-C2 fusion was suited to displaced unstable type 2 fracture. Displaced type 3 fractures incurred a risk of non-union. Early surgery may be recommended in case of lateral mass displacement.

Disclosure of interest

The authors declare that they have no competing interest.

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Contribution

Maxime Lleu: drafted the article and collected the study data at the Dijon University Hospital.

Yann Philippe Charles: led the SFCR round table discussion, was the chief investigator, designed the study, analysed the data, drafted the article, and collected the study data at the Strasbourg University Hospital.

Benjamin Blondel: collected the study data at the Marseille University Hospital.

Laurent Barresi: collected the study data at the Nice University Hospital.

Benjamin Nicot: collected the study data at the Grenoble University Hospital.

Vincent Challier: collected the study data at the Bordeaux University Hospital.

Joël Godard: collected the study data at the CHU de Besançon University Hospital.

Pascal Kouyoumdjian: collected the study data at the Nîmes University Hospital.

Nicolas Lonjon: collected the study data at the Montpellier University Hospital.

Paulo Marinho: collected the study data at the Lille University Hospital.

Eurico Freitas: collected the study data at the Lyon University Hospital.

Sébastien Schuller: collected the study data at the Strasbourg University Hospital.

Stéphane Fuentes: collected the study data at the Marseille University Hospital.

Jérémy Allia: collected the study data at the Nice University Hospital.

Julien Berthiller: methodologist, performed the statistical analyses, analysed the data.

Cédric Barrey: headed the SFCR round table discussion, was the chief investigator, designed the study, analysed the data, and collected the study data at the Lyon University Hospital.

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