Original article

C1-C2 stabilization by harms arthrodesis: Indications, technique, complications and outcomes in a prospective 26-case series

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\textbf{A B S T R A C T}

\textbf{Introduction:} C1-C2 arthrodesis is a surgical challenge due to the proximity of neurovascular structures (vertebral arteries and spinal cord) and the wide range of motion of the joint, hampering bone fusion. A variety of techniques have been successively recommended to reduce anatomic risk and improve results in terms of biomechanical stability and fusion rates. Recently, Harms described a new technique using polyaxial screws in the C1 lateral masses and C2 pedicles.

\textbf{Material and method:} The present study reports our experience in a consecutive series of 26 patients operated on by C1-C2 arthrodesis using the Goel and Harms technique, and details technical aspects step by step. Routine systematic immediate postoperative CT and 6-month CT controlled screw positioning and assessed fusion. Follow-up was at least 1 year, except in 2 cases (10 months).

\textbf{Results:} Twenty-six patients with a mean age of 57 years were included. Indications comprised: C2 non-union (n=11), C1-C2 fracture and/or dislocation (n=11), inflammatory pathology (n=2) and tumoral pathology (n=2). The results showed the technique to be reliable (no neurovascular complications and 85% of screws with perfect positioning) and an excellent rate of fusion (100% at 6 months).

\textbf{Conclusion:} Anatomic and biomechanical considerations, combined with the present clinical and radiological outcomes, indicate that Goel and Harms fusion is to be considered the first-line attitude of choice for posterior C1-C2 arthrodesis.

\textbf{Level of Evidence:} Level IV prospective study.

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1. Introduction

C1-C2 instability may have various causes, usually involving the C1-C2 axis or disc and ligamentary structures. Etiology is predominately acute trauma, odontoid non-union, inflammatory pathology (rheumatoid arthritis) or tumor [1,2].

Atlanto-axial arthrodesis is technically demanding due to the anatomic relations and wide range of motion of the joint, hampering good-quality bone fusion [3]. Surgical C1-C2 fusion was first described by W. Gallie in 1939, and consisted in posterior wiring [4], as subsequently developed by Brooks in the 1970s [5]. Biomechanical efficacy, however, was limited and wiring served more to maintain the interlaminar graft in position than to achieve real three-dimensional stability: a rigid cervical collar with 5 supports and a frontal band was associated for a minimum 3 months. Later, interlaminar hooks, with better biomechanical properties than wiring, were introduced [6]. Transarticular atlanto-axial screw fixation, introduced by Magerl in 1986 [7], provided very high quality biomechanical stability, with spectacularly improved fusion rates as compared to the earlier posterior wiring techniques [8–12]. There were, however, several drawbacks, notably including the difficulty of performance in case of atlanto-axial dislocation or subluxation with loss of C1-C2 alignment.

In 2001, Harms developed Goel’s work on atlanto-axial screw fixation, describing a stabilization technique based on fixation of the C1 lateral masses and C2 isthmus using polyaxial screws [13]. Biomechanical results are comparable to those with Magerl’s technique [14,15] and surgery remains possible in case of posterior arcligament involvement (unlike with hook fixation) or loss of C1-C2 alignment (unlike with Magerl’s procedure).

The present report is of an original consecutive prospective series of 26 patients managed by cervical or occipito-cervical arthrodesis including C1-C2, using the Harms technique.

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2. Materials and methods

Patients aged over 18 years were consecutively included from January 1st, 2009 to January 1st, 2012. Minimum follow-up was 1 year in all but 2 cases, in which it was for 10 months.

In all patients, posterior cervical arthrodasis including C1-C2 was indicated consensually by the center’s spinal surgery team.

Inclusion was independent of etiology.

The following clinical data were analyzed: age, gender, etiology of instability, operative time, blood loss, pre- and postoperative neurological status, and complications (neurological, infectious and general).

The following CT data were analyzed: cortical fracture (> 2 mm) on immediate postoperative imaging, and rate of fusion on 6-month postoperative CT. Mechanical complications (displacement, rupture of osteosynthesis material, screw detachment, etc.) were collected from the two postoperative CT scans.

C1-C2 fusion used polyaxial screws with a diameter of 3.5 mm in C2 and 4 mm in C1, connected up by 3.2-mm titanium rods (VERTEX, Medtronic®, Minneapolis, MIN, USA), on either side independently. All patients were operated on by the same surgeon (CB), to reduce variability related to surgical technique.

2.1. Surgical technique

Patients were positioned prone, with a Mayfield® skull clamp, with the head held in neutral position or slight flexion so as to facilitate C1-C2 exposure.

A classic midline posterior cervical approach was performed, exposing the spine from C0 to C3. Exposure had to be sufficiently lateral for the whole posterior arch of C2 and also the vertebral artery groove on the posterior arc of C1 to be visible. Particular care was taken in dissecting the posterior arc of C1 to avoid vertebral artery lesion (non-traumatic subperiosteal dissection).

The entry point for the C2 isthmus screw was at the junction of the superomedial and superolateral quadrants of the isthmus, slightly outside of the junction between the lamina and the facet at mid-height of the posterior arch (Fig. 1). The screw-hole was created using a 2.7 mm bit held about 30° upward and 20° convergent. Lateral fluoroscopic control allowed sagittal orientation to be adjusted. The diameter of the polyaxial Medtronic® VERTEX C2 isthmus screw (Fig. 2) was usually 3.5 mm, with length ranging between 18 and 30 mm depending on the patient’s anatomy (whence the importance of pre-operative planning, with precise measurement of the direction and diameter of the C2 isthmus).

The C2 root was systematically spared, being distracted downward using an Olivecrona spatula, taking care to limit (usually by swabbing) bleeding of the venous plexuses that are very numerous in this region.

The entry point for the C1 lateral mass lies at the intersection of a sagittal axis through the middle of the C1-C2 joint and a transverse axis through the junction of the posterior arc and the C1 lateral mass (Fig. 3). Depending on its morphology, the posterior arc of C1 may be partially rasped to facilitate screw placement. The screw-hole is created using a 3 mm bit, with a slightly upward (20°) and convergent (10°) direction. Lateral fluoroscopic control allows sagittal
adjustment. Screw diameters were 4 mm, with length usually of 28 to 32 mm, depending on patient anatomy. Like for C2, the polyaxial Medtronic® VERTEX screw was used (Fig. 4).

After screw positioning, radiological control was repeated and 2 Medtronic® VERTEX rods were fitted to connect the pairs of screws on either side (Figs. 4 and 5). Additional distraction/compression maneuver on the screws heads along the rod could be achieved to improve reduction and/or C1-C2 realignment.

After radiological control, the posterior arcs were freshened under abundant irrigation using a large-diameter (4 or 5 mm) burr. A large interlaminar graft was performed using decortication bone harvested during surgery associated to hydroxyapatite granules (Fig. 5).

3. Results

Mean age was 57 years (SD, 19.3 years), with 16 male and 10 female patients (Table 1).

Eleven of the 26 patients (Fig. 6) presented odontoid fracture non-union, 2 inflammatory pathologies (1 pannus on rheumatoid arthritis, 1 gout), 11 trauma (fracture or severe C1-C2 sprain) and 2 tumors (1 chordoma, 1 odontoid metastasis).

Mean operative time was 160 minutes (SD, 53 min; range, 1 h 15 min–4 h 50 min) and mean blood loss 260 mL (SD, 203 mL;...
## Table 1
Summary of indications, pre- and postoperative neurological status and operative data.

<table>
<thead>
<tr>
<th>Age</th>
<th>Gender</th>
<th>Indication</th>
<th>Preoperative neurological status</th>
<th>Type of assembly</th>
<th>Associated decompression</th>
<th>Postoperative neurological status</th>
<th>Operative time</th>
<th>Blood loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td>M</td>
<td>Non-union of odontoid fracture (4nm), facing odontoid granuloma (type 2)</td>
<td>Frankel C</td>
<td>Harms C1-C2</td>
<td>C1 laminectomy</td>
<td>Frankel D</td>
<td>2 h 15</td>
<td>15 mL</td>
</tr>
<tr>
<td>59</td>
<td>M</td>
<td>Complex C2 fracture, severe C1-C2 sprain</td>
<td>Frankel E</td>
<td>Harms C1-C2 (left) and transarticular (right), Posterior graft, odontoid screw fixation</td>
<td>No</td>
<td>Frankel E</td>
<td>3 h 50</td>
<td>50 mL</td>
</tr>
<tr>
<td>18</td>
<td>M</td>
<td>Non-union of odontoid fracture (OBAR type 2)</td>
<td>Frankel E</td>
<td>Harms C1-C2, odontoid screw fixation</td>
<td>No</td>
<td>Frankel E</td>
<td>3 h 50</td>
<td>400 mL</td>
</tr>
<tr>
<td>73</td>
<td>F</td>
<td>Fracture of both C2 lateral masses</td>
<td>Frankel E</td>
<td>Harms C1-C2, anterior arthrodesis, posterior graft</td>
<td>No</td>
<td>Frankel E</td>
<td>1 h 15</td>
<td>120 mL</td>
</tr>
<tr>
<td>84</td>
<td>M</td>
<td>Odontoid non-union (OBAR, type 2), retro-odontoid panus</td>
<td>Frankel E</td>
<td>Harms C1-C2, interlaminar graft</td>
<td>No</td>
<td>Frankel E</td>
<td>1 h 30</td>
<td>250 mL</td>
</tr>
<tr>
<td>71</td>
<td>F</td>
<td>Non-union of odontoid base fracture + granuloma</td>
<td>Frankel E</td>
<td>Harms C1-C2, interlaminar graft</td>
<td>No</td>
<td>Frankel E</td>
<td>2 h 15</td>
<td>890 mL</td>
</tr>
<tr>
<td>25</td>
<td>M</td>
<td>Fracture of C1 lateral masses (congenital CO-C1 fusion) CO-C1 dislocation</td>
<td>Frankel E</td>
<td>Harms C0-C1-C2, interlaminar graft</td>
<td>No</td>
<td>Frankel E</td>
<td>2 h 45</td>
<td>410 mL</td>
</tr>
<tr>
<td>51</td>
<td>M</td>
<td>Non-union of odontoid fracture (horizontal)</td>
<td>Frankel A</td>
<td>Harms C0-C1-C2, interlaminar graft</td>
<td>No</td>
<td>Frankel D</td>
<td>2 h 15</td>
<td>50 mL</td>
</tr>
<tr>
<td>77</td>
<td>F</td>
<td>Fracture of odontoid base with 11 mm posterior displacement</td>
<td>Frankel E</td>
<td>Harms C1-C2, interlaminar graft</td>
<td>No</td>
<td>Frankel E</td>
<td>1 h 30</td>
<td>160 mL</td>
</tr>
<tr>
<td>70</td>
<td>M</td>
<td>Fracture of odontoid base with 11 mm posterior displacement</td>
<td>Frankel E</td>
<td>Harms C1-C2, interlaminar graft</td>
<td>No</td>
<td>Frankel E</td>
<td>3 h 15</td>
<td>140 mL</td>
</tr>
<tr>
<td>33</td>
<td>M</td>
<td>Bi-articular C2 fracture, C2-C3 subluxation</td>
<td>Frankel E</td>
<td>Harms C1-C3, interlaminar graft</td>
<td>No</td>
<td>Frankel E</td>
<td>1 h 30</td>
<td>90 mL</td>
</tr>
<tr>
<td>60</td>
<td>F</td>
<td>Non-union of odontoid base fracture + granuloma</td>
<td>Frankel E</td>
<td>Harms C1-C2, interlaminar graft</td>
<td>No</td>
<td>Non-assessable (coma)</td>
<td>1 h 45</td>
<td>250 mL</td>
</tr>
<tr>
<td>74</td>
<td>M</td>
<td>Non-union of odontoid fracture + panus (congenital CO-C1 fusion)</td>
<td>Frankel C</td>
<td>Harms C1-C2</td>
<td>Laminectomy</td>
<td>Frankel D</td>
<td>2 h 15</td>
<td>210 mL</td>
</tr>
<tr>
<td>27</td>
<td>M</td>
<td>Fracture of C1 lateral masses (congenital CO-C1 fusion) CO-C1 dislocation</td>
<td>Frankel D</td>
<td>Harms C1-C2, interlaminar graft</td>
<td>No</td>
<td>Frankel E</td>
<td>2 h 00</td>
<td>240 mL</td>
</tr>
<tr>
<td>65</td>
<td>F</td>
<td>Pathologic fracture (complete C2 body lysis)</td>
<td>Frankel E</td>
<td>C1 to C5 with C2 isthmus screw fixation, C2 and C4 cementoplasty</td>
<td>No</td>
<td>Frankel E</td>
<td>4 h 50</td>
<td>300 mL</td>
</tr>
<tr>
<td>58</td>
<td>F</td>
<td>Intracranial clivus chordoma</td>
<td>Frankel E</td>
<td>Harms C0-C4 (NB: right C1 and left C2 not screwed)</td>
<td>No</td>
<td>Frankel E</td>
<td>2 h 50</td>
<td>320 mL</td>
</tr>
<tr>
<td>20</td>
<td>M</td>
<td>Non-union of odontoid fracture (OBAR on Roy-Camille classification)</td>
<td>Frankel E</td>
<td>Harms C1-C2</td>
<td>No</td>
<td>Frankel E</td>
<td>2 h 30</td>
<td>250 mL</td>
</tr>
<tr>
<td>58</td>
<td>F</td>
<td>C2-C3 dislocation fracture</td>
<td>Frankel E</td>
<td>Harms C1-C3, C2-C3 cage plate</td>
<td>No</td>
<td>Frankel E</td>
<td>3 h 30</td>
<td>170 mL</td>
</tr>
<tr>
<td>36</td>
<td>F</td>
<td>C1-C2 instability on rheumatoid arthritis</td>
<td>Frankel E</td>
<td>Harms C1-C2, interlaminar graft</td>
<td>No</td>
<td>Frankel E</td>
<td>2 h 15</td>
<td>150 mL</td>
</tr>
<tr>
<td>60</td>
<td>M</td>
<td>C1-C2 tophus (on gout) and odontoid fracture</td>
<td>Frankel E</td>
<td>Harms C1-C2</td>
<td>No</td>
<td>Frankel E</td>
<td>2 h 45</td>
<td>220 mL</td>
</tr>
<tr>
<td>58</td>
<td>F</td>
<td>Fracture non-union (OBAR, type 2)</td>
<td>Frankel E</td>
<td>Harms C1-C2, odontoid screw fixation</td>
<td>No</td>
<td>Frankel E</td>
<td>3 h 30</td>
<td>100 mL</td>
</tr>
<tr>
<td>82</td>
<td>M</td>
<td>Non-union of odontoid fracture (OBAR, type 2)</td>
<td>Frankel E</td>
<td>Harms C1-C2, odontoid screw fixation</td>
<td>No</td>
<td>Frankel E</td>
<td>4 h 00</td>
<td>850 mL</td>
</tr>
<tr>
<td>64</td>
<td>M</td>
<td>C2 Fracture non-union (hook detachment)</td>
<td>Frankel E</td>
<td>Harms C1-C2, interlaminar graft</td>
<td>No</td>
<td>Frankel E * resolution of posterior cordal syndrome</td>
<td>3 h 00</td>
<td>150 mL</td>
</tr>
<tr>
<td>66</td>
<td>M</td>
<td>Complex C2 fracture, severe C1-C2 sprain</td>
<td>Frankel A</td>
<td>Harms C1-C3, interlaminar graft</td>
<td>No</td>
<td>Frankel A</td>
<td>2 h 30</td>
<td>400 mL</td>
</tr>
<tr>
<td>63</td>
<td>M</td>
<td>Bipedicular C2 fracture</td>
<td>Frankel E</td>
<td>Harms C1-C3, interlaminar graft</td>
<td>No</td>
<td>Frankel E</td>
<td>2 h 00</td>
<td>320 mL</td>
</tr>
<tr>
<td>57</td>
<td>M</td>
<td>Anderson III C2 fracture</td>
<td>Frankel E</td>
<td>Harms C1-C3, odontoid screw fixation, interlaminar graft</td>
<td>No</td>
<td>Frankel E</td>
<td>4 h 00</td>
<td>150 mL</td>
</tr>
</tbody>
</table>

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range, 90–890 mL), taking all assemblies together. For 1-step Harms posterior C1-C2 assemblies, the mean figures were 130 min and 240 mL.

There was no postoperative neurological aggravation. Five of the 7 neurologically impaired patients showed clinical neurological improvement (Fig. 7): 3 with non-union of an Anderson type-II fracture, and 2 with traumatic C1-C2 dislocation.

Immediate postoperative radiological control, performed within 2 days of surgery, comprised thin-slice CT centered on C1-C2, with sagittal and coronal multiplanar reconstruction (Fig. 8). In 2 cases, the scanner was not available in the intensive care setting, and AP and lateral upper cervical spine X-rays were taken instead.

All screws were correctly positioned, with no cortical damage in most cases (22 out of 26: 85%). In the other 4 cases, the cortical fracture was less than 2 mm, without clinical impact; there were no fractures longer than 2 mm. Three of the 4 fractures were of the C0-C1 joint line, and the fourth of the transverse canal at C2 (without vascular impact) (Figs. 9 and 10). No revision operations were required and there were no clinical or radiological consequences (notably vascular or neurological).

Patients were followed up at 6 months and 1 year. Systematic CT control at 6 months (Fig. 11) found no non-union or displacement of material. C1-C2 bone bridges were systematic, although of variable quality. Grafts were of poorer quality in case of C1 and/or C2 laminectomy, with smaller bone bridges.

4. Discussion

The present results are strictly in line with the literature [13,16,17]: an excellent rate of fusion, and very good reproducibility of correct screw positioning, testifying to the reliability of the technique.

The fact that there were no cases of non-union or mechanical complications in the present series confirms the interest of this technique for achieving high-quality fusion. The early posterior wiring techniques of C1-C2 arthrodesis, mentioned above, achieved fusion in only two-thirds of cases [18,19] despite 3 months’ cervical collar immobilization; the collars, moreover, incurred well-established specific morbidity such as delayed healing or operative site infection or scabbing (especially in elderly subjects, who frequently show denutrition) and non-negligible psychological impact. Following Harms arthrodesis, we recommend temporary (6 weeks) use of a supple collar when (and only when) the cervical spine resumes load-bearing.

As in Harms’ own series of 37 patients [13], all of the screws were more or less well positioned, and there were no vascular or neurologic lesions. We did, however, find it wise to use short monocortical and isthmus screws in C2, to minimize to risk of lesion to the vertebral artery in its groove forward of the tip of the screw. The main technical difficulty encountered concerned venous bleeding due to the large number of plexuses around the C2 root and
facing the entry point on the C1 lateral mass. During exposure, these plexuses should be painstakingly distracted downward, preventively, using 1 or 2 spatulas and hemostatic agents. In case of persistent bleeding, which is of venous origin, prolonged swabbing is usually effective. Also, due to the proximity of the C2 root, unprotected by any bony structure, bipolar forceps coagulation is to be preferred to monopolar sectioning.

Some authors recommend C2 root ligature, to promote hemostasis; this is not, however, without clinical consequences (hypoesthesia of the gonion and retroauricular region, associated with risk of neuralgia), and we consider the techniques described above to be sufficiently effective in almost all cases. The quality of the interlaminar grafts, moreover, is not such as to encourage C1–C2 grafting sacrificing the C2 root.

C1–C2 hooks (linked by rods or clamps) avoid the risk of vertebral artery lesion incurred by screwing, but have the disadvantage of involving intracanal surgery (with supplementary neurological risk) and cannot be used in case of laminar involvement (e.g., post-traumatic or secondary to laminectomy). Biomechanically, moreover, although laminar hooks provide anteroposterior stability comparable to Magerl’s C1–C2 screw fixation, stability in rotation is much poorer [8]. The posterior interlaminar graft is also larger and more satisfactory when performed medially (between rods, as is the case in screwing) rather than laterally (as in hook fixation, where it is lateral to the rods linking the hooks).

Biomechanically, transarticular C1–C2 screw fixation, as initially described with Magerl’s technique, provides much better stability in both flexion/extension and rotation than do wiring techniques [8,20,21].

Stability has been compared between the Harms and Magerl techniques [8,17,22]: the two are equivalent; the Harms technique has the better biomechanical properties reported so far with posterior C1–C2 arthrodesis. Given the potential technical difficulties of Magerl screw fixation, especially when C1–C2 alignment is not conserved, and the greater risk of vertebral artery lesion (due to less convergent screw positioning), the Harms technique appears preferable. Associating posterior wiring to the Magerl technique, as suggested by several teams in case of difficulty [11,23], does not seem indicated; it involves an intracanal step, increasing neurologic risk for a biomechanical benefit that has not been assessed.

Certain authors have described a minimally invasive Harms procedure [24]. Only 5 cases have as yet been reported, and benefit and interest remain to be elucidated.

Navigation techniques have recently been described, and can doubtless enhance reliability [25], especially in difficult cases, although the upper cervical spine is not the ideal site for navigation (limited exposure, deep operative site, mobile segment, etc.).

Taken together, the above arguments and present findings suggest to us that Harms fusion is the first-line reference method for posterior C1–C2 arthrodesis.

Fig. 10. C1–C2 dislocation fracture (left). Day-2 postoperative CT (right) shows vertebral artery canal fracture on the left side.

Fig. 11. Immediate postoperative (left) and 6-month (right) X-ray and CT control in a patient receiving Harms fusion with extension to C0. Excellent posterior fusion at 6 months, with posterior bone graft remodelling.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References