Comparison of fusion rates between rod-based laminar claw hook and posterior cervical screw constructs in Type II odontoid fractures

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ABSTRACT

Background: This study was aimed (i) to compare the fusion rates of rod-based laminar claw hook constructs to that of posterior C1/C2 screw constructs in odontoid fractures, and (ii) to evaluate any complications associated with claw hook/rod constructs. To our knowledge, no study in contemporary literature has presented the effects of using modern rod-based laminar claw hooks for treating odontoid fractures. Unlike laminar clamps from the 1980s, contemporary laminar hook–rod instrumentation systems provide better immobilisation of the cervical spine and allows for building reliable frame-like constructs similar to cervical screw–rod systems.

Methods: A retrospective review of a series of 167 consecutive odontoid fractures from a single-institution was conducted. 30 cases from the series were treated using posterior atlantoaxial fusion, 12 using C1/C2 posterior screws (control group), and 18 with rod-based laminar claw hooks (study group). Hooks were mounted bilaterally in a claw manner on each individual lamina and were rigidly fixed to perpendicular rods with a transverse connector whenever feasible. The minimum follow-up period was one year. Bony union was determined using computed tomography (CT) scan, while stability at the fusion site was assessed using dynamic radiograms.

Results: The study group had an overall fusion rate of 89% (non-geriatric 93% while geriatric subgroup 75%) with a 100% stability rate at the fusion site in all cases. In the control group fusion rate was 100%. There were no major complications in both control and study groups. Four minor complications, three in the control and one in the study group, were noted in 3 patients.

Conclusion: Preliminary results of this study suggest that laminar claw hook–rod systems are useful alternatives to posterior screw techniques. Moreover, the fusion rate in non-geriatric patients is comparable to that of posterior screws. Importantly, they are devoid of the disadvantages and complications posed by screw constructs. Further studies are necessary to confirm these promising results.

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Introduction

Contemporary laminar hook–rod systems offer reliable rigid immobilisation of adjacent vertebrae in the cervical spine. When a pair of hooks is mounted in a claw manner on either side of individual lamina, they provide a firm grip to the whole cervical vertebra. When adjacent cervical vertebrae are instrumented in this way and interconnected to longitudinal rods with tightening nuts, they create a biomechanically reliable rigid frame-like construct similar to posterior screw–rod systems. Modern laminar hook–rod systems overcome all the biomechanical disadvantages of their predecessors, such as laminar clamps that were popular in the 1980s. These systems are commonly available on the market; yet only limited reports in literature cite their use in odontoid fractures. Database searches conducted to identify recent publications on modern hook–rod instrumentation yielded only three research publications from the last decade [1–3]. Manufacturers of contemporary rod-based laminar hooks do not provide any mounting instructions, leaving this at the discretion of the operating surgeon. It is likely that most surgeons mount these

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hooks in a similar manner as laminar clamps were mounted in the 1980s, which has a number of shortcomings. We thus developed a strategy to mount the new rod-based laminar hooks in a claw-like manner in Type II odontoid fractures, and compared the results, in this retrospective study, to the more commonly used posterior screw method. In this paper, we present findings from our evaluation, and the advantages associated with our method.

Materials and methods

Study design

Aim of the study

1. Evaluate the fusion rate achieved with rod-based laminar claw hook constructs in Type II odontoid fractures, and
2. compare the fusion rates with those obtained for posterior screw constructs, using both published data, as well as, personal data of the first author from his series of Type II odontoid fractures.

Patients

Of 167 consecutive cases of odontoid fractures from a single institution, 30 patients were treated by selective C1/C2 posterior fusion with rod based laminar claw hooks (18 cases) and C1/C2 posterior screws (12 cases). The inclusion and exclusion criteria set for the study and the control groups are given below.

Inclusion criteria for the study group.

- The patients with Type II odontoid fractures were operated on by posterior selective C1/C2 fusion and stabilised with rod-based laminar claw hooks.
- The hooks were mounted in a claw-like manner and rigidly assembled to rods.
- The patients had no accompanying C1 and/or C2 fractures (e.g. mixed fractures like Hangman/odontoid, Jefferson/odontoid, etc.).
- Patients were available for a final assessment at a minimum of one year post surgery.

Exclusion criteria for the study group.

- Stabilisation, other than atlantoaxial (e.g. occipito-cervical) extension of construct to the subaxial spine.
- Accompanying fractures of C1 and/or C2 (hangman, Jefferson etc.).
- Hooks mounted in non-claw manner.
- Surgery was conducted less than a year ago.

Inclusion criteria for the control group.

- Posterior selective C1/C2 fixation with screws either transarticular or a combination of lateral mass/pedicle screws.
- No accompanying fracture of C1 and/or C2 (e.g. mixed fractures like Hangman/odontoid, Jefferson/odontoid etc.).
- Assessment at a minimum of one year after surgery.

Exclusion criteria for the control group.

- Construct extended beyond C2 (e.g. to the subaxial spine) or to the occiput.
- Accompanying fractures of C1 and/or C2.
- Surgery was conducted less than a year ago.

Methods

Retrospective clinical study. Medical files of 167 patients with odontoid fractures treated in the Department of Neurosurgery, St Luke Hospital, Tarnów, Poland between 2002 and 2012 were reviewed. Of these patients, 130 were managed surgically: 88 through the anterior approach with direct odontoid screws, and 42 through the posterior approach (Table 1). Of the latter, 23 patients were stabilised with rod-based laminar claw hooks, 12 with C1/C2 posterior screws (control group), and 7 with occipital screws/subaxial cervical lateral mass screws. Of the 23 patients with laminar claw hook constructs, 18 had selective C1/C2 fixation and therefore entered the study group (Table 1). In the control group 8 patients had transarticular screws (Magerl’s method), while 4 patients C1 lateral mass/C2 pedicle screws (Harms or Goel method) (Table 1). Therefore the study group included 18 while the control group had 12 cases of selective atlantoaxial fusion (Table 1).

Surgical treatment. The first author of this paper operated all patients in the study and control groups between 2002 and 2012. The study is non-randomised and there were no specific selection criteria for posterior screws or laminar claw hook fixation. The type of instrumentation chosen for fixation, posterior screws or laminar claw hooks, was at the discretion of the operating surgeon.

Laminar claw hook – rod instrumentation. Two different instrumentation systems, SSE Cervical by Braun/Aesculap and Vertex by Medtronic, were used on the patients. Both provide a choice of hooks that can be mounted in a claw-like manner and rigidly secured to longitudinal rods. A single lamina was captured with two pairs of hooks each configured in a claw-like manner (‘kissing hooks’). One pair of claw hooks was mounted on the left, while the other on the right side of the spinous process (Figs. 1a and b and Fig. 2). When feasible, hooks were mounted in a claw mode on both adjacent vertebrae (axis and atlas) (Fig. 2). There were some cases in which only one (either C1 or C2) lamina could be captured with claw hooks, while the laminae of the adjacent vertebrae were captured in a non-claw manner. In such circumstances the construct was compressed against the heads of the hooks interposed between adjacent laminae (Fig. 3). Due to the rigid mechanical connection to perpendicular rods, hooks interposed between adjacent laminae could not migrate. This is unlike the early hook systems used in the 1980’s and commonly known as

<table>
<thead>
<tr>
<th>Treatment modality</th>
<th>Number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservative</td>
<td>37</td>
</tr>
<tr>
<td>Surgical</td>
<td>130</td>
</tr>
<tr>
<td>Total</td>
<td>167</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgical (130 cases)</td>
<td></td>
</tr>
<tr>
<td>Odontoid screw</td>
<td>88</td>
</tr>
<tr>
<td>Posterior fusion</td>
<td>42</td>
</tr>
<tr>
<td>Total</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior fusion (42 cases)</td>
<td></td>
</tr>
<tr>
<td>C1/C2 posterior screws (control group) transarticular screws (8 cases) + C1 lateral mass/C2 pedicle screws (4 cases)</td>
<td>12</td>
</tr>
<tr>
<td>Rod based laminar claw hooks</td>
<td>23</td>
</tr>
<tr>
<td>Occipital screws/subaxial cervical lateral mass screws total</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Rod based laminar claw hooks (23 cases)</td>
<td></td>
</tr>
<tr>
<td>C1/C2 rod based claw hooks (study group)</td>
<td>18</td>
</tr>
<tr>
<td>Occipital screws/rod based laminar claw hooks</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
</tr>
</tbody>
</table>
interlaminar clamps. The stiffness of these early systems relied on a wedge shaped bone graft interposed between adjacent laminae and secured against migration by mounting hooks in compression. Such constructs were unable to effectively prevent shear motions, and easily failed to secure the lamina due to the migration of the bone graft (Fig. 4a and b). Although, there is no biomechanical evidence on contemporary laminar hook rod systems to date, based on our clinical observations, we speculate that laminar hooks may control shear motion, better than their predecessors, by providing a rigid connection to the rods.

Acceptance criteria for CT healed fusion. CT scans with sagittal and coronal reconstructions were viewed by staff radiologists at our hospital to assess fusion. If one or more scans showed continuity of the bone (bone bridges), between adjacent laminae or between the base of the peg and the body of the axis, it was identified as fused. Regardless of whether it was only the odontoid peg or the posterior bone graft that healed, it was considered a successful fusion. This

Fig. 1. (A) Radiogram of C1–C2 laminar claw hook–rod construct. (B) CT sagittal reconstruction of the construct from (A).

Fig. 2. Intraoperative photo of C1–C2 laminar claw hook–rod construct with transverse connector (The Vertex Reconstruction System by Medtronic).

Fig. 3. The combination of C2 laminar claw hooks and C1 laminar hooks. The pair of hooks, (black dot) interposed between C1 and C2 laminae, allows reliable compression of the construct. Laminae are compressed against the head of the hooks similarly, but much more effectively than in Brooks–Jenkins method, laminar clamps, or interlaminar clamps (see Fig. 4a and b). Unlike the bone strut in sublaminar techniques or laminar clamps, hooks cannot migrate from between the adjacent laminae because of their rigid mechanical connection to perpendicular rods. This patient had unsuccessful fusion following direct osteosynthesis of the dens with odontoid screw. Re-operation was performed using laminar hook–rod instrumentation system.
criterion is important because in a few cases managed with posterior fusion, the bone graft failed to fuse posteriorly while the dens itself healed. Bony union of odontoid peg is an expected outcome in posterior atlanto-axial fusion and it occurs in addition to posterior bony union. Maiman and Larson described a fusion rate of 35% across the fracture line after posterior fixation and fusion for C2 odontoid fractures [4].

**Stability criteria.** A fusion site was considered stable if the C1–C2 angle was less than 2° in dynamic X-rays. Assessment was performed by staff radiologists at our hospital.

**Results**

**Perioperative and late complications observed in the study and control group**

Perioperatively, no major systemic complications (e.g. respiratory, cardiovascular, urinary, deep vein thrombosis or pulmonary embolism) were noted in the evaluated groups. No injuries to the vertebral artery (VA) or neurological deficits were observed after surgery in both the groups. There were 4 minor complications, which occurred in 3 cases (one patient had two complications), accounting for 10% of all patients in both control and study groups (Table 2). One late complication (kyphosis of the subaxial spine) occurred in a patient from the control group.

**Comparison of fusion rates between claw–hook/rod constructs and posterior screws**

A 100% fusion rate was obtained in 12 patients who were operated with posterior screws (control group). An 89% fusion rate, with 100% stability at the fusion site, was obtained in patients instrumented with the rod-based laminar claw hook (study group) (Table 3). All non-union patients had stability at C1/C2 segment on dynamic radiograms. In the study group, the age of 4 patients was between 65 and 87 years. When divided into geriatric (>65 yrs) and non-geriatric (<65 yrs) subgroups, the outcomes were as follows: in the geriatric subgroup, bony union was achieved in 75% with stability in 100% of patients; in the non-geriatric subgroup (14 patients), the corresponding figures were 93% and 100%, respectively (Table 3). The union rate obtained with hook–rod instrumentation in our non-geriatric group of patients is comparable to rates achieved with posterior screws both in our study and within those of other researchers. The only union failure in the non-geriatric group occurred in a patient who had C1/C2 fusion performed with the use of bone graft substitute. If not for this one outlier, the fusion rate would have been 100% in the non-geriatric subgroup.

**Discussion**

The past decades have seen a remarkable evolution in surgical management of odontoid fractures. Modern techniques of instrumentation allow firm and deep anchoring of implants in the strongest parts of the atlas and the axis. This has resulted in increased strength of atlantoaxial constructs and therefore higher fusion success rates, better outcomes, and even eliminated the need for external orthosis in some cases. The last step in the evolution of atlantoaxial fixation is represented by techniques based on instrumentation of lateral masses of C1/pedicles of C2 (Harms or Goel technique), and C1/C2 joints (Magerl’s technique). These techniques were introduced into clinical practice in the mid-nineties and mid-eighties, respectively; however, they became popular and were widely used only in the last decade [5–7]. In the last few years, numerous reports on their clinical effectiveness and biomechanical performance were published [8–15]. These techniques proved to have excellent biomechanical performance as measured by either in vitro biomechanical tests or fusion rates [16–21]. The fusion rate achieved with posterior screws is close to or 100% as observed and published by many authors. For example, the success rate of bony fusion with transarticular screws in the non-geriatric population is about 90%, ranging from 71.5 to 99% depending upon the method used for assessing fusion [22–25]. The fracture-healing rate for geriatric patients was reported as low as 33% [26]. In contrast, a fusion rate near or of 100% is achieved with C1 lateral mass/C2 pedicle screws. Few studies reported 100% fusion rates with these technique [5,6,8,10,13,15]. Fusion rates
above 90% are reported by other authors [12,14]. The fusion rate obtained with posterior screws, whether transarticular or C1 lateral mass/C2 pedicle, in our series is 100%, and therefore comparable to those cited by other authors.

For comparison between posterior screws vs. modern laminar claw hook–rod instrumentation of the upper cervical spine, very little information is found in literature. We did not come across studies on clinical effectiveness of modern laminar hook–rod constructs, or studies comparing outcomes of hooks and posterior screws. Our search yielded one paper dealing with outcomes achieved with C1–C2 claw hooks in a group of seven patients [1]. The paper was published in Turkish. The abstract was translated in English and provided no data about the fusion rate. It only mentioned that satisfactory stabilisation was achieved in all patients. We also found an abstract of a poster by Litrico et al. [27], presented at the joint meeting of the French Society of Neurosurgery and the European Association of Neurosurgical Societies in Marseille, France in 2009. The authors analysed a series of 22 cases implanted with laminar hooks for various pathologies of the craniovertebral junction. They concluded that fixation with hooks in surgery of craniovertebral junction is an effective and safe technique with comparable (to screws) results in terms of fusion and neurological improvement. They also found that this technique is easier than the posterior screw method with a lower morbidity [27].

In contrast to laminar hooks, techniques using screws are technically more demanding and have the added risk of serious complications. Injury to VA is the most common complication. It varies from 0 to 13.1% for the Magerl technique, being the lowest in larger series for this technique [14,28–32]. The incidence for the Harms technique ranges from 0 to 5.8% [14], and was 0% as found by Wang et al. [13], the largest series ever published. Neurological complication following VA injury may vary from 0 to 33% [14,33].

Thorough familiarity with the anatomy of the upper cervical spine is essential to avoid possible complications inherent in the screw techniques, and also to preoperatively preclude the use of C1 and C2 screws. Several authors have reported that up to 20% of patients are not candidates for transarticular screws based on the size of the pars interarticularis of C2 [28,34–38]. In a series of 50 adult patients, Spangenberg et al. [39] found that optimal transarticular C1–C2 screw placement was not possible in 26% of those cases, and even hazardous in 15%. Paramore et al. [38] using axial and parasagittal CT reconstructions for the assessment of the feasibility of transarticular screw fixation found that 18–23% of trajectories were unsafe. However, even a thorough preoperative plan may not appear to be feasible during surgery. Vergara et al. [14] reported that in their series of 76 planned Magerl fixations, it was not feasible in four cases. They also found that the Harms technique was not suitable in 8.5% because of small C2 pedicles [14]. In contrast to screws, feasibility or suitability of hooks does not depend on bony anatomy (except for the defect of laminae) or the course of VA.

The aid of navigation guidance systems may increase feasibility of C1 lateral mass, C2 pedicle, and transarticular screw instrumentation [40,41]. However, the use of this modern technology increases surgery time and requires extensive preoperative diagnostic work-up and planning. Although, modern navigation technologies have extended the usefulness of posterior screw fixation, still a population of patients will exist whose bony anatomy will eliminate possibility of C1–C2 transarticular or C2

Table 2
Perioperative and late complications in the study and control groups (4 complications in 3 patients).

<table>
<thead>
<tr>
<th>Complication</th>
<th>Posterior screws</th>
<th>Laminar claw hooks</th>
<th>Total number of complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Misplacement of implants</td>
<td>Patient no. 1</td>
<td>–</td>
<td>1</td>
</tr>
<tr>
<td>Migration of implants/hardware failure</td>
<td>–</td>
<td>Patient no. 3</td>
<td>2</td>
</tr>
<tr>
<td>Deep wound infection</td>
<td>–</td>
<td>–</td>
<td>0</td>
</tr>
<tr>
<td>Kyphosis of the subaxial spine (developed gradually in late post-op period)</td>
<td>– (the same as above)</td>
<td>–</td>
<td>1</td>
</tr>
<tr>
<td>Vertebral artery injury</td>
<td>–</td>
<td>–</td>
<td>0</td>
</tr>
<tr>
<td>Permanent occipital neuralgia</td>
<td>–</td>
<td>–</td>
<td>0</td>
</tr>
<tr>
<td>Neurological deficit/iatrogenic injury to the spinal cord</td>
<td>–</td>
<td>–</td>
<td>0</td>
</tr>
<tr>
<td>Systemic complications (cardiovascular, respiratory, urinary, deep vein thrombosis, pulmonary embolism, etc.)</td>
<td>–</td>
<td>–</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>3 Complications in 2 patients (17% of patients in control group)</td>
<td>1 (6% of patients in study group)</td>
<td>4 Complications in 3 patients (10% of patients in control and study group together)</td>
</tr>
</tbody>
</table>

Table 3
Bony union achieved in the study (C1/C2 posterior screws) and control (rod based laminar claw hooks) groups.

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>Bony union (%)</th>
<th>Non-union (CT) (%)</th>
<th>Stability at the fusion site (dynamic radiograms) (%)</th>
<th>Unstable at the fusion site (dynamic radiograms) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, C1/C2 Posterior screws (12 patients)</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>3, C1/C2 rod-based laminar claw hooks (18 patients)</td>
<td>89</td>
<td>11 (2 Patients)</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>(a) Non-geriatric (14 patients)</td>
<td>93</td>
<td>7 (1 Patient)</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>(b) Geriatric (4 patients)</td>
<td>75 (3 Patients)</td>
<td>25 (1 Patient)</td>
<td>100 (4 Patients)</td>
<td>0</td>
</tr>
</tbody>
</table>
pedicle screw instrumentation. Unlike screws, laminar hooks do not require such extensive preoperative work-up to recognise the location of the VA and the diameters of bone structures to safely instrument the spine. Building constructs using hooks and rods neither requires the aid of computer navigation systems nor the use of the C-arm. It is our observation that in contrast to screws, the use of C-arms during hook instrumentation surgery helps verify spinal alignment more than the position of the implants. Therefore, intraoperative exposure of the operative team and the patient to radiation is significantly reduced, often to only one or two shots.

Unlike screws, laminar hooks do not require the exposure of the spine in the vicinity of VA. Also one does not need to manoeuvre C2 nerve roots and risk bleeding from adjacent venous plexus, which often takes additional time to control. C2 nerve roots could be damaged during mobilisations that are necessary to expose the entry points for C1 lateral mass screws. Sometimes the C2 nerve root has to be sacrificed to make screw insertion feasible. Lateralgenic damage to the C2 nerve root can result in severe paresthesias and severe persistent occipital neuralgia [15,42–44]. Exposure of entry points into C1 lateral masses and C2 pedicles requires extensive subperiosteal dissection of paraspinal muscle, extended far laterally to achieve the correct angle of screw insertion. Therefore, the approach in posterior screw techniques is much more injurious to paraspinal musculature compared to the approach used in the laminar hook method. Laminar hooks can be mounted on laminae with much lesser exposure of the spine.

Instrumentation with laminar hooks does not need sophisticated technology. It is much simpler than screw techniques. Implanting laminar hooks does not require drilling lateral masses and pedicles, observing appropriate angles and directions, as required with screws, coping with bleeding from the venous plexus around the C1–C2 joint, and focusing surgical efforts on careful retraction of the C2 nerve root. Unlike screws, which are anchored within spongiosa, laminar hooks do not need to rely on the quality of the bone, which is crucial in instrumentation of geriatric fractures, since hooks grip the cortical bone of the lamina without the risk of loosening inside the osteoporotic spongiosa.

We have presented the observations from our evaluation of only 18 cases of odontoid fractures. However, our surgical experience with laminar rod-based hooks so far is based on more than 50 patients, including non-trauma mainly rheumatoid arthritis cases. Further studies, preferably randomised controlled trials on a larger number of patients, are necessary to arrive at sound conclusions based on reliable statistical analysis. Nevertheless, our preliminary results are promising enough to consider the modern rod-based laminar claw system as a possible alternative to posterior screw techniques. Modern laminar hook instrumentation should receive more attention in the literature, thus allowing its fair comparison to other methods used in the stabilisation of the upper cervical spine.

Conclusions

The fusion rate achieved with posterior atlantoaxial laminar claw hook–rod instrumentation was 93% in non-geriatric patients in our series. This result is comparable to the union rates cited in literature for posterior fusion using the Magner technique and C1 lateral mass/C2 pedicle screws. We believe that rod-based cervical laminar claw hook constructs are a viable alternative to posterior screw techniques.

Conflict of interest statement

None declared.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.injury.2015.01.042.

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