

# Accuracy of freehand fluoroscopy-guided placement of C1 lateral mass and C2 isthmic screws in atlanto-axial instability

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## Abstract

**Background** The C1 lateral mass and C2 isthmic stabilization, as introduced by Goel and Laheri and by Harms and Melcher, is a well-known fixation technique. We present the clinical and radiographic results with freehand fluoroscopy guided C1 lateral mass and C2 isthmic fixation in a consecutive series of 28 patients, evaluating the accuracy of screw placement.

**Methods** Twenty-eight consecutive patients suffering from post-traumatic and other C1-C2 instability were operated on between 2001 and 2010. Indications for surgery were: trauma ( $n=21$  cases), os odontoideum ( $n=1$ ), craniovertebral malformation ( $n=1$ ), and arthritis ( $n=3$ ) and idiopathic instability ( $n=2$ ). C1 lateral mass and C2 isthmic screws were placed according to the usual anatomical landmarks with lateral fluoroscopy guidance. All patients underwent a postoperative CT scan. The extent of cortical lateral or medial breach was determined and classified as follows: no breach (grade A), 0–2 mm (grade B), 2–4 mm (grade C), 4–6 mm (grade D), more than 6 mm (grade E). Grade A and B screws were considered well positioned.

**Results** A total of 56 C1 lateral mass and 55 C2 isthmic screws were placed. Accuracy of screw placement was as follows: 107 grade A (96.4%), four grade B (3.6%), and no grade C, D or E. Clinical and radiological follow-up showed

improvement in symptoms (mainly pain) and stability of the implants at the end of the follow-up.

**Conclusions** Freehand fluoroscopy-guided insertion of C1 lateral mass and C2 isthmic screws can be safely and effectively performed.

**Keywords** C1-C2 instability · C1-C2 internal fixation · Computer-assisted spinal surgery · Screw placement

## Introduction

C1-C2 instability may result from trauma, tumor, infection, arthritis, and malformations, and it frequently requires surgical fixation. Different techniques have been described in the literature to achieve C1-C2 stabilization. Magerl introduced transarticular C1-C2 fixation, coupled to posterior wiring and bone grafting. This is considered biomechanically the strongest technique with fusion rates approaching 100% [4, 20]. Nevertheless, it is associated with a risk of vertebral artery (VA) damage. In order to reduce this risk and to achieve equivalent stability, first Goel and Laheri [5], and then Harms and Melcher [6], introduced a technique in which C1 lateral mass and C2 isthmic/pedicle screws are used [10, 12, 15].

A residual risk remains for any technique in C1-C2 fixation, due to the proximity of the screw trajectory and the VA, the spinal cord, the internal carotid artery, and the hypoglossal nerve. Even if the risk of neurological deficit from VA injury has been calculated to be 0.2% per patient and 0.1% per screw, the consequence of VA injury can lead to brain infarction, massive bleeding and even death [32].

Consequently, different intraoperative image-guided systems have been developed to reduce the risk for malpositioning of the screws [7–9], allowing the surgeon to achieve

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a solid fixation in a safe way. Navigation and robotic systems are now available in the majority of spine centers, where so-called “computer assisted surgery” (CAS) is performed. Potential advantages of CAS are well known: the ability to plan a preoperative surgical strategy, the possibility to simulate surgery by advance, the safety of the procedure, and, when associated with minimally invasive techniques, less length of hospitalization time for patients, less postoperative pain and smaller complication rates. Nevertheless, CAS is apt to inaccuracy as well, which might be particularly relevant in such a delicate and mobile region as the cranio-cervical junction [27]. Adequate preoperative imaging and deep knowledge of anatomical structures and landmarks are thought to be sufficient to perform surgical fixations in this region.

We therefore analyzed our experience with C1 lateral mass and C2 isthmic screw fixation in 28 patients to define placement precision relying on traditional anatomical landmarks and intraoperative lateral fluoroscopy.

## Materials and methods

Twenty-eight consecutive patients, ten male and 18 female, with a mean age of 59.8 years have been operated on for C1-C2 instability or painful osteoarthritis in the Department of Neurosurgery between 2001 and 2010. Twelve of these patients were included in a previous report with a short follow-up, and under different viewpoints [19]. C1-C2 instability was caused by: trauma in 21 cases (75%), malformation in one (3.5%), os odontoideum in one (3.5%). Three patients (10.7%) suffered from painful osteoarthritis and two patients (7.1%) had idiopathic C1-C2 instability. Among the 21 trauma cases, the indications for surgery were: highly unstable fractures ( $n=9$ , 42.8%), failure of conservative treatment with hard collar ( $n=7$ , 33.4%), pseudoarthrosis after anterior screw placement for odontoid fractures ( $n=4$ , 19.1%), and old non-healed odontoid fracture ( $n=1$ , 4.7%) (Table 1).

Preoperative symptoms were: pain (in all), and cervical myelopathy (in two). Neck pain was classified according to the visual analogue score (VAS). The mean preoperative VAS for cervical pain was 4.9 (Table 1). All patients had a preoperative bone computed tomography (CT) with angiographs and cranio-cervical magnetic resonance imaging (MRI). The CT scan allowed for studying the bony anatomy of the region and the course of the vertebral artery. Measurements of C1 lateral mass and C2 isthmus were performed on preoperative CT axial and sagittal views to calculate the maximum space available for the screws. The size of the screws used during the surgery was recorded on the operative chart.

Postoperative thin-cut CT was performed 1–3 days post surgery. The accuracy of the screws was evaluated according

to the Gertzbein and Robbins grading [3]: grade A (perfectly into the pedicle), grade B (0–2 mm of cortical breach), grade C (2–4 mm), grade D (4–6 mm), and grade E (more than 6 mm). Grade A and B screws were considered well positioned.

Mean follow up was 10 months, ranging from 2 to 48 months (Table 1).

## Surgical technique

The surgical technique used by authors has been already described in details in a previous paper [19].

Briefly, the patient is placed in the prone position with the head in a Mayfield head-holder in a “military tuck” position in order to facilitate the access to C1-C2 region. Manual reduction under fluoroscopic lateral view is attempted prior to surgery. A midline skin incision is performed from the occiput to the C3 spinous process. After opening of the fascia and subperiosteal dissection of cervical posterior muscles, anatomical bony landmarks are identified: C1 posterior arch with posterior tubercle, C2 posterior arch with posterior bifid spinous process, C2-C3 articular rim, medial border of the C2 isthmus.

The C1 lateral mass entry point is identified just below the posterior arch by pushing caudally the C2 nerve root with a hook. Hemostatic sponge or gel is used to control the venous plexus bleeding. The medial and lateral borders of the lateral mass of C1 are identified and palpated. The entry point is in the midway, and an electric drill 2.7 mm is used for a pilot hole. The sagittal cranio-caudal direction is determined by pointing to the C1 anterior tubercle on lateral C-arm view. Around 10° of convergence are needed. The screw path is completed, till the anterior cortex is gently pierced. The usual length of the C1 screw is 30–34 mm, necessary to allow rod placement posteriorly.

The entry point for C2 isthmic screw is about 2–3 mm above the C2-C3 articulation and 2–3 mm lateral from its center. The sagittal cranio-caudal direction is determined under direct fluoroscopic view, aiming at the C1 anterior tubercle until the tip of the screw reaches the posterior border of C2 vertebral body. Usually, the VA is projected anterior to this line, so by staying posterior to it, less risk for VA damage is expected. The trajectory is quite steep in order to have the longest purchase into the isthmus. At that point, if needed, pulling the spinous process in a cranial direction with a clamp allows for a steep sufficiently trajectory. The trajectory is convergent, aiming towards the medial wall of the C2 isthmus. The usual length of the C2 isthmic screw is 14–20 mm. Then, the head of the screws are connected with rods (here: Vertex System, Medtronic, Memphis, TN, USA). A monocortical bone graft from the posterior iliac crest is put between C1 and C2

**Table 1** Case series

Sex	Age	Indication	Preop neck pain (VAS)	C1 screws MC/BC	C1 screws GR Grade	C2 screws GR Grade	Neck pain at F-UP	Stability at F-UP
F	65	Pseudoarthrosis type III odontoid fracture	7	One BC, one MC	A-A	A-A	2	Yes
M	48	Pseudoarthrosis type II odontoid fracture	6	Both BC	A-A	A-A	4	Yes
F	75	Pseudoarthrosis type II odontoid fracture	8	Both BC	A-A	A-A	1	Yes
M	64	C1C2 instability with malformation	6	Both BC	A-A	A-B	3	Yes
F	72	C1C2 osteoarthritis	8	Both BC	A-A	A-B	2	Yes
M	77	Pseudoarthrosis after odontoid screwing	5	Both BC	A-A	A-A	0	Yes
M	78	Pseudoarthrosis after odontoid screwing	5	Both BC	A-A	A-A	5	Yes
F	23	Complex C2 fracture	0	Both BC	A-A	A-A	0	Yes
F	62	Complex C2 fracture	7	Both BC	A-A	A-A	3	Yes
F	27	Pseudoarthrosis of C2 fracture	0	Both BC	A-A	A-A	1	Yes
F	38	Unstable Jefferson fracture	7	Both BC	A-A	A-A	4	Yes
F	49	Complex C2 fracture	7	Both BC	A-A	A-A	0	Yes
F	85	Pseudoarthrosis after odontoid screwing	0	Both BC	A-A	A-A	0	Yes
F	75	Pseudoarthrosis after odontoid screwing	5	Both BC	A-A	A-B	0	Yes
F	40	Unstable type III odontoid fracture	4	Both BC	A-A	A-A	0	Yes
F	50	Unstable type III odontoid fracture	7	One MC, one BC	A-A	A-A	4	Yes
M	60	Unstable type II odontoid fracture	4	Both BC	A-A	A-A	1	Yes
F	75	Pseudoarthrosis type II odontoid fracture	0	One MC, one BC	A-A	Translaminar-A	0	Yes
F	82	Pseudoarthrosis type II odontoid fracture	4	Both BC	A-A	A-A	1	Yes
M	23	Pseudoarthrosis type II odontoid fracture	3	Both MC	A-A	A-A	0	Yes
F	34	Os odontoides	4	Both BC	A-A	A-A	0	Yes
M	59	Pseudoarthrosis type II odontoid fracture	5	One BC, one MC	A-A	A-A	2	Yes
M	51	Complex C2 fracture	6	Both MC	A-A	A-A	1	Yes
M	68	Unstable Jefferson fracture+type II odontoid fracture	4	Both B	A-A	A-A	0	Yes
M	60	Idiopathic C1C2 instability	7	Both BC	A-A	A-B	1	Yes
F	75	C1C2 osteoarthritis	8	Both BC	A-A	A-A	4	Yes
F	78	C1C2 osteoarthritis	8	Both BC	A-A	A-A	6	Yes
F	82	Idiopathic C1C2 instability with stenosis	4	Both BC	A-A	A-A	2	Yes

M male, F female, VAS visual analogue score, MC monocortical, BC bicortical, GR Gertzbein and Robbins, F-UP follow-up

posterior arches according to Gallie technique, modified by Sonntag. The different layers are closed on a suction drainage. Patients are mobilized from the first postoperative day on in a soft collar.

## Results

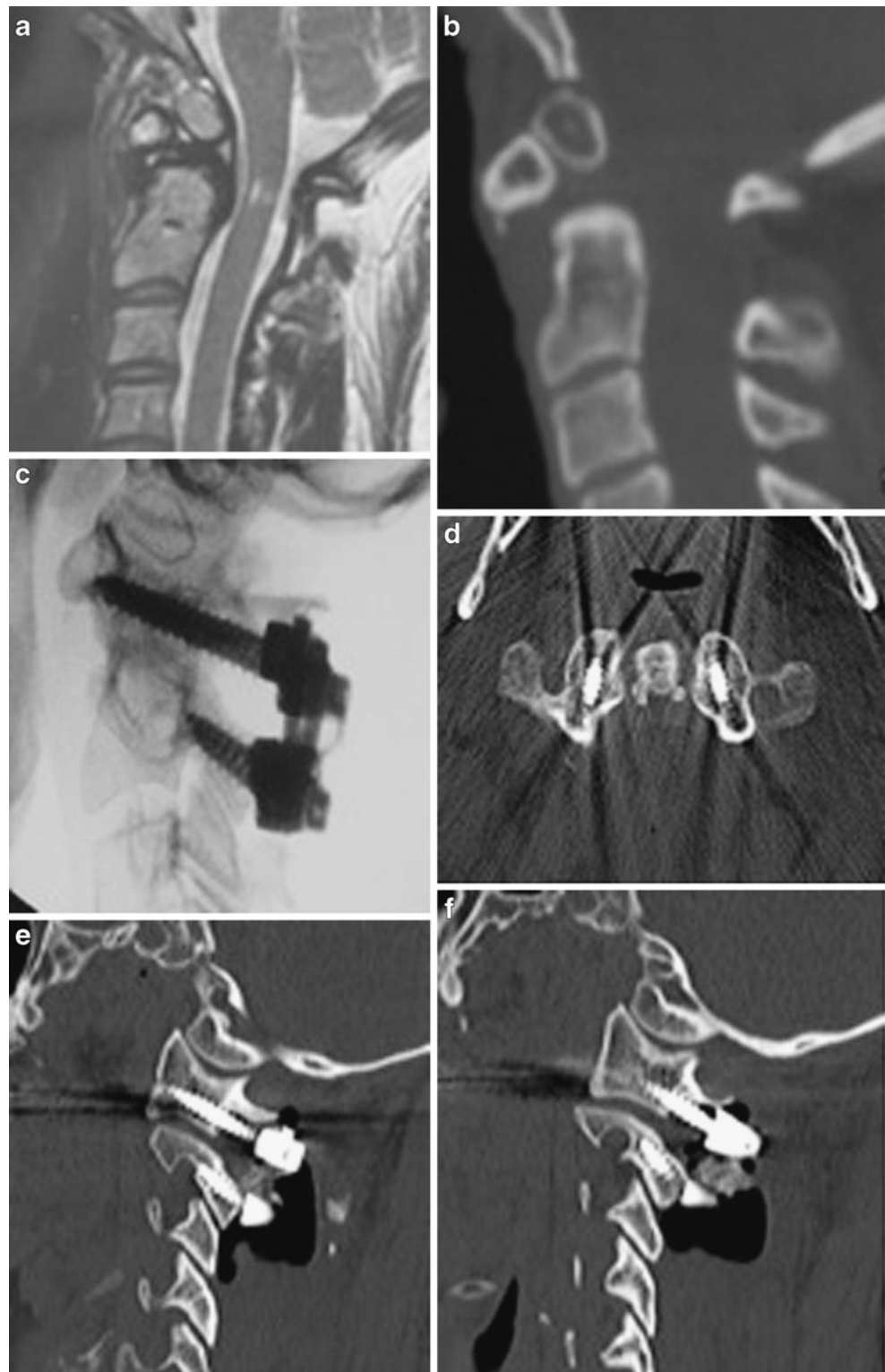
Examples of screw fixations are shown in Figs. 1, 2, 3, and 4.

Fifty-six C1 lateral mass screws were inserted: 25 screws were 34 mm long (44.6%), 22 (39.3%) screws were 32 mm, and nine screws (16.1%) were 30 mm. Fifty-five C2 isthmic screws were implanted: 19 screws were 14 mm long (34.5%), 15 screws were 16 mm long (27.3%), 12 screws

were 18 mm long (22%), seven screws were 20 mm long (12.7%), and two screws were 12 mm long (3.6%). In one case, a 26-mm C2 laminar screw had been inserted because of an iatrogenic fracture of the lateral part of the isthmus.

Twenty-eight postoperative CT scans were analyzed. All 56 C1 lateral mass screws (100%) were grade A according to the Gertzbein and Robbins grading. C1 lateral mass screws breaching the anterior cortex were not considered to be malpositioned, because this is part of the surgical technique. Eight out of 56 C1 screws (14.3%) were monocortical. Four C2 isthmic screws resulted to be grade B (7.2%), while the remaining 51 were considered grade A (92.8%) and one screw was translaminar because of an iatrogenic isthmic fracture. Considering grade A+B as ideal

**Fig. 1** Os odontoideum. **a** MR image showing an os odontoideum with a high cervical spinal cord hypersignal. **b** CT scan showing an os odontoideum non-fused to the clivus. **c** Postoperative lateral X-ray showing a C1-C2 posterior fixation. **d** Postoperative axial CT scan showing well-positioned C1 LM screws. **e** Postoperative sagittal CT scan showing right C1 LM and C2 isthmic screws. **f** Postoperative sagittal CT scan showing left C1 LM and C2 isthmic screws



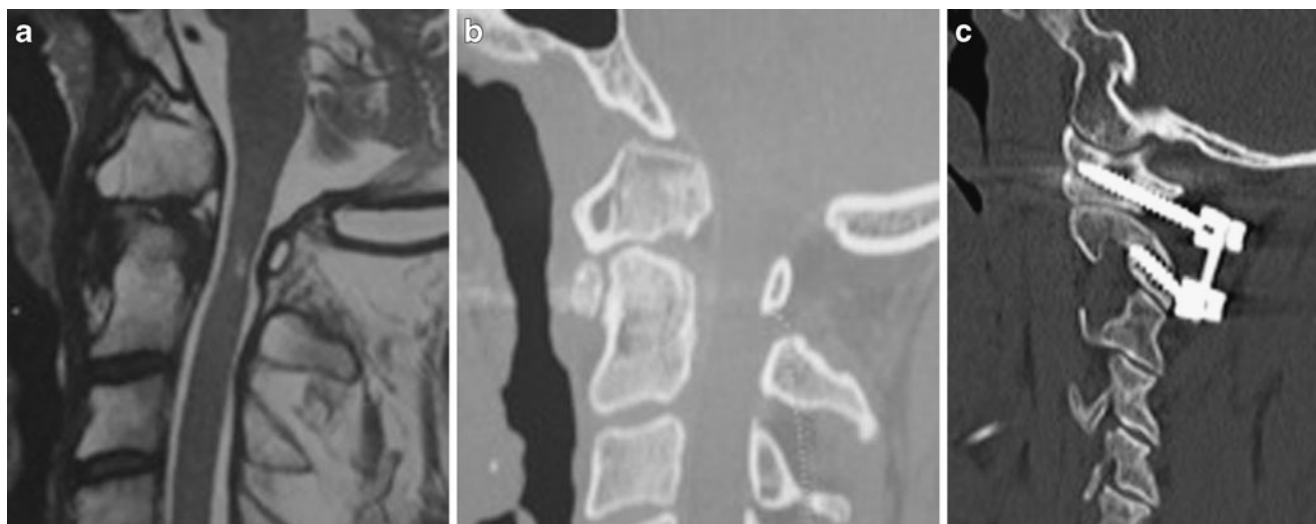
positioning, all screws had showed to be well positioned (Table 1).

Mean operating time was 152.9 min (ranging from 90 to 225 min). Mean blood loss was 477 ml (ranging from 150 to 800 ml). At the end of the follow-up the postoperative mean VAS score for cervical pain was 1.6. At the end of the

follow-up, all 28 patients (100%) showed stability on dynamic X-rays and a solid fusion was obtained (Table 1).

Complications occurred in six patients (21.4%). A greater occipital nerve neuralgia was evident in three cases (10.7%). The pain was treated with specific drugs with complete recovery at the end of the follow-up in all cases.





**Fig. 2** Old non-healed type II odontoid fracture. **a** MR image showing an old non-healed type II odontoid fracture with fusion between the anterior C1 arch and the bony fragment. **b** CT scan

showing an old non-healed fracture. **c** Postoperative CT scan showing C1 LM and C2 isthmic screws on the right side. The first one is unicortical

This relatively high incidence of transitory neuralgia is maybe related to a conflict between the screw and the C2 nerve root at the entry site. In up to 25% of cases some of the C1 lamina may need to be removed to achieve an adequate entry site. Alternatively, pre-ganglionic division of the C2 nerve root can be utilized to gain access to the entry site [5, 30].

Furthermore, we had a superficial wound infection in one case (3.5%), which has been successfully treated with intravenous antibiotics. One patient (3.5%) had pain at the iliac harvested site for several weeks with spontaneous regression. A posterior progressive intestinal herniation through the iliac scar was seen in one case (3.5%), which required surgical repair.

## Discussion

### Techniques of C1-C2 fixation

Atlanto-axial instability can be related to a variety of pathologies: trauma, tumors, infections, arthritis, and congenital malformations. It might be associated with pain or neurological compromise, and if misdiagnosed or mistreated it may lead to catastrophic neurological consequences.

C1-C2 fixation and stabilization can be achieved with different techniques. Magerl and Freeman [12] first introduced in 1987 the so-called transarticular procedure, in which atlanto-axial stability is obtained by a bilateral placement of transarticular screws. This technique has biomechanical advantages in term of stiffness and stability, but it presents also some limitations: first, the two articular

processes must be well aligned and the pre-existing degree of luxation needs to be reduced; then, it can be performed only if the VA is not “in the way” of the trajectory of the screw [4]. Furthermore, VA anatomical variants occur in up to 20% of patients, thus resulting in a potential conflict between the screw and the medially located VA [17]. It has been calculated that in the transarticular technique there is a risk of VA damage of 2% per screw [32].

First Goel and Laheri in 1994 [5] and then Harms and Melcher in 2001 [6] introduced a different technique in which C1 lateral mass and C2 pedicle/isthmic screws are connected, respectively, with plates or rods. In literature, it is still unclear which of the two techniques is biomechanically the stiffest. Anyway, the Goel-Harms procedure can be performed even if the C1-C2 luxation is not completely reduced. Furthermore, the risk for damaging the VA is clearly reduced. We prefer the latter technique, and have already published our own results with this technique in a consecutive series of 12 patients [19].

### Unicortical or bicortical C1 lateral mass screw?

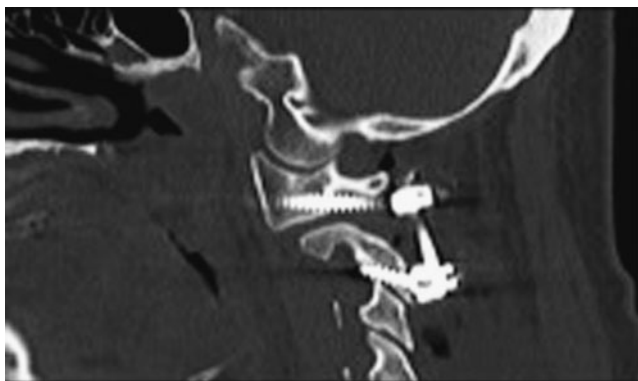
The need for unicortical or bicortical fixation in C1 lateral mass remains a point of debate. A unicortical purchase has been advocated in literature, in order to reduce the risk of injury to the ICA and the hypoglossal nerve, which both lie directly in front of the lateral mass [11]. We prefer a bicortical purchase for biomechanical reasons. The perforation of the anterior cortex cannot be seen during the operation, but it can be felt with a pedicle feeler during the drilling procedure as a loss of resistance. Thereafter in this series, 87.4% of C1 screws were found to be bicortical on the postoperative CT.

**Fig. 3** Idiopathic C1-C2 instability. **a** MR image showing a spinal cord compression at C1/2 due to retrodental pannus of unknown origin; a diffuse idiopathic skeletal hyperostosis (DISH) is evident in the lower C spine. **b** Postoperative CT confirms correct screw positions in C1 and C2 on sagittal CT reconstruction and axial cuts after C1-C2 fixation and C2 laminectomy. **c** Lateral and anteroposterior (AP) radiographs after 6 months



Eck et al. [2] presented a biomechanical study of pullout strength of unicortical versus bicortical C1 lateral mass

screws performed on 15 cadaveric cervical spine specimens. The mean pullout strengths of the unicortical screws and



**Fig. 4** Example of C2 GR grade B screw. A C2 isthmic screw is breaching the anterior cortex by 2 mm

bicortical screws were 588 N (range, 212–1,234 N) and 807 N (range, 163–1,460 N), respectively ( $P=0.008$ ). They concluded that bicortical C1 lateral mass screws were significantly stronger than unicortical ones.

#### Navigation systems for C1-C2 screw placement

Navigation systems for the reduction of the risk for vessel and spinal cord injuries had gained popularity in spinal surgery. Thanks to technologically developed “online” camera-tracking of a patient’s spinal anatomy with calibrated instruments, based on preoperative or intraoperative CT or three-dimensional (3D) rotational radiographic imaging, implant positioning has been described as safe and efficient in many reports, including the CCJ [14]. While image-guided surgery is a logical effort to improve safety and precision, several imprecisions are unavoidable in such a highly mobile region as the craniocervical junction (CCJ). Thus, even with perfect data transformation, navigation accuracy is reduced by several factors:

1. Calibration errors: they have been shown in 3D fluoroscopy-based systems, for example, to account for approximately 1 mm accuracy in a phantom model [25].

2. Bending of instruments: in a cadaver model, navigation inaccuracy was around 2.5 mm due to bending of instruments and or reference during manipulation [26]; in practice, occasional blocking of the camera field of view or inadvertently touching/hitting references can cause additional loss of precision [27].

3. Non-rigid connection between the reference base and the actual surgical site: concerning specifically CCJ, attaching a reference frame in this region is problematic; therefore, the reference frame is often attached to the head, creating potentially important motion between the actual surgical site at C1 or C2 and the frame [27].

Due to these navigation inaccuracies, most surgeons verify their drilling and screw positioning and lengths by conventional intraoperative fluoroscopy and do not show

complete faith in image guidance [18]. So far, there is not a single report where the surgeon trusted the image-guidance more than intraoperative fluoroscopic or anatomic verification. It remains unclear whether the computer-assisted surgery leads to a lower incidence of screw replacement and a lower incidence of screw-placement-related complications [22, 28].

On the other hand, Mueller et al. [13] state that the use of spinal navigation in C2 pedicle screw insertions is justified by the high rate of misplaced screws, despite the fact that no neurovascular injury occurred. They reported on the technique of transpedicular C2 screw fixation without spinal navigation. The accuracy was assessed on postoperative CT scans according to Gertzbein and Robbins (GRGr) (see above). A total of 47 C2 pedicle screws in 27 patients were performed. An association between intraoperative direct visualization and fluoroscopy was used. The postoperative CT findings showed in 55.3% GRGr 1, in 27.7% GRGr 2, in 10.6% GRGr 3, and in 6.3% GRGr 4 pedicle screw insertion accuracy. Screw malpositioning (i.e., GRGr 3 and 4) was observed mainly with thin (<5 mm) pedicle diameters. If a GRGr 4 screw placement occurred, angiography was performed to exclude VA damage.

#### Freehand C1-C2 screw placement

Nevertheless, this paper shows that C1 lateral mass and C2 isthmic screws may be safely inserted without any navigation assistance.

Liu et al. [11] reported on a series of 46 C1 lateral mass screws inserted in 24 consecutive patients. All C1 lateral mass screws were inserted unicortically using a microscope-assisted freehand technique. No vertebral artery injury or cerebral spinal fluid leakage during the screw insertion was observed and all the C1 screws were considered to be well positioned. They stated that C1 lateral mass screws can be inserted without fluoroscopy with microscope assistance, and they considered the intraoperative fluoroscopy time consuming, cumbersome, and dangerous as it exposes both the patient and surgical team to radiation. Simsek et al. [23] demonstrated that unicortical C1 lateral mass screws could be placed safely and rapidly without fluoroscopy guidance in 17 consecutive patients. No screw malpositions or neurovascular complications related to screw insertion were observed. They concluded that C1 lateral mass screws might be used in upper cervical spine without intraoperative fluoroscopy guidance and the use of the spinal navigation systems. In our series, all 56 C1 screws were well positioned. We personally think that fluoroscopy is a useful tool and that the total amount of radiation can be limited to few shots per procedure. It is mainly useful to decide the depth of C1 bicortical lateral mass screw in relationship to the anterior

atlas tubercle and the sagittal direction of the C2 isthmic screws in relationship to the VA groove.

Ondra et al. [16] showed that an open technique combined with lateral C-arm guidance provides rapid and safe placement of C2 pedicle screws in a retrospective review of 150 C2 pedicle screw. As we normally do, they exposed the C2 isthmic and they palpated it with a dissector to provide coronal orientation while a lateral C-arm radiograph was obtained for sagittal orientation. A total of 71 patients had bilateral screws placed and eight patients had unilateral screws placed. In this series, eight non-critical and one critical (then revised) screw misplacement occurred.

Wang et al. [31] made a retrospective radiographic study of the technique for C1 lateral mass screw (C1LMS) and C2 pedicle screw (C2PS) fixation on 319 patients with atlanto-axial instability. They used a freehand fluoroscopy-guided technique. CT angiography or magnetic resonance angiography were performed after surgery in cases with malpositioned screws to assess potential VA injury. In 95.5% of C1LMS fixations and of C2PS fixations, the screws were found to be in a “good” position, which meant a screw respecting the outer borders of C1 lateral mass and C2 isthmic in axial, sagittal and coronal cuts. Even if six cases presented with misplaced screws, no vascular problem was noted. Thus, they stated that the technique for C1LMS and C2PS fixation appears to be safe and effective for achieving posterior C1-C2 fixation.

Sciubba et al. [21] made a prospective follow-up of 55 consecutive patients who underwent C2 instrumented fusion. The cortical breaches were classified upon the percentage of screw diameter beyond the cortical edge. One hundred consecutive screws were placed. They had 15% total breaches. The magnitude of the breach was classified as I (<25%) in ten cases (66.7% of breaches), II (26-50%) in three cases (20% of breaches), III (51-75%) in one case (6.7%), and IV (76-100%) in one case (6.7%). They concluded that when the isthmic interarticularis/pedicle is assessed preoperatively with CT scan and found to be suitable for screw placement, freehand placement of screws in the C-2 pedicle could be done safely and effectively without the use of intraoperative fluoroscopy or navigation. But we argue that their 15% of total breaches is too high and not acceptable in a delicate region as C1-C2.

Stulik et al. [24] evaluated the accuracy of C1 lateral mass and C2 pedicle freehand screw placement in their series of 28 consecutive patients operated on for atlanto-axial fixation. All 56 C1 screws were well positioned and all but one were bicortical, while three of the 56 C2 screws were malpositioned (5.4%). Chen et al. [1] presented their technique for C1-C2 fixation. In their series of 11 cases, only one C2PS violated the medial wall of the pedicle without any clinical consequence. In the series of Vilela et

al. [29], any cortical violation of C1LM was detected in the postoperative CT scans of their 11 patients (21 LM screws).

## Conclusion

Knowledge of anatomical landmarks is mandatory for performing safe C1-C2 internal fixation procedures. In experienced hands, the accuracy of the freehand fluoroscopy-guided Harms-Goel technique is high. Navigation-assisted screw placement systems might reduce the rate of misplaced screws in selected cases.

**Conflict of interest** None.

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## Comment

The authors present a series of 28 patients treated with C1-2 fusion using C1 lateral mass C2 isthmus screws placed with a freehand technique based on anatomical landmarks. There were no significant screw-related complications and screw placement was accurate based on postoperative CT in the vast majority of screws, with results comparable with series using computer-aided navigation. While this is only a retrospective case series, it emphasizes the fact that well-trained surgeons do not require the use of expensive adjuncts to perform procedures. A thorough knowledge of patient anatomy and adequate training allow for the safe performance of these procedures.

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