



USE OF INTRAOPERATIVE CONE BEAM TOMOGRAPHY AND OPTICAL NAVIGATION FOR C1–C2 POSTERIOR SCREW FIXATION: A CLINICAL CASE AND LITERATURE REVIEW

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Objective. To analyze the features of the surgical technique and evaluate the effectiveness of intraoperative CT navigation in posterior screw fixation of the C1–C2 vertebrae using a clinical case as an example and a literature review.

Material and Methods. A clinical case is presented to provide a detailed description of the surgical technique for posterior screw fixation of the C1–C2 vertebrae under intraoperative navigation using a mobile cone beam CT scanner. A narrative review of the literature is also conducted.

Results. The described technique for performing posterior screw fixation of the C1–C2 vertebrae ensures precise positioning of the screws with minimal radiation exposure to the operating team, which increases the safety of such operations.

Conclusion. Effective use of cone beam tomography and optical navigation requires careful preoperative assessment of the acceptable screw insertion trajectory based on CT study and CT angiography, rigid head fixation on the operating table, the use of official navigation equipment and instruments, and preliminary staff training in surgical technique using simulation models.

Key Words: upper cervical spine; intraoperative navigation; posterior screw fixation; intraoperative computed tomography.

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The craniovertebral junction is characterized by a complex, variable anatomy and a significant range of motion [1–3]. Craniovertebral junction injury can lead to instability with a high risk of neurovascular structure damage [1, 2, 4]. Posterior screw fixation of the upper cervical spine is characterized by high biomechanical stability [5, 6]. However, according to the literature [6, 7], the risk of vertebral artery injury during freehand posterior screw fixation reaches 8.2–16.7%. Various modalities of spinal navigation are utilized to mitigate the risk of neurovascular injury. Navigation systems based on intraoperative three-dimensional fluoroscopy and preoperative CT are characterized by inaccurate patient registration in the system and a large margin of error due to the high mobility of the cervical spine and the unstable nature of craniovertebral junction fractures [8–11]. The use of an

intraoperative cone-beam computed tomography (CBCT) system (O-arm) integrated with spinal navigation can enhance the accuracy of implant placement. However, there is a scarcity of Russian literature evaluating the technique and efficacy of this navigation method for posterior screw fixation of the upper cervical spine [12–15].

The aim of the study is to analyze the features of the surgical technique and evaluate the effectiveness of intraoperative CT navigation in posterior C1–C2 screw fixation, based on a clinical case and a literature review.

Case study

Patient R., a 47-year-old male, first presented for medical attention 30 days after sustaining a closed cervical spine injury from a fall from standing height. Upon admission, the patient complained of neck pain radiating to the occipital

region, as well as a restricted range of motion in the neck. No neurological deficit was noted. A CT scan of the cervical spine revealed an ununited Anderson and D'Alonzo type II fracture of C2 odontoid process (Fig. 1).

Given the unstable nature of the fracture and the time elapsed since the injury, a decision was made to perform C1–C2 posterior screw fixation using the Goel–Harms technique, guided by intraoperative CT (O-arm) and spinal navigation.

Surgical planning using CT-guided navigation did not differ from the preparation required for standard fluoroscopy-guided surgery. During the analysis of preoperative CT scans, the width of the C1 lateral masses, the height of the C1 posterior arch, the width of the C2 pedicles, and the height of the C2 isthmus (pars interarticularis) were measured bilaterally using previously described techniques [19, 20]. The measurement data enabled the selection of the opti-

mal method for C1 and C2 pedicle screw implantation.

Surgical technique and procedure steps may vary depending on the equipment used. In this case, an intraoperative mobile O-arm cone-beam computed tomography system with a navigation station was utilized.

The patient was placed in the prone position with rigid cranial fixation. Surgical field preparation and draping were performed according to the standard technique. Following a standard midline approach, the reference frame was fixed to the clamp (Fig. 2). Fixation of the frame to the spinous process of the C2 vertebra is permissible [19].

The reference frame was positioned to ensure that the surgeon's hands did not obstruct the line of sight between the frame and the optical camera of the navigation station during the procedure. The initial intraoperative computed tomography (O-arm) scan was performed to obtain a three-dimensional reconstruction of the cervical spine and for its direct registration with the navigation station. Next, the pointer and other instruments required for screw placement were registered: a high-speed bur, tap, screwdrivers, etc. (Fig. 3).

The registration of unofficial instruments was ensured by attaching universal trackers to them. Registration accuracy was verified by placing the pointer on anatomical landmarks (Fig. 4).

Following verification of registration accuracy, screws were implanted in C1 and C2 vertebrae. Screw insertion points and trajectories were selected under navigation guidance. To improve the accuracy of screw placement in patients with high C1–C2 mobility caused by both the functional characteristics of the upper cervical spine and traumatic instability, the screw channel was prepared using a navigated bur. The screws were implanted using a navigated screwdriver. The navigation system allowed for the determination of the optimal screw length and diameter (Fig. 5). The position of the implanted screws was verified by a follow-up O-arm CT scan (Fig. 6). The procedure was completed in a standard fashion (Fig. 7).

Discussion

The malposition of screws in posterior cervical spine fixation remains a significant concern. According to an anatomical study by Yoshida et al. [21], trajectories were high-risk for neurovascular injury in 13.3% of C1–C2 transarticular screws and 9.7% of C2 pedicle screws. The trajectory was considered unacceptable in 3.2% and 4.0% of the screws, respectively.

In a study by Neo et al. [22] evaluating the accuracy of freehand cervical pedicle screw placement for degenerative pathology at the C2–C6 levels, a 29% malposition rate was reported. In 84% of cases, malposition was lateral toward the transverse foramen, with 15% of screws being placed with significant malposition (grades 2–3) [22]. In a multicenter study by A.V. Gubin et al., the accuracy of screw placement and the complication rate were evaluated for freehand posterior screw fixation at the C1 and C2 levels. In a total cohort of 41 patients, the rate of malposition was 37.0% at the C1 level and 40.5% at the C2 level. None of the cited studies reported any neurovascular injury.

The maximum incidence of vertebral artery injury reached 16.7% in certain series with C1–C2 transarticular fixation,

and 9.1% with C1–C2 screw-rod fixation [24–26].

Lee et al. [7] investigated the incidence of vertebral artery injury during various cervical spine surgeries. A multicenter study included 512 cases of fluoroscopy-guided freehand posterior C1–C2 screw fixation. Injuries were recorded in 1.35% of cases during posterior C1–C2 Goel–Harms fixation (4 cases at the C1 level and 3 at the C2 level). All vertebral artery injuries at the C1 and C2 levels occurred due to instrument malposition during the stages of screw channel preparation with a high-speed burr, probing of the screw channel, and screw insertion into the lateral masses of C1 and transpedicularly into C2. Among seven cases of vertebral artery injury at the C1–C2 level, acute cerebrovascular accident was verified in one patient [7]. Thus, freehand posterior C1–C2 screw fixation carries a risk of life-threatening complications related to screw malposition due to an underestimation of aberrant vertebral artery anatomy and post-traumatic atlantoaxial dislocation.

The use of optical intraoperative CT navigation for posterior C1–C2 screw fixation is reported in the current literature only in small case series. This is likely due to the complex surgical anatomy of the C1 and C2 vertebrae and

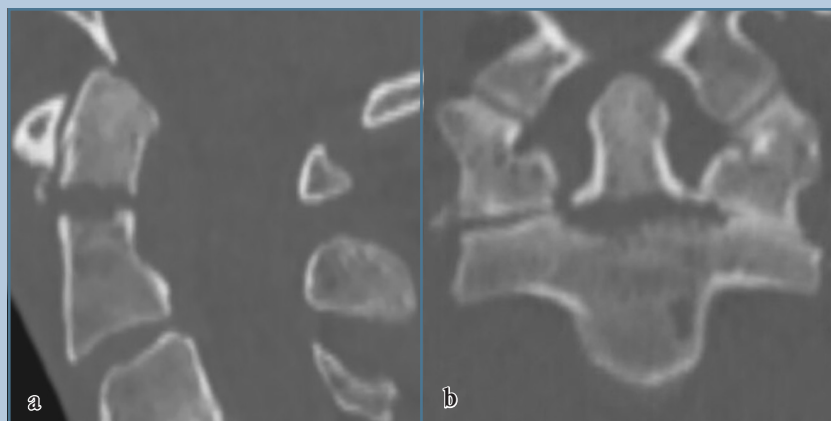
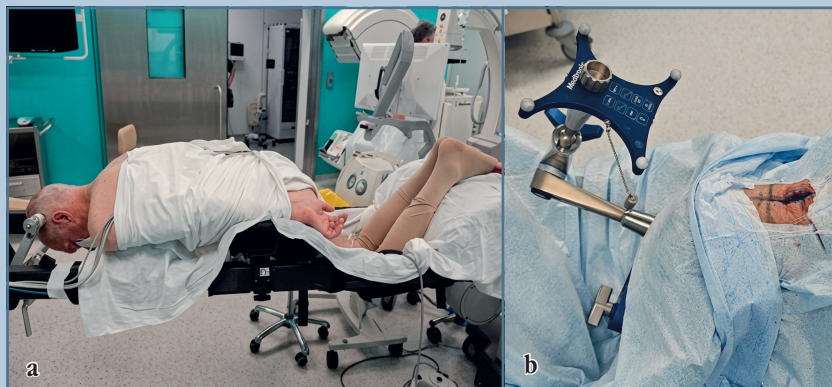
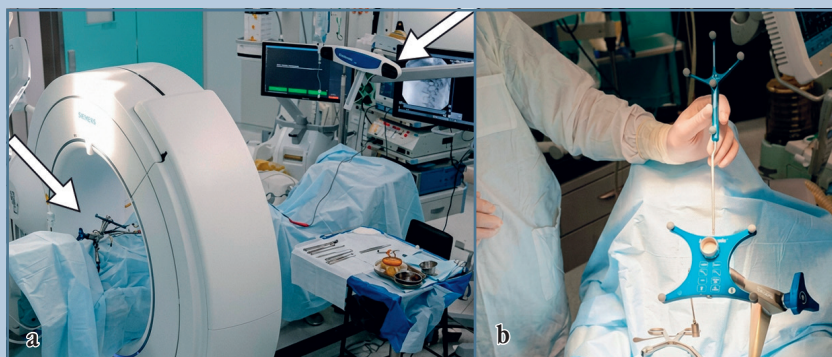


Fig. 1

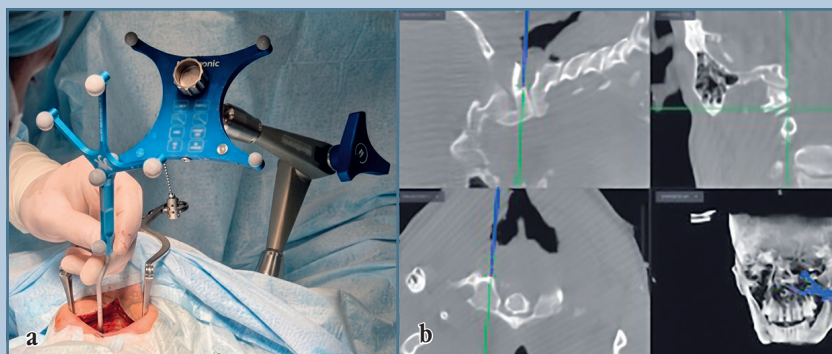
Preoperative CT scan of a 47-year-old male patient (Patient R.): **a** – sagittal CT reconstruction showing an Anderson and D'Alonzo type II odontoid fracture (C2) with a 5 mm fragment diastasis; **b** – coronal CT reconstruction

**Fig. 2**

Patient positioning on the operating table: **a** – general view of the patient; **b** – fixation of the patient reference frame to the clamp

**Fig. 3**

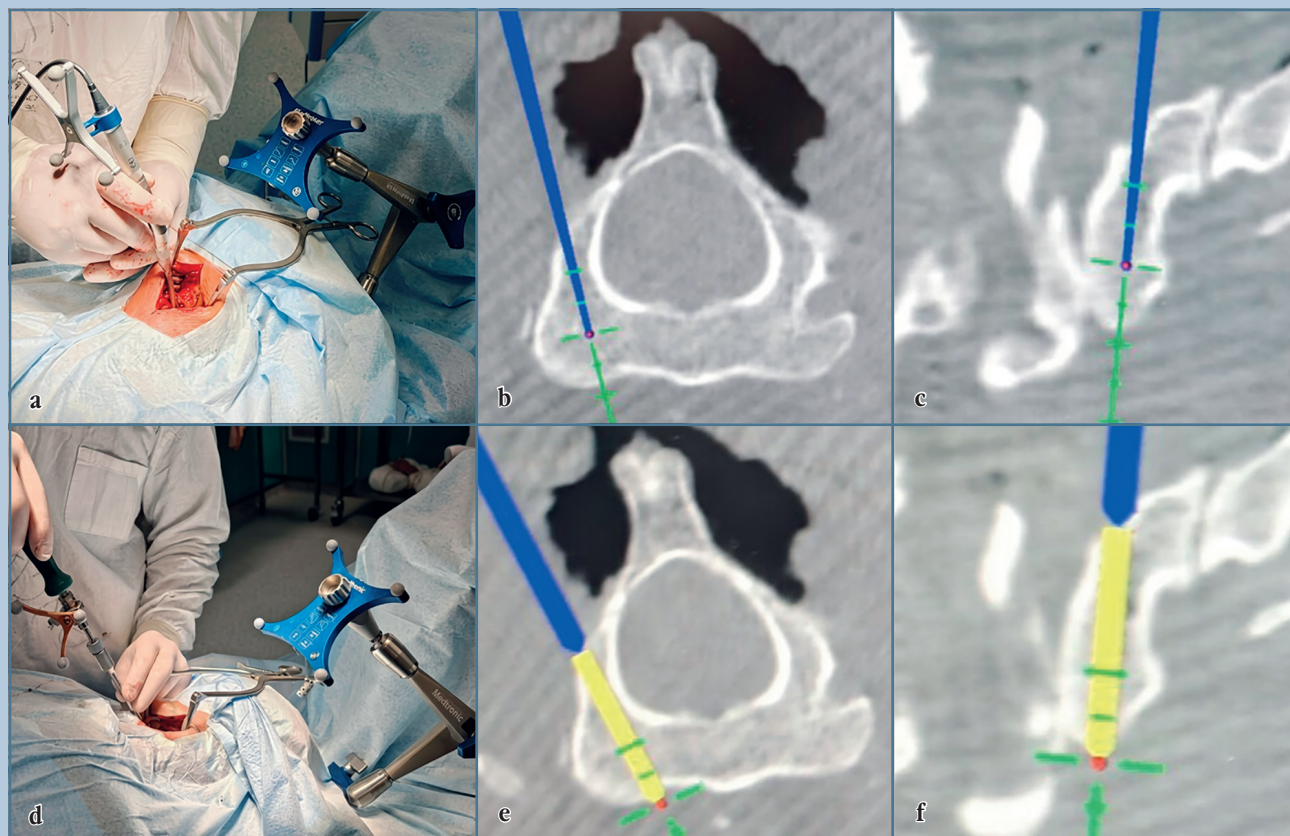
Intraoperative CT and patient auto-registration: **a** – O-arm and patient positioning (arrows indicate the patient reference frame and the navigation system camera); **b** – pointer registration

**Fig. 4**

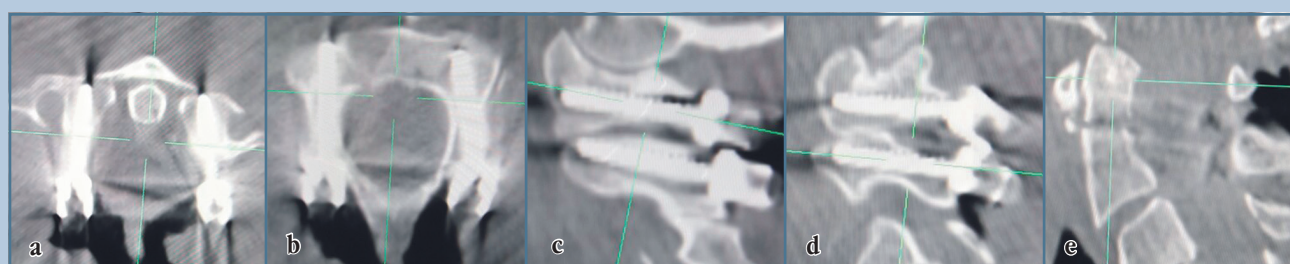
Accuracy assessment of anatomical landmark-based navigation and choice of screw insertion trajectory into the C1 vertebra: **a** – intraoperative view of the pointer in the surgical wound; **b** – position of the pointer on the navigation workstation monitor

the high mobility of the upper cervical spine, which hinder the application of navigation and increase the risk of complications. Czabanka et al. [19] utilized this navigation method for posterior C1–C2 fixation using the Goel–Harms technique in 12 patients. Malposition was noted in one case. Harel et al. [27] utilized optical navigation combined with intraoperative CT in five cases of C1–C2 Goel–Harms fixation. Malposition was identified twice at the C1 level. In one case, revision surgery was required for screw repositioning. Two screws were malpositioned at the C2 level. In both cases, there was a screw deviation outside the C2 pedicle of less than 2 mm. In a series by Carl et al., nine patients underwent posterior C1–C2 screw fixation (32 Goel–Harms screws and 2 Magerl screws) using intraoperative optical CT-based navigation. The rate of malposition was 2.9%. Intraoperative CT revealed medial malposition of one C1 screw, requiring revision.

The instrumentation and surgical technique in the aforementioned studies differed from the method demonstrated in our case. In the studies by Czabanka et al. and Carl et al. [19, 28], an AIRO cone-beam computed tomography (CBCT) scanner was utilized, with the reference frame fixed to the spinous processes of the C2–C3 vertebrae. This frame fixation technique is unreliable and carries a potential risk of navigation inaccuracy, particularly in cases of traumatic injury to the posterior vertebral structures, specifically in Hangman's fractures. Furthermore, the reference frame obscures visualization of the surgical field. Carl et al. [28] utilized a specialized mask for head immobilization, which still may not prevent head and neck movement during the procedure. In the implantation method described by Czabanka et al. [19], cannulated screws were used, which are rarely employed in upper cervical spine surgery. Similar to our case report, Harel et al. [27] utilized the StealthStation S8 navigation system and the O-arm cone-beam computed tomography scanner. However, Harel et al. did not focus on the technical nuances of using navigation equipment. Specifically, the method

**Fig. 5**

Screw implantation stage: **a** – navigated drill in the surgeon's hands; **b, c** – navigation-guided drilling in axial and sagittal views; **d** – navigated screwdriver in the surgeon's hands; **e, f** – navigation-guided screw placement (the same CT views)

**Fig. 6**

Intraoperative CT on the O-arm workstation: **a, b** – correct placement of C1 and C2 screws in the axial plane. **c, d** – right and left screw groups on sagittal reconstruction; **e** – reduction of the C2 dens

of patient head fixation and the attachment site of the reference frame are not specified, which, in our opinion, is of fundamental importance when working with navigated instruments and performing screw implantation.

These studies demonstrate that while intraoperative CT navigation minimizes the risk of screw malposition, it does not entirely eliminate it. This is likely due to the high mobility of the upper cervical spine, the unstable nature of the injuries,

and the small anatomical dimensions of the C1 and C2 vertebrae. However, as demonstrated in our study, the use of rigid head fixation and a high-speed navigated burr improves the accuracy of

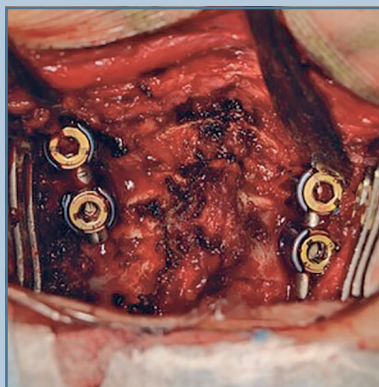


Fig. 7

Appearance of the surgical wound after rod fixation

intraoperative trajectory control for the implantable screw.

Operative time associated with CT-guided navigation represents a key factor in adopting this technology in clinical

settings. A number of studies have reported conflicting data regarding the impact of O-arm navigation on operative time [27–29]. The initial increase in operative time can be attributed to the learning curve. Routine implementation of the navigation system is associated with a reduction in operative time. On the other hand, the use of optical navigation and mobile intraoperative CT can reduce the need for intraoperative screw revision and repeat surgeries.

Low radiation exposure to the surgical team is one of the advantages of CT navigation [30]. The surgeon leaves the operating room during intraoperative CT scanning. Fluoroscopy should be utilized only during patient positioning and vertebral reduction. Bratschitsch et al. [30] reported that intraoperative CT navigation allows spinal surgeons to perform ten times more surgeries per year before reaching the maximum permissible effective radiation dose.

Study limitation. The limitations are related to the low level of evidence of a non-systematic literature review and the lack of a prospective case series.

Conclusion

According to a narrative literature review, intraoperative optical CT-based navigation provides more accurate screw placement for posterior C1–C2 fixation compared to the freehand technique. Compared with the standard fluoroscopy-guided technique, this method may offer additional advantages by reducing operative time and minimizing radiation exposure for the surgical team. However, effective utilization of O-arm-based navigation requires a meticulous preoperative CT and CT angiography assessment of the permissible screw trajectory, rigid cranial fixation, standard proprietary navigation equipment and instruments, and preliminary staff training in the operative technique using simulation models.

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Additional information

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