Original Article

Perioperative complications associated with fluoroscopy C1 lateral mass screw fixation (Goel technique) versus computed tomography-guided navigation technique: A review of 202 cases from the German Spine Registry (DWG-Register)

ABSTRACT

Background: Overview of the literature – Fractures of the C1 constitute 3%–13% of all cervical spine injuries in adults. Most isolated C1 fractures are stable and can be treated nonoperatively with external immobilization. Traditional surgical options for C1 fracture treatment are occiput-to-C2 fusion or C1 with lateral mass screws (LMSs). Purpose – The aim is to assess the management and perioperative complications of C1 fractures undergoing LMS fusion between fluoroscopy and computed tomography (CT)-guided navigation.

Methods: This was a retrospective multicenter study of data from the DWG-Register of patients who underwent operative treatment for C1 traumatic fracture with LMSs from January 2017 to September 2022. Inclusion criteria – traumatic injury and age > 18 years old.

Results: In total, 202 patients with traumatic C1 fracture requiring spinal surgery were identified in the registry; $n = 175$ (Group 1) were treated conventionally without CT-guided navigation and $n = 27$ were treated with CT-guided navigation (Group 2). C1-LMS was principally performed by spine surgeons $n = 90$ (53.4%) and $n = 72$ (18.5%) by neurosurgeons in both the groups. Intraoperative adverse events were as follows: dural tear in group 1 $n = 0$ and in group 2 $n = 1$, vascular injury, with one case in group 1 and no cases in group 2. General complications were: cardiovasculars in group 1 $n = 6$ (3.4%) and Group 2 $n = 4$ (14.8%) ($P = 0.03$), pulmonary complications in group1 $n = 2$ (1.1%) and $n = 9$ in group 2 (33.3%) ($P < 0.001$), stroke $n = 1$ (0.57%) in group1 and $n = 4$ in group 2 (14.8%) ($P < 0.001$), gastrointestinal bleeding $n = 1$ (0.57%) in group1 and no cases in group 2, renal insufficiency $n = 2$ (1.1%) in group 1 and $n = 3$ (11.1%) in group 2 ($P = 0.01$) .One death was recorded in group 2 (3.7%).

Conclusion: This series of 404 screws placed in 202 patients over 5 years who underwent two types of C1 fracture fixation had a considerably lower incidence of screw malposition and vertebral artery injury than has previously been reported in the literature. C1 screws can be safely placed with a low risk of vertebral artery and neurologic injury with and without CT-guided navigation support.

Keywords: C1 instrumentation, C1 lateral mass screw, Spine registry, Spine surgery

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INTRODUCTION

Fractures of the C1 constitute 3%–13% of all cervical spine injuries in adults.[1-3] They occur most frequently after motor vehicle accidents, falls, diving into shallow water, and sports injuries. At clinical presentation, patients often have neck pain and limited neck movement.[1-3] Neurologic impairment has been reported; however, it is rare in isolated C1 fractures.

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In 40%–44% of cases, there is also an axis fracture associated with the C1 fracture.[1-3]

The treatment of C1 fractures is often affected by an adjacentncervical spine fracture, most commonly C2[3] .Most isolated C1 fractures are stable and can be treated nonoperatively with external immobilization, whereas evidence for the management of unstable atlas fractures is still inadequate,[4,5] the integrity of the transverse atlantal ligament is a commonly used as a factor between stable and unstable C1 injuries, with a ruptured ligament implicating an unstable fracture and a candidate for operative treatment..[3-6] Traditional surgical options for C1 fracture treatment are occiput-to-C2 fusion or C1-2 fusion with lateral mass screws (LMSs) [Figure 1].[3,6-9] The unique and variable nature of C1 anatomy can make instrumentation at this level challenging and prone to potentially severe, even life-threatening complications such as vertebral artery or spine cord injury. The benefits of selective C1 fixation must be weighed against neurological injury. The benefits of selective C1 fixation must be weighed against the safety and potential complications of the procedure.

The aim of this study was to assess the management and perioperative complications of C1 fractures undergoing LMS fusion between fluoroscopy (conventional treatment) and computed tomography (CT)-guided navigation.

PROCEDURE

This was a retrospective study of data from the DWG-Register of patients who underwent operative treatment for C1 traumatic fracture with LMSs from January 2017 to September 2022. Patient recruitment in all 170 departments in Germany was performed with the permission of the ethics committee of the concerning federal-state medical association.

Demographic collected data included age, gender, and American Society of Anesthesiologists (ASA) score and use of CT-guided navigation. Intraoperative and perioperative data, such as operative time, intraoperative blood loss, and use of allogeneic blood transfusion, were evaluated.

A complication was defined as major if the patient required reoperation, was considered life-threatening, or resulted in spinal cord or nerve root injury. Any minor complication could be reclassified as a major complication if it resulted in required re-required another surgery. Complications were defined as "perioperative" if they occurred within the hospital stay.

Inclusion criteria

1. Indication for C1-LMS by traumatic injury
2. Age >18 years old.

Exclusion criteria

1. Nontraumatic C1 injury
2. Pregnancy
3. Previous instrumentation at the same level
4. Neoplasia
5. Infection (previous or florid) at the operation level.

Statistical analysis

These data were analyzed using the program JMP-16.[10] It calculated the mean and standard deviation of all variables. In addition, Bartlett's test for homoscedasticity is automatically performed by the program.

For normally distributed continuous variables, the Student's *t-test* was used. For non-continuous variables, the Wilcoxon Kruskal–Wallis test was performed. Tables with <5 cells were analyzed using Fisher's exact test and categorical variables using the Chi-squared test. Differences were considered statistically significant at $P < 0.05$.

RESULTS

In total, 202 patients with traumatic C1 fracture who required surgical treatment were identified in the registry; of which, n = 175 (Group 1) were treated conventionally without CT navigation and n = 27 were treated with CT navigation (Group 2). The mean age in Group 1 was 75.2 years; women were more frequently affected (53.1%) than men. Meanwhile, in Group 2, the mean age was 74.4 years, with male dominance (66.6%). Regarding surgeon's experience, C1-LMS was principally performed by spine surgeons $n = 90$ (53.4%) and $n = 72$ (18.5%) by neurosurgeons in both the groups (Group 1 $n = 75$ [42.8%], $n = 24$ [13.7%] and in Group 2 $n = 15$ [55.5%] and $n = 4$ [14.8%] respectively). No differences were identified between the groups when orthopedic surgeons performed the operations. In addition, no significant differences were found in further demographic characteristics and preoperative evaluation, such as ASA score, age, or gender [Table 1]. Nevertheless, there was a significant difference in operative-time >2 h between the groups: group 1 $n = 75$ (28.4%) and Group 2 $n = 19$ (70.3%) [Table 1].

No difference was found in the number of blood transfusions between groups. However, a significant difference in blood loss ≥500 ml was found (Group 1 $n = 49$ [28%] and Group 2 $n = 3$ [11.1%], $P = 0.05$) [Table 1].

Furthermore, the extent of the surgery was from C0 to C3 (occiput to C3). A total of $n = 117$ (66.8%) patients in

Table 1: Demographics, clinical evaluation, location, and preoperative characteristics from patients undergoing C1 lateral mass screw fixation versus computer tomography (computed tomography-guided) navigation technique

	Group 1 (n=175), n (%)	Group 2 (n=27), n (%)	*P*
Gender (male/female)	82/93	18/9	0.06
Age (years) (median, range)	75.2±16.5	74.4±16.1	0.07
Preoperative status			
ASA score 1	10 (5.7)	1 (3.7)	0.46
ASA score 2	19 (10.8)	4 (14.8)	
ASA score 3	73 (41.7)	7 (2.6)	
ASA score 4	73 (41.7)	15 (55.5)	
Credentials			
Spine surgeon	75 (42.8)	15 (55.5)	0.31
Orthopedian	24 (13.7)	4 (14.8)	
Neurosurgeon	68 (38.8)	6 (22.2)	
Resident in orthopedics	0	0	
Resident in neurosurgery	0	2 (7.4)	
Traumatologist	8 (4.5)	0	
Intraoperative bleeding			
Blood loss >500 mL	49 (28)	3 (11.1)	0.05
Blood transfusion	21 (12)	3 (11.1)	0.89
Operative time >2 h	75 (28.4)	19 (70.3)	0.04

Significant differences between the groups were determined by Chi-square test or Fisher's exact test for dichotomized or categorical data. Continuous data were obtained using the Independent sampling Student's *t*-test or Mann–Whitney *U*-test. ASA - American Society of Anesthesiologist status score

the fluoroscopy group and $n = 19$ (70.3%) patients in the CT-guided group underwent a Goel screw/rod construct. A total of $n = 48$ (27.4%) patients in Group 1 and $n = 10$ (37%) patients in Group 2 underwent fixation to occiput. In our studied groups with C1 fracture, there were $n = 11$ (6.2%) cases of decompression in Group 1 and $n = 2$ (7.4%) cases in Group 2 besides internal fixation.

Moreover, intraoperative adverse events, such as dural tear, occurred in Group 1 $n = 0$ and in Group 2 $n = 1$ due to C2 nerve root damage, different as in vascular injury, with one case in Group 1 and no cases in Group 2.

Furthermore, concerning surgical complications before discharge, the following differences were found: superficial hematoma in group 1 $n = 1$ (0.57%) and in group 2 $n = 0$, superficial wound infection in group 1 $n = 1$ (0.57%) and in group 2, $n = 1$ (3.7%) ($p = 0.22$), deep wound infectionin group 1 $n = 0$ and in group 2 $n = 1$ (3.7%), hypoglossal injury in group 1 $n = 1$ (0.57%) and in group 2 $n = 0$, and cerebrospinal fluid leakage in group 1 $n = 0$ and in group 2 $n = 1$ (3.7%) [Table 2].

The differences found between groups were: cardiovascular in Group 1 $n = 6$ (3.4%) and in Group 2 $n = 4$ (14.8%) ($p = 0.03$), pulmonary $n = 2$ (1.1%) and $n = 9$ (33.3%) ($p < 0.001$), stroke $n = 1$ (0.57%) and $n = 4$ (14.8%) ($p < 0.001$), gastrointestinal bleeding $n = 1$ (0.57%) and no cases in Group 2, renal insufficiency $n = 2$ (1.1%) and $n = 3$ (11.1%) ($p = 0.01$), and one death in group 2 (3.7%), respectively.

The follow- up of the studied patients until discharge was a follows: uneventful stay in group 1 $n = 127$ (72.5%) and in group 2 $n = 15$ (55.5%), stay in intensive care unit (ICU) >2 days in group 1 $n = 12$ (6.8) and in group 2 $n = 10$ (37%) ($P = 0.04$), and extended stay > 10 days in group 1 $n = 36$ (20.5%) and in group 2 $n = 2$ (7.4%).

DISCUSSION

Posterior instrumentation of C1 has become an increasingly common anchor point in treating occipitocervical and atlantoaxial spinal pathology. Technical errors leading to the vertebral artery and neurologic injury at this level can lead to catastrophic consequences. Thus, even small improvements in the accuracy of surgical instrumentation can have a significant impact on patient mortality and morbidity.

The primary advantages of rigid fixation, such as C1 LMS, over wiring techniques with onlay bone grafting included higher fusion rates, decreased postoperative malalignment, and decreased need for postoperative immobilization with a halo or Minerva type brace.[11-13]

In their original article in 2001, describing C1 LMSs, Harms and Melcher[14] reported a series of 37 patients who underwent posterior C1–C2 fixation with polyaxial C1 LMS and C2 pedicle screws and rods. They reported a zero incidence of iatrogenic vascular injury or postoperative deterioration of neurologic status. Numerous subsequent authors have characterized the safety of C1 LMS fixation through small series case reports. Gunnarsson *et al*.[15] reported a series of 25 patients who underwent C1 LMS fixation in the setting of complex cervical spine procedures, including isolated C1–C2 fixation, occipitocervical fusion, and constructs that extended to the subaxial cervical spine. They reported no neurologic or vascular complications, with the exception of three patients with transient C2 neuralgia. Similarly, Vilela *et al*.[16] detailed a series of 21 C1 LMS screws in 11 patients without neurologic or vascular injury. Thus, there is a precedence of C1 screws being placed without neurologic or vascular complications, yet the small size of these series limits any conclusion that can be drawn regarding accuracy rate. In our series of 404 screws placed in 202 patients in C1, we did observe one vascular complication in the fluoroscopy group and one unintended durotomy, despite CT navigation.

Table 2: Operative, postoperative variables and complications from patients undergoing C1-lateral mass screw with and without computed tomography navigation

	Group 1 (n=175), n (%)	Group 2 (n=27), n (%)	P
Intraoperative adverse events			
Vascular injury	1 (0.57)	0	
Dural tear	0	1 (3.7)	
Surgical complications before discharge			
Superficial hematoma	1 (0.57)	0	0.22
Superficial wound infection	1 (0.57)	1 (3.7)	
Deep wound infection	0	1 (3.7)	
Hypoglossal injury	1 (0.57)		
CSF leakage	0	1 (3.7)	
General complications before discharge			
Cardiovascular	6 (3.4)	4 (14.8)	0.03
Pulmonary	2 (1.1)	9 (33.3)	<0.001
Stroke	1 (0.57)	4 (14.8)	<0.001
Gastrointestinal bleeding	1 (0.57)	0	
Renal insufficiency	2 (1.1)	3 (11.1)	0.01
Death	0	1 (3.7)	
Hospital stay			
Uneventful	127 (72.5)	15 (55.5)	0.45
ICU >2 days	12 (6.8)	10 (37)	0.04
Extended stay	36 (20.5)	2 (7.4)	0.47

Significant differences between the groups were determined by Chi-square test or Fisher's exact test for dichotomized or categorical data. Continuous data were obtained using the independent sampling Student's *t*-test or Mann–Whitney *U*-test. ICU - Intensive care unit; CSF - Cerebrospinal Fluid

The 0.57% incidence of vertebral artery injury and the 3.7% incidence of incidental dural tear are consistent with that reported in smaller series.[17-21] Although the surgeons relied in the fluoroscopy group on fluoroscopic visualization to assist with screw placement, this was limited primarily to the lateral projection to assist with the optimization of craniocaudal angulation, without the use of specialized projections or computer navigation. Emphasis was instead placed on direct visualization of the key anatomic components of the posterior C1 vertebra to establish the appropriate screw trajectory, particularly with regard to obtaining the correct medial-lateral positioning of the starting point and appropriate transverse-plane screw angulation.[17-21] In our study, fortunately, the lesion of the vertebral artery in Group 1 was on the nondominant side. The lesion was treated endovascularly with coilings of the affected artery. The patient does not show any neurological deficits after the procedure.

Furthermore, a rare postoperative complication, paralysis of the hypoglossal nerve, was identified in group 1; This type of complication is recognized as a rarity, which can only be found in very few cases in the current literature.[22]

Because of the seemingly prevailing opinion that posterior upper cervical fixation is commonly associated with large-volume blood loss, we also evaluated blood loss >500 ml between fluoroscopy positioning of the LMS versus CT guided. Patients undergoing CT-guided navigation allowed the assessment of screw suitability, entrance point, trajectory, and LMS dimensions, hence bled less than patients without CT-guided navigation, due to sparing in preparation, as seen in other studies. On the other hand, operative time >2 h was more often found in the CT-guided navigation, whence this procedure needs its own learn curve; hence, at the beginning, the operative time cost is longer than the standard procedure without CT-guided navigation. In general, the increase in reported complications for navigation, seems to be attributed to the longer operating time. However, these findings do not correspond to the experiences reported in our study. Indeed, this is probably tied in to the finding that the blood loss is significantly less when using navigation. The reason is easy to see: navigation enables a surgeon to go straight to the entry point of the C1 lateral mass and the smoothier dissection around the abundant venous plexus surrounding the C2 root. Surprisingly, general complications before discharge were more often found in the group of CT-guided navigation, mainly related to lung infections, and cardiac and cerebral ischemic diseases in the ICU, probably related to the longer operative times in previous debilitated patients (ASA score 3–4). Nevertheless, CT-guided navigation is particularly useful in case of a ponticulus posticus. This anatomical variation occurs in 13%–15% of the population[23-29] and may conceal the vertebral artery residing over the cranial edge of the posterior C1 arch. This could depict a false impression of a thicker posterior C1 arch, therefore, burring into this

Figure 1: Postoperative views of Goel screw/rod construct patients in: (a) Sagittal computed tomography (CT), (b) Coronal CT, (c) Axial at the C1 massa lateralis level, and (d) At the pedicle C2 screw level, (e) Lateral X-ray view after fluoroscopy placement, (f) Axial CT by C1 screw placement through the posterior arch under fluoroscopy, (g) Three-dimensional reconstruction of a CT-angiography showing a nondominant right vertebral artery preoperative, (h) A variant of Goel screw/rod construct to C3, (i) An alternative to C1 fixation trough C1/C2 joints (Magerl screw) CT-guided (Depicted by an Arrow)

arch, at the C1 LMS entry point may cause intervertebral artery injury.[24-29]

Limitations

There are multiple limitations to this study: first, the retrospective study design has to be discussed critically. In addition, the differing number of patients in both the groups has to be considered, especially concerning the significance of the differences between the groups. Furthermore, the DWG-Register database only tracks patients until discharge. The long-term outcome, including but not limited to pseudoarthrosis, quality of life, pain, range of motion, need for further operations, neurological function, or postoperative complications after hospital dismissal, could not be evaluated. Moreover, the data are sampled from hospitals around Germany, and the variability of the surgeons experience, as mentioned at the beginning of this section, should be taken into consideration. Furthermore, there is a limitation in the literature research. However, the data from the DWG-Register, with its high number of included patients, can be used to describe spinal surgery care in "real life" in uncommon spine pathologies such as C1 LMSs. Future studies will be needed to evaluate transitional care programs that may reduce the readmission rate of patients undergoing spinal surgery.

CONCLUSION

This series of 404 screws placed in 202 patients over 5 years who underwent two types of C1 fracture fixation had a considerably lower incidence of screw malposition and vertebral artery injury than has previously been reported in the literature. Familiarity with these two techniques is advisable for surgeons performing posterior instrumentation of the C1 vertebra. C1 screws can be safely placed with a low risk of vertebral artery and neurologic injury with and without CT-guided navigation support.

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Conflicts of interest
All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements) or nonfinancial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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