INTRODUCTION

On 1994, Goel and Laheri first described a C1-C2 fusion utilizing C1 lateral mass screws, C2 pedicle screws, and a metal plate.[4] The introduction of polyaxial cervical screws allowed the modification of technique introduced by Harms and Melcher on 2001.[5] The surgical technique includes screw insertion utilizing anatomical landmarks and fluoroscopy. Intraoperative imaging and navigation systems were introduced to spine surgery to allow for more accurate screw insertion, while minimizing the surgical team exposure to radiation.[1,5,8] Several studies have previously examined screw insertion with navigation in complex craniocervical cases;[9] however, the results did not encompass complications, screw insertion accuracy, and estimated blood loss.
Harel, et al.: Intraoperative imaging and navigation for C1-C2 posterior fusion

Surgical Neurology International • 2019 • 10(149) | 2

Here, we compared the accuracy of screw placement using fluoroscopy versus O-arm navigation-guided C1-C2 instrumentation, along with an assessment of the attendant risks/complications and other variables.

METHODS

With IRB approval, we performed a retrospective review (2011–2016) utilizing the Harm’s procedure for C1-C2 screw fixation performed under either fluoroscopic guidance (nine patients) or image-assisted O-arm navigation (five patients).

Surgical technique

The surgical technique for the fluoroscopic-guided group was previously described in multiple papers. As for the navigation-guided group, the O-arm was introduced; a lateral and AP views were taken to determine scan position. Following exposure, a scan was performed and transferred to the navigation unit. The lateral mass of C1 and C2 pedicle was drilled utilizing a navigated drill guide. The screwdriver was fitted with a Universal Tracker Instrument (Suretrak, Medtronic, Louisville, CO, USA), and screws were inserted into the drilled holes. O-arm scan confirmed screw positions. At the senior surgeon discretion, screw positions were adjusted during surgery. We reviewed patient's demographics and statistical analysis was performed using the Student's t-test and Chi-squared test. $P = 0.05$ was considered statistically significant.

RESULTS

Before 2015, nine consecutive patients had fluoroscopic guidance for C1-C2 fusions, while between 2015 and 2016, five consecutive patients utilized O-arm navigation [Table 1]. Both groups exhibited comparable demographics and risk factors. For the fluoroscopy group, the EBL was doubled and mean surgical and anesthesia durations were shorter (27 and 18 min, respectively). Proved not statistically significant.

Assessment of the accuracy of screw placement with fluoroscopy versus O-arm

All the screws in the navigated group were graded as either optimal position (90% and 80%) or acceptable position (10% and 20%) [Table 2].

In the fluoroscopy group, only one of nine patients showed an unacceptably placed C1 screw (e.g., 1 Grade II (>2 mm, <4 mm) C2 screw). The fluoroscopic C1 accuracy rate was ideal (83%) and C2 Grade 0 (no deviation; 56%).

Table 1: Demographics, surgical specifications, and outcomes comparing the study group to the control group.

|                               | O-arm navigation group | Fluoroscopy group | P-value |
|-------------------------------|------------------------|-------------------|---------|
| Patients                      | 5                      | 9                 |         |
| Age                           | 39.6                   | 44.5              | 0.71    |
| Gender (% males)              | 40%                    | 67%               | 0.58    |
| Risk factors                  | 0                      | 0                 |         |
| Smoking                       | 0                      | 0                 |         |
| Diabetes mellitus             | 0                      | 0                 |         |
| IHD                           | 0                      | 3 (33%)           |         |
| Pathology                     | 3 (60%)                | 5 (55.6%)         |         |
| Trauma                        | 2 (40%)                | 4 (44.4%)         |         |
| EBL (cc)                      | 260                    | 556               | 0.16    |
| Surgery duration (min)        | 128                    | 101               | 0.032   |
| Anesthesia-surgical time (min)| 92                     | 74                | 0.17    |
| Length of stay (days)         | 3.2                    | 3.9               | 0.52    |
| Length of follow-up (months)  | 1.8                    | 2.4               | 0.64    |
| Intraoperative screw reposition| 1 (20%)                | 0 (0%)            |         |
| Screw malposition             | 0 (0%)                 | 2 (22%)           |         |
| Revision of surgery           | 0                      | 0                 |         |
| Neurologic change             | 5 (100%)               | 5 (56%)           | 0.13    |
| Improve                       | 0 (0%)                 | 4 (44%)           |         |
| Stable                        | 0 (0%)                 | 0 (0%)            |         |
| Deteriorate                   |                        |                   |         |
| Discharge destination         | 6 (100%)               | 7 (78%)           | 0.51    |
| Home                          | 0 (0%)                 | 2 (22%)           |         |
| Rehabilitation                |                        |                   |         |
| Total complications           | 0 (0%)                 | 2 (22%)           | 0.64    |
In 9 of 18 C2 screws in the fluoroscopy group, the surgeon decided to perform laminar screw rather than pedicle screw due to anatomical variations including narrow pedicle or hypertrophied vertebral artery.

Complications involving O-arm navigation and fluoroscopic C1-C2 screw placement

All of the O-arm navigated cases were treated with C2 pedicle screws. One intraoperative scan demonstrated medial C1 screw position requiring repositioning during surgery (e.g., confirmed with a secondary scan) [Figure 1].

Using 2D fluoroscopy, there was one malpositioned C2 screw. This was picked up on the post-operative CT scan that demonstrated a lateral and inferior screw breach [Grade 2, Figure 2]. Of interest, both groups demonstrated comparable clinical and neurological outcomes, with only one misplaced screw being found in each group.

DISCUSSION

The subaxial cervical spine demonstrates high anatomical variability that increases surgical risks and suboptimal screw position. Utilization of navigation systems reportedly increases screw placement accuracy. Costa et al.\(^3\) reported 92.6% accuracy rate at C1-2 traumatic fractures operated with intraoperative 3D imaging-based navigation. Smith et al.\(^9\) used the O-arm in seven patients; of four patients undergoing C1-C2 stabilization, 75% of C2 screws were graded as medial pedicle breaches ranging 0.8–2.9 mm, but these caused no complications. Attia et al.\(^2\) reported using the O-arm for C1-C2 fusions and reported all screws to be in the desired trajectory without complications. In the current study, C2 screws were aborted for anatomical variations in the fluoroscopic group only, but all the C2 screws were inserted in the navigated group as navigation allows for more precise trajectory planning.

When Hitti et al.\(^7\) used the Harm’s procedure in 20 navigated versus 25 fluoroscopy cases over a 9 years period,

| Table 2: C1 lateral mass screw and C2 pedicle screw accuracy. |
|---------------------------------------------------------------|
|                                                               |
| C1 screws total | O-arm navigation group | Fluoroscopy group |
| Type I: Ideal placement | 9 (90%) | 15 (83%) |
| Type II: Acceptable placement | 1 (10%) | 2 (11%) |
| Type III: Unacceptable placement | 0 (0%) | 1 (6%) |

| C2 screws total | Grade 0 (no deviation) | Grade 1 (<2 mm) | Grade 2 (>2 and <4 mm) | Grade 3 (>4 mm) |
|-----------------|------------------------|-----------------|------------------------|-----------------|
| 10              | 8 (80%)                | 2 (20%)         | 0 (0%)                 | 0 (0%)          |
| 9               | 5 (56%)                | 3 (33%)         | 1 (11%)                | 0 (0%)          |

Figure 1: After screw placement, O-arm scan reveals left C1 screw medially displaced (a), the screw was repositioned and a later scan reveals ideal position (b).

Figure 2: A patient undergoing C1-2 fluoroscopic-guided procedure for Os odontoid. (a) Demonstrates lateral fluoroscopic view. Post-operative CT scan reveals a malpositioned right C2 screw that was not evident on 2D fluoroscopy. Post-operative sagittal (b) and axial (c) scans demonstrate lateral and inferior screw breach (Grade 2).
they documented a major reduction of EBL (by over 50%) and a significantly longer procedure (157 vs. 198 min) time in the navigated group. In both Hitti's study and the current study, the EBL was reduced by 50% as a result of navigation utilization. We assume that navigated screw insertion reduces the need for anatomical dissection in the C1-C2 region, thus reducing intraoperative blood loss as we did not alter our surgical technique with navigation.

Fluoroscopic-guided Harm's procedure exposes the surgeons and the operating room team to ionizing radiation, forcing the team to work with lead aprons, thyroid shields, and protective eye covers. The surgeons need to customize their standing posture as the C-arm is partially obstructing access to the surgical site. Imaging-assisted navigation minimizes the surgical team radiation exposure, eliminates the need for radiation shields, and allows for comfortable access to the surgical site. This in turn may reduce potential complication and personal health issues.[1,5]

**CONCLUSION**

The anatomical properties of C1-C2 stabilization procedure necessitate accurate and safe screw insertion. Imaging-assisted navigation reduces surgical team radiation exposure and seems to allow for higher screw accuracy rates and reduces EBL.

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**Conflicts of interest**

There are no conflicts of interest.

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