Comparison of two techniques for the treatment for atlantoaxial instability injury: C1–C2 transarticular screws and C1 lateral mass–C2 pedicle screws

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Research article

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Abstract

Background: The aim was to evaluate the effectiveness and safety of transarticular C1–C2 screw fixation (C1C2-TAS) and C1 lateral mass–C2 pedicle screw fixation (C1LM-C2PS) in patients with C1–C2 instability injuries.

Methods: This study was a prospective, self-controlled, single-institute study on two fixation techniques for the treatment of atlantoaxial instability caused by injury. From 06/2006 to 02/2017, 118 patients were allocated into two groups: group 1 (C1C2-TAS group) with 52 patients and group 2 (C1LM-C2PS group) with 66 patients. The investigated variables were noted before, during and after surgery. All patients were closely followed up through physical examination and radiological imaging at 3 months postoperatively.

Results: There were significant differences in operation time, blood loss, and hospital length-stay between the two groups (p <0.001). Compared with those in the C1LM-C2PS group, the mean operation time was shorter (78.94 vs. 110.91 min; p = 0.0003), blood loss during surgery was lower (122.31 vs. 258.33 ml; p <0.0001) and hospital length-stay was shorter (5.31 vs. 8.34 days; p = 0.0003) in the C1C2–TAS group. The complication of surgery was low with no injury of vertebral artery.

After surgery, clinical presentations were significantly reduced and were statistically significant in both groups. The remaining patients showed satisfactory internal fixation in the postoperative radiographs and CT examination.

Conclusion: C1C2-TAS and C1LM-C2PS demonstrated effectiveness and safety in the treatment of patients with atlantoaxial instability injury. Notably, C1C2-TAS resulted in shorter surgical time, lower blood loss during surgery and shorter in-hospital stay than C1LM-C2PS.

Background

The cervical spine is divided into two parts, namely, the upper and lower cervical spines, on the basis of anatomical and functional characteristics. The C1 and C2 elements in the upper cervical region are very flexible in function but complicated in anatomical structure, comprising a network of joints and ligaments that are at risk of diverse anatomical lesions caused by injuries/trauma (1). Cervical spine injuries pose a high risk of severe neurological complications and account for 50–75% of spinal cord injuries. The modern technology of imaging diagnostics is used to reveal the details of anatomical lesions that help surgeons select correct management (2). The range of surgical methods used for treatment is diverse. The principle of surgical interventions is to prevent neurological complications and restore the typical anatomical structures of damaged segments. The selection of the appropriate surgical method is influenced by many factors. One of these factors is dislocation stability, with craniovertebral junctions accounting for up to 20% of all cervical injuries (3). For these reasons, preoperative halo traction treatment has been used in some cases (4–6). Each method has its advantages and disadvantages. When the inferior or posterior arch of the C1 element is fractured, C1 lateral mass–C2 pedicle screw fixation (Modified Harm’s technique) surgery is inapplicable despite its advantages in fixation; in this
situation, transarticular C1–C2 screw fixation is the preferred method and results in a high rate of bone fusion. The purpose of our study was to evaluate the effectiveness and safety of two surgical methods, namely, transarticular C1–C2 screw fixation (transarticular screw fixation combined with bone grafts) and C1 lateral mass–C2 pedicle screw fixation (modified Harm's technique) in patients with C1–C2 instability injuries.

**Methods**

This study was a prospective, self-controlled, single-institute study on two fixation techniques for the treatment of atlantoaxial instability caused by injury. From June 2006 to February 2017, 118 patients were admitted to our hospital (Viet Duc Hospital) because of atlantoaxial instability caused by injury. These patients were allocated into two groups. Group 1 was designated as the transarticular C1–C2 screw fixation group (C1C2-TAS group) with 52 patients, and group 2 was designated as the C1 lateral mass–C2 pedicle screw fixation group (C1LM-C2PS group) with 66 patients. This study was approved by the IRB of Viet Duc Hospital, and informed consent was obtained from each patient.

Inclusion criteria were confirmed atlantoaxial instability caused by injury with radiographically visible damage to C1–C2 elements (Spence index > 6–9 mm), ADDs diagnosed as unstable and transverse atlas ligament injury on MRI imaging and requirement for stability reconstruction. Exclusion criteria were the presence of changes in the craniovertebral region (such as changes caused by rheumatoid diseases) and defects and fractures in the skull. Patients with contraindication for surgery were excluded, as well as patients with psychiatric disease and related disorders that could affect the assessment of the evaluated indexes. The diagnoses of patients were confirmed through clinical examination and radiological imaging. After that, all necessary preparations for surgery were completed. In the case of patients with severe ADD, halo traction was applied for 1–2 weeks until the patient was able to undergo surgery. C1C2-TAS or C1LM-C2PS was performed. The investigated variables were noted before, during and after surgery. All patients were closely followed up through physical examination and radiological imaging at 3 months postoperatively. At the time of follow-up, preoperative and 3-month postoperative clinical characteristics, VAS scores, NDI scores and ASIA classification were analysed and compared. The indexes, such as surgical characteristics, complications and bone fusion rate, that were used to evaluate the effectiveness of surgery were compared between the two groups.

**Statistical analysis.** Data processing was performed in SPSS v21 package for statistical data analysis. Descriptive analyses were performed with mean and standard deviation. Comparing characteristics between the two groups used a Student’s t-test with the level of significance set at 95%. The comparison of serial measurement was performed by two-way ANOVA test.

**Results**

Demographics, injury cause and clinical characteristics are shown in Table 1. Notable results were recorded and were commonly found in working-age (approximately 30–40 years old) male patients. In
both groups, the causes were traffic injury. Clinical characteristics varied, and two common symptoms were pain and limited neck activity. Table 2 shows the radiological classification of the patients in detail. This table indicates that significantly higher proportions of patients in the C1LM-C2PS group had odontoid fracture only (54.55% vs. 23.11%) and C1 fracture only (13.64% vs. 9.6%) than patients in the C1C2-TAS groups. Halo traction was applied for five patients in the C1C2-TAS group and six patients in the C1LM-C2PS group. The results after traction were good, with all patients returning to normal or type 1 (table 3).

The differences in operation time, blood loss and hospital length stay between the two groups were statistically significant (p < 0.001; Table 4). Compared with those in the C1LM-C2PS group, the mean operation time was shorter (78.94 vs. 110.91 min; p = 0.0003), blood loss during surgery was lower (122.31 vs. 258.33 ml; p < 0.0001) and hospital length-stay was shorter (5.31 vs. 8.34 days; p = 0.0003) in the C1C2-TAS group.

Surgical complications are shown in Table 5. During the placement of screws, no injuries to the vertebral artery in two groups were observed. During the placement of screws, three patients in the C1C2-TAS group and one patient in the C1LM-C2PS group experienced the burst bleeding of the C1–C2 venous plexus during surgery. After that, all patients were managed well. One patient in the C1C2-TAS group experienced immediate pain and numbness in the occipito-cervical region caused by C2 nerve root irritation. One patient in the C1C2-TAS group experienced surgical site infection.

After surgery, clinical presentations significantly reduced, and this reduction was statistically significant in both groups (Table 6). The improvement in bladder and bowel control was statistically significant in both groups (C1C2-TAS: p = 0.0199; C1LM-C2PS: p = 0.017). NDI significantly changed from 27.42 points to 21.69 points in the C1C2-TAS group and from 32.89 points to 14.12 points in the C1LM-C2PS group (Table 7). In both groups, the ASIA scale improved after surgery, but no statistical significance was noted (Table 8). No neurological and vascular complications were observed. The postoperative images of the remaining patients showed satisfactory internal fixation. Screw position accuracy was high in both groups (Table 9). High rates of bone fusion of 96.2% and 95.4% were achieved in the C1C2-TAS and C1LM-C2PS groups, respectively. The odontoid process fracture was the same in both groups (Table 10).

**Discussion**

In our study, most patients were of working age (mainly aged 30–40 years old). The major concern was that the leading aetiology of injury is traffic accidents, not work accidents. The proportion of males involved in traffic accidents was higher than that of females. In line with our study, Wang et al. showed that the average age of cases is 38.3 years old and that 74.1% of cases are male (7). The average age of the population without injuries but other diseases, such as congenital diseases, rheumatoid diseases and osteoarthritis, is high. In this population, the gender proportion is equal (8, 9).

The estimated blood loss and operative time of the C1LM-C2PS group were significantly higher than those of the C1C2-TAS group. These differences might be attributed to the surgical technique used
(exposure time); the variation in the anatomy of the C1–C2 complex; the expert's skills for technique and complications during surgery, such as the ineffective control of bleeding from venous plexus injuries. From the technical perspective, in the C1C2-TAS group, 104 screws were used in 52 patients. In the C1LM-C2PS group, 264 screws were used for 66 patients. The number of screws for each patient in the C1LM-C2PS group was double that for each patient in the C1C2-TAS group. Both groups showed variations in the C1–C2 complex anatomy in accordance with trauma. All patients in our study underwent surgery by the same surgeon to eliminate intersurgeon variability. Dr. Hoang Gia Du performed all surgeries in the C1C2-TAS group, and Dr. Vu Van Cuong performed all surgeries in the C1LM-C2PS group.

Complications during surgery, such as bleeding, had a considerable effect on operation time and blood loss during surgery. No cases of vertebral artery injury (VAI) were observed in both groups in our study. This was a notable outcome because both surgeries carried a potential risk of fatal injury to the vertebral artery [5]. The rate of VAI varies from 3.7% (1/27 patients) to 8.2% (5/61 patients) (10, 11). A large survey reported that 2.4% of patients have known VAI, and 1.7% of patients are suspected of having VAI (12). This might be the result of the carefully evaluated preoperative assessments and step-by-step surgical process. In line with the surgeon's experience and familiarity with the technique, careful preoperative planning to access the vertebral artery is essential from the anatomical perspective. Bilateral variations and unilateral variations with a high risk of VAI are found (13). Although neither technique has an inherently increased anatomic risk of VAI, the placement of a pedicle screw is significantly safer than that of a transarticular screw in case of the presence of a high-riding vertebral artery (14). In addition, examining the isthmus of the axis before surgery is recommended. Many surgeons advise against screw fixation if the isthmus is insufficiently wide.

Venous plexus injury is another concern in addition to VAI. Ineffective bleeding control is the leading cause of blood loss in such a kind of surgery. The presence of venous injury-inducing thin-walled sinuses suggests that efforts to control bleeding will encounter difficulty (15). In the C1C2-TAS group, the epidural veins around the atlantoaxial joint are the main factor to consider when exposing joints. In the C1LM-C2PS group, the exposure of the C1 lateral mass is a potential factor that induces bleeding from the epidural veins around the atlantoaxial joint. In our study, one patient suffered from venous plexus injury because of extended exposure when determining the width of the posterior vertebral arch of C1. Therefore, the posture of the patient requires a slightly bowed head to widen the posterior arc of C1 and C2 to increase the number of accessible identifiable anatomical landmarks.

Good clinical and radiographic outcomes in patients who were treated with C1C2-TAS or C1LM-C2PS were observed. Pre- and postoperative clinical outcomes, such as NDI and ASIA scale, showed statistically significant differences. In line with these results, the high fusion rate, accurate screw position and low screw-related complications in two groups were notable. Some screws were incorrectly placed. For example, in two patients in the C1C2-TAS group and one patient in the C1LM-C2PS group, the axis pedicle screws penetrated the vertebroarterial foramen (region 1). Other screws were incorrectly placed in region two. All patients with incorrectly placed screws underwent revision surgery to fix screws and obtained acceptable results. A careful preoperative study of each patient's anatomy with a three-
dimensional CT scan is the key for the safety of screw insertion. Overall, these complications were acceptable. The factors to consider in posterior transarticular C1–C2 fixation are the potential risk of screw-associated complications, such as inadequate head fixation, and the approach (posterior midline approach) and length of screws (3.5 mm). Understanding the above factors will help the surgeon select appropriate strategies on the basis of available resources; this consideration is especially important in developing countries with limited resources (16).

The decision to use C1C2-TAS or C1LM-C2PS depends on strict indications, the contraindications of each technique and the surgeon's familiarity with the techniques used. We believe that both techniques are associated with few operative risks and effective in achieving excellent surgical results. Rajinda et al. compared C1–C2 transarticular screws and C1 lateral mass–C2 pedicle screws and found good outcomes for both techniques; however, bleeding volume and operation time tend to be better in the C1–C2 transarticular screw group than in the other group (17). The high rate of correct screw position reduced the screw-related complications, primarily vascular and nerve injury.

The decision of whether to use C1C2-TAS or C1LM-C2PS depended on strict indications, contraindications of each technique, and the surgeon's familiarity with the techniques used. We believed that both techniques were associated with fewer operative risks and effective in achieving excellent surgical results. Rajinda et al. compared C1-C2 transarticular screws and C1 lateral mass–C2 pedicle screws that showed good outcomes for both techniques, and the volume of bleeding and operation time tended to be better in C1-C2 transarticular screws group (18). In line with the conclusion that both techniques are effective, Vergara et al. pointed out that the Harms technique (C1 lateral mass–C2 pedicle screws) appears to be safer than other techniques (19). The clinical context is highly complicated, and the appropriate surgical method must be chosen on the basis of numerous factors. In case C1 screw placement is unsuitable when using C1–C2 screw fixation in the treatment of atlantoaxial instability, posterior atlantoaxial fixation by using C1 titanium cables and C2 pedicle screw-rod can be an alternative method (20). Some new techniques for atlantoaxial instability treatment have been introduced, such as the combination of C1 lateral mass and C1–C2 TAS or a novel technique wherein a polyaxial screw rod system is utilised (21). Further studies are needed to evaluate the safety and efficacy of these new techniques. The use of available techniques with the best evidence is essential. Posterior C1–C2 pedicle screw fixation and fusion is a reliable method for the treatment of atlantoaxial instability (22). Posterior C1 lateral mass and C2 isthmic screws with fluoroscopy without navigation is a safe and feasible method for the treatment of atlantoaxial fractures but is not free from the risk of VAI (23).

Atlantoaxial instability is commonly treated via C1–C2 fixation performed via posterior approaches. The methods outlined by Magerl (C1C2-TAS) and Harms (C1LM-C2PS) are the optimal approaches amongst all dorsal techniques. The contraindications for these techniques include the wrong location of vertebral arteries and the fractures of C1–C2 posterior structures. In these cases, anterior transarticular fixation is an alternative. Several available screw insertion trajectories have been reported. Lvov et al. reported two cases of anterior transarticular fixation through a single approach if one screw is inserted by using the Reindl technique and another is inserted via a contralateral trajectory (24). Polli et al. successfully
installed anterior transarticular screws (performed with a classic retropharyngeal approach) in 14 patients without complications. This approach offers several advantages over posterior approaches and is considered as an effective and safe treatment for C1–C2 instability even in patients with systemic comorbidities (25). A cadaveric study identified the primary anatomic considerations in anterior transarticular screw fixation for atlantoaxial instability. The screw must be inserted with lateral angulation, and the maximum angles of the lateral and posterior angulations are 26° and 30°. This study provided vital information for surgeons to avoid injuries of the vertebral artery and violations of the spinal canal or atlanto-occipital joint (26). The feasibility of the use of anterior transarticular crossing screws (ATCSs) was confirmed in the cadaveric specimen, and this method has been used in clinics. This study has helped surgeons perform ATCS safely and accurately, Liu et al. documented the morphometric characteristics of ATCS on radiologic images and provided the range of the angles and lengths of ATCSs on the basis of multiple slides of the coronal and sagittal plane (27).

**Conclusion**

Transarticular C1–C2 screw fixation and C1 lateral mass–C2 pedicle screw fixation demonstrated effectiveness and safety in the treatment of patients with atlantoaxial instability injury. Notably, transarticular C1–C2 screw fixation resulted in shorter surgical time, lower blood loss during surgery and shorter in-hospital stay than C1 lateral mass–C2 pedicle screw fixation.

**Abbreviations**

C1C2-TAS
transarticular C1–C2 screw fixation
C1LM-C2PS
C1 lateral mass–C2 pedicle screw fixation
VAI
vertebral artery injury

**Declarations**

**Ethics approval and consent to participate**

The Ethics Committee of Viet Duc Hospital approved the study protocol and authorized its conduct and follow-up. The study was in line with the Declaration of Helsinki. Individual patient consent for inclusion in the study was obtained. Before operation, written informed consent was provided to all participants after a thorough explanation of the purpose of this study. Patients had the right to discontinue at any time during the study.

**Consent for publication**
Not applicable.

**Competing interests**

The authors declare that they have no competing interest.

**Availability of data and materials**

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

**Funding**

Not applicable.

**Authors’ contributions**

All authors contributed to drafting and revising the article, gave final approval of the version to be published, and agree to be accountable for all aspects of the work. Particularly, HGD made substantial contributions to the conception and design of study and is the first author. DXT, VXP, NDH, LDT and HGD contributed to collect data. HGD and NVT contributed to acquisition data, interpret data, analyze data and draft the article. NVT prepared and revised this manuscript, acquisition of data, interpretation of data, and drafting the article and is the corresponding author. All authors have read and approved the manuscript.

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Tables
Table 1: Demographics

| Characteristics          | C1C2-TAS group (n = 52) | C1LM-C2PS group (n = 66) |
|--------------------------|-------------------------|--------------------------|
|                          | Number (Percentage)     | Number (Percentage)      |
| Age                      | 31.58 ± 11.733          | 38.27 ± 13.69            |
| Gender                   | 37 (71.2)               | 58 (87.88)               |
| Male                     | 15 (28.8)               | 8 (12.12)                |
| Female                   |                         |                          |
| Injury causes            |                         |                          |
| Traffic injury           | 41 (78.9)               | 37 (56.06)               |
| Falling injury           | 5 (9.6)                 | 20 (30.3)                |
| Sport injury             | 1 (1.9)                 | 2 (3.03)                 |
| Heavy injury             | 1 (1.9)                 | 7 (10.61)                |
| Slip injury              | 4 (7.7)                 | 0 (0)                    |
| Occupation               |                         |                          |
| Heavy worker             | 39 (75)                 | 43 (64.15)               |
| Working in office        | 13 (25)                 | 23 (34.85)               |
| Clinical characteristics  |                         |                          |
| Neck and occipital pain  | 52 (100)                | 66 (100)                 |
| Neck stiffness           | 52 (100)                | 16 (24.24)               |
| Activity limitation of neck | 52 (100)          | 60 (90.91)               |
| Numbness of limbs        | 11 (21.1)               | 21 (31.81)               |
| Movement disorder        | 9 (17.3)                | 9 (13.64)                |
| Loss of bladder or bowel control | | |

Table 2: Radiological classification

| Classification                        | C1C2-TAS group (n = 52) | C1LM-C2PS group (n = 66) |
|---------------------------------------|-------------------------|--------------------------|
| C1 fracture only                      | 5 (9.6)                 | 9 (13.64)                |
| Odontoid fracture only                | 12 (23.1)               | 36 (54.55)               |
| Atlantoaxial dislocation              | Odontoid fracture       | 23 (44.3)                | 12 (18.18) |
| Odontoid nonunion                     | 9 (17.3)                | 7 (10.6)                 |
| Only                                  | 3 (5.7)                 | 2 (3.03)                 |
| Classification | C1C2-TAS group | C1LM-C2PS group |
|----------------|----------------|-----------------|
|                | Pre-traction (n = 5) | Post-traction (n = 5) | Pre-traction (n = 6) | Post-traction (n = 6) |
| Normal         | 0 (0)            | 4 (80)           | 0 (0)            | 3 (50)            |
| Type 1         | 0 (0)            | 1 (20)           | 0 (0)            | 3 (50)            |
| Type 2         | 0 (0)            | 0 (0)            | 0 (0)            | 0 (0)             |
| Type 3         | 1 (20)           | 0 (0)            | 6 (100)          | 0 (0)             |
| Type 4         | 4 (80)           | 0 (0)            | 0 (0)            | 0 (0)             |

| Characteristics | C1C2-TAS group (n = 52) X ± SD | C1LM-C2PS group (n = 66) X ± SD | p-value |
|-----------------|--------------------------------|--------------------------------|---------|
| Operation time (min) | 78.94 ± 25.40                | 100.91 ± 35.58                | 0.0003  |
| Blood loss during surgery (ml) | 122.31 ± 46.46              | 258.33 ± 113.17              | <0.0001 |
| Hospital length-stay (days) | 5.31 ± 2.76                 | 8.33 ± 5.34                 | 0.0003  |
### Table 5: Complications of surgery

| Complications                              | C1C2-TAS group (n = 52) | C1LM-C2PS group (n = 66) |
|--------------------------------------------|-------------------------|--------------------------|
| C2 nerve root injury                       | 1 (1.9)                 | 0 (0)                    |
| Dural tear                                 | 0 (0)                   | 0 (0)                    |
| Vertebral artery injury                    | 0 (0)                   | 0 (0)                    |
| Venous plexus injury                       | 3 (5.7)                 | 1 (1.51)                 |
| C1 posterior arch fracture                 | 0 (0)                   | 1 (1.51)                 |
| Penetrating into the vertebroarterial foramen | 2 (3.8)               | 2 (3.03)                 |
| Hypoglossal nerve injury                   | 0 (0)                   | 0 (0)                    |
| Respiratory failure                        | 0 (0)                   | 0 (0)                    |
| Surgical site infection                    | 1 (1.9)                 | 0 (0)                    |

### Table 6. Clinical characteristics

(*): Between preoperative and postoperative was statistically significant.

| Clinical characteristics                  | C1C2-TAS group | C1LM-C2PS group |
|-------------------------------------------|----------------|-----------------|
|                                           | Pre-operation  | Post-operation  | Pre-operation  | Post-operation  |
| Neck and occipital pain (*)               | 52 (100)       | 1 (1.9)         | 66 (100)       | 14 (21.21)      |
| Neck stiffness (*)                         | 52 (100)       | 3 (5.7)         | 16 (24.24)     | 8 (12.12)       |
| Activity limitation of neck (*)           | 52 (100)       | 3 (5.7)         | 60 (90.91)     | 14 (21.21)      |
| Numbness of limbs                          | 1 (1.9)        | 0 (0)           | 1 (1.52)       | 0 (0)           |
| VAS score (*)                              | 6.0 ± 1.37     | 1.69 ± 0.94     | 5.3 ± 0.76     | 1.53 ± 0.65     |
| Bladder and bowel control (*)             | 43 (82.7)      | 51 (98.1)       | 57 (86.36)     | 64 (96.97)      |
| Normal                                    | 9 (17.3)       | 1 (1.9)         | 9 (13.64)      | 2 (3.03)        |
| Dysfunction                               |                |                 |                |                |
### Table 7: Improve of cervical spine functions based on NDI score

| NDI score | C1C2-TAS group (n = 52) | C1LM-C2PS group (n = 66) |
|-----------|-------------------------|--------------------------|
|           | Pre-operation           | Post-operation           | Pre-operation | Post-operation |
| X ± SD    | 27.42 ± 11.47           | 21.69 ± 14.42            | 32.89 ± 4.82  | 14.12 ± 3.2   |
| None (<10%) | 15 (28.8)              | 0 (0)                    | 0 (0)         | 11 (16.67)    |
| Mild (10–29%) | 30 (57.7)          | 46 (89.5)                 | 12 (18.8)     | 54 (81.82)    |
| Moderate (30–49%) | 3 (5.7)              | 5 (9.6)                   | 54 (81.2)     | 1 (1.52)      |
| Severe (50–69%) | 6 (7.8)              | 1 (1.9)                   | 0 (0)         | 0 (0)         |
| Complete (≥ 70%) | 0 (0)               | 0 (0)                     | 0 (0)         | 0 (0)         |

### Table 8: Neurological recovery: ASIA (American Spinal Injury Association) classification.

| ASIA     | C1C2-TAS group (n = 52) | C1LM-C2PS group (n = 66) |
|----------|-------------------------|--------------------------|
|          | Pre-operation           | Post-operation           | Pre-operation | Post-operation |
| Grade A  | 0 (0)                   | 0 (0)                    | 0 (0)         | 0 (0)         |
| Grade B  | 0 (0)                   | 0 (0)                    | 1 (1.52)      | 0 (0)         |
| Grade C  | 7 (13.5)                | 1 (1.9)                  | 12 (18.18)    | 1 (1.52)      |
| Grade D  | 4 (8.6)                 | 6 (11.6)                 | 8 (12.12)     | 7 (10.61)     |
| Grade E  | 41 (78.9)               | 45 (86.5)                | 45 (68.18)    | 58 (87.88)    |

### Table 9: Accuracy of screw position

| Accuracy | C1C2-TAS group (104 screws) | C1LM-C2PS group (264 screws) |
|----------|-----------------------------|-----------------------------|
|          | Vis C1 (132 screws)         | Vis C2 (132 screws)         |
| Correct  | 102 (98.1)                  | 64 (96.97)                  |
| Incorrect| 2 (1.9)                     | 2 (3.03)                    | 2 (3.03)      | 4 (6.06)      |
| Variables                                      | C1C2-TAS group (n = 52) | C1LM-C2PS group (n = 66) |
|------------------------------------------------|-------------------------|--------------------------|
| **Outcomes of bone fusion**                    |                         |                          |
| Achieved                                       | 50 (96.2)               | 63 (95.4)                |
| Non-achieved                                   | 2 (3.8)                 | 3 (4.6)                  |
| Achieved at odontoid process fracture          | 38/47 (80.9)            | 28/36 (77.8)             |
| **Complications**                              |                         |                          |
| Screw breakage                                 | 1 (1.9)                 | 0 (0)                    |
| Screw shifting                                 | 0 (0)                   | 1 (1.52)                 |
| Screw loosening                                | 1 (1.9)                 | 0 (0)                    |
| Resorption of the graft                        | 1 (1.9)                 | 3 (4.55)                 |