INTRODUCTION

Anderson and D’Alonzo Type II odontoid fractures are the most common among three types of odontoid fractures. These are treated surgically sometimes right after the injury or after failed conservative management. Surgical fixation can include either an anterior or posterior approach. The C1 and C2 posterior screw fixation (C1-C2 PSF) is one of the posterior surgical
options particularly in cases with a high-riding vertebral artery in the C2 pars/pedicle.\cite{3,7} Here, we further assessed/correlated the healing and fusion versus pseudoarthrosis processes of the odontoid fractures fixation.

MATERIALS AND METHODS

This was a retrospective IRB approved review of 15 cases of Anderson and D’Alonzo Type II odontoid fractures treated with C1-C2 PSF by one surgeon (2011-2015).\cite{1} All patients underwent pre- and post-operative cervical spine plain radiographs and computed tomography (CT) scans. The gender, age, time from injury to surgery, and material for onlay graft over the C1-C2 interlaminar space were recorded. The primary goal of the surgery was fusion of the odontoid process.

Clinical patient data

There were 15 patients who underwent C1-C2 PSF for Anderson and D’Alonzo Type II odontoid fracture.\cite{1} Eight out of 15 patients were male. They averaged 71.3 years of age. Fractures were due to 11 ground level falls, two motor vehicle accidents, and two unwitnessed falls. The median time from injury to surgery was 119 days. All patients underwent CT scans to evaluate bone fusion an average of 12 months postoperatively.

Use of CT studies to document fusion

We examined pre- and post-operative CT characteristics associated with fracture nonunion using Hounsfield units at the odontoid base and fractured odontoid tip (i.e., regarding bone density) and maximum bone gap of the fracture site [Figure 1]. Other parameters were also studied [Table 1].

Surgery

Out of 30 total C2 screws inserted, 24 screws were placed in the pars interarticularis, and six screws in the C2 lamina (i.e., due to high-riding vertebral arteries). After the installation of screws and rods, the laminae of C1 and C2 were decorticated for the subsequent placement of onlay bone grafting. In the first five cases, cancellous bone was harvested from the ilium, while in the last ten cases, we utilized allograft/demineralized bone matrix (DBM). Patients were instructed to use a cervical collar for 6 weeks after the surgery.

Statistical analysis

Statistical analysis was performed by a computer software (SPSS Inc., IBM, Chicago, IL). Tests utilized included: the Shapiro–Wilk test, Student’s t-test, nonparametric Mann–Whitney U-test, and the Fisher’s exact test.

RESULTS

Incidence of bone fusion in 1–3 areas

Bone fusion was seen in three different areas in the atlantoaxial cervical spine [Figure 2]: The primary fracture site in the odontoid process (9/15 patients), the atlantoaxial interspace (ADI) (10/15 patients), and the C1-C2 interlaminar space after onlay bone grafting (4/15 patients).
Of note, all four of five patients receiving iliac autograft fused versus none using allograft/DBM.

Only 1 (6.7%) patient showed bone fusion in all three areas while six patients fused in two areas, while eight patients had bone fusion in only one area, (i.e., either at the primary fracture \( n = 2 \) or ADI \( n = 6 \) sites) [Table 2].

**Differences in SVA and ADI fusion rates**

The preoperative C2-C7 SVA was significantly greater for the nonunion versus union group patients and these patients were typically older [Table 3]. Bone fusion at the level of the ADI was significantly more frequent in the nonunion (6/6 patients) versus the union patients (4/9 patients) [Table 4].

**DISCUSSION**

**Stress shielding effect in ADI as a possible cause of fracture nonunion**

Considering that the directions of the screws in C1-C2 PSF are not perpendicular to the fracture line but more parallel to the axial plane of the C1 lamina, those screws appear to press fractured odontoid process toward the anterior arch of the atlas more than its basal part. Once a bone fusion in ADI is established, it may lead to a stress shielding effect to the fracture site with subsequent delayed or failed fracture union. This hypothesis may explain why a bone fusion in ADI was significantly more common in the fracture nonunion group (100%) than union group (44%).

**The union rate of fractured odontoid process after C1-C2 PSF evaluated by CT scan**

Several studies used CT scans to evaluate the union rates of odontoid fracture safer C1-C2 PSF.\[2,4-8\] Ours and Wang's study showed union rates of 60% and 65%, respectively.\[7\] The remaining five studies showed much higher union rates ranging from 92% to 100. The overall mean ages of ours and Wang's study, which showed generally lower union rates, were 71.3 years and middle forties (precise number not provided), respectively.\[7\] The union rate and mean ages of Huang's, Yuan's, Bisson's and Faure's studies were 94.8% and 40.7 years, 96% and 42 years, 92% and 75 years, and 100% and 85.5 years, respectively.\[2,5,6,8\]

**Cervical sagittal balance and bone union in odontoid fractures**

The influence of cervical sagittal balance on the fracture angle in odontoid fractures and postoperative fracture union rate has rarely been discussed. Wang et al. revealed that advanced age (>45 years), long duration of the fracture (>2 months), and preoperative separation of the fractured dens (>4 mm) were

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**Table 2:** The areas and numbers of the bone fusion after C1-C2 posterior screw fixation for odontoid fractures.

| The number of the area with bone fusion per the patient | The area of bone fusion | Number (% per total 15 cases) |
|--------------------------------------------------------|------------------------|-------------------------------|
| 3                                                      | Primary fracture in the odontoid process | ○ | ○ | ○ | 1 (6.7) |
| 2                                                      | ○ | ○ | ○ | 3 (20) |
| 2                                                      | ○ | ○ | × | 3 (20) |
| 1                                                      | ○ | × | × | 2 (13.3) |
| 1                                                      | × | ○ | × | 6 (40) |
| Total number of the cases (%)                          | 9 (60%)                 | 10 (67%)                      | 4 (27%) |
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Table 3: The values of total patients and the comparison between fracture union and fracture nonunion group.

| Variables                                      | Total patients (n=15) | Fracture union group (n=9) | Fracture nonunion group (n=6) | P-value | Statistical tests |
|------------------------------------------------|-----------------------|-----------------------------|------------------------------|---------|------------------|
| Sex (male/female)                              | 8/7                   | 5/4                         | 3/3                          | 1.00    | Fisher’s exact test |
| Age (mean±S.D.)                                | 71.3±13.5             | 66.2±7.1                    | 78.5±14.8                    | 0.08    | Student’s t-test |
| graft type (autograft/allograft)               | 5/10                  | 4/5                         | 1/5                          | 0.58    | Fisher’s exact test |
| The median from injury to surgery (days: IQR)  | 119: 43-140           | 94.5: 39.25-122.75          | 119: 61-169                  | 0.33    | Mann-Whitney U-test |
| HU of the fractured odontoid process           | 683.9±181.8           | 658.9±169.0                 | 721.6±209.7                  | 0.53    | Student’s t-test |
| HU of the base of odontoid process             | 429.3±101.2           | 443.5±97.3                  | 408.0±112.3                  | 0.53    | Student’s t-test |
| Maximum separation (mm)                        | 3.8±2.8               | 3.7±1.9                     | 3.7±1.9                     | 0.96    | Student’s t-test |

Parameters for sagittal balance

| Cervical lordosis (degree)                     | 9.5±16.3              | 12.2±14.9                   | 5.5±18.9                    | 0.46    | Student’s t-test |
| C2-C7 SVA (mm)                                | 37.5±19.3             | 28.8±17.7                   | 50.5±14.3                   | 0.03*   | Student’s t-test |
| T1 slope (degree)                              | 35.3±11.6             | 33.5±13.2                   | 38.1±9.0                    | 0.47    | Student’s t-test |
| O-C2 angle (degree)                            | 26.5±10.1             | 24.5±8.7                    | 29.6±12.0                   | 0.36    | Student’s t-test |
| Cervical mismatch (degree)                     | 25.8±13.0             | 21.3±8.7                    | 32.5±16.2                   | 0.1     | Student’s t-test |

Table 4: Studied postoperative factors associated with fracture union

|                          | Fracture union group (n=9) | Fracture nonunion group (n=6) | P-value |
|--------------------------|----------------------------|-------------------------------|---------|
| Radiolucent area around the screws |                             |                               |         |
| Yes                      | 2                          | 3                             | 0.33    |
| No                       | 7                          | 3                             |         |
| Fusion in ADI            |                            |                               |         |
| Yes                      | 4                          | 6                             | 0.04*   |
| No                       | 5                          | 0                             |         |
| Fusion in C1-C2 interlaminar space |                     |                               |         |
| Yes                      | 4                          | 0                             | P=0.1   |
| No                       | 5                          | 6                             |         |

*Statistically significant difference. ADI: Atlanto-dental interval

independently associated with fracture nonunion after C1-C2 PSF. In addition, our study revealed that C2-C7 SVA was positive correlated with the patients’ age (Pearson’s correlation coefficient; r = 0.627, P = 0.012, data not shown in the table). This could suggest that an increased C2-C7 SVA secondary to advanced age was contributing to fracture nonunion.

CONCLUSION

Our study identified three anatomical areas where bone fusion likely occurs after C1-C2 PSF. Increased sagittal balance in the cervical spine may negatively impact the fusion of odontoid fractures. Bone fusion occurring at other sites besides the primary fracture location may causing stress-shielding effect to the odontoid fracture and may contribute to delayed or failed fusions.

Declaration of patient consent

Institutional Review Board (IRB) permission obtained for the study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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