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Original Investigation

Clinical Outcomes of Posterior C1 and C2 Screw-Rod Fixation for Atlantoaxial Instability

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ABSTRACT

AIM: To share our experiences and to contribute to the literature by making a retrospective analysis of the patients we operated with a screw-rod system for atlantoaxial instability in our clinic.

MATERIAL and METHODS: Archive files of adult patients, who were operated for posterior C1-C2 stabilization with screw and rod in our clinic between January 2006 and January 2016, were analyzed. Twenty-eight patients, who had pre- and postoperative images, follow-up forms and who were followed for at least one year, were analyzed. Preoperative clinical and radiological records, preoperative observations, postoperative complications, and clinical responses were evaluated.

RESULTS: The mean age of the 28 patients (11 females and 17 males) was 44.7 years (range 21-73 years). Fixation was performed with a C1-C2 screw-rod system on the basis of the following diagnoses; type 2 odontoid fracture (n=16), basilar invagination (n=5), C1-C2 instability (n=5), and atlantoaxial subluxation secondary to rheumatoid arthritis (n=2). Lateral mass screws were inserted at the C1 segment. C2 screws were inserted on bilateral pedicle in 12 cases, bilateral pars in 4, bilateral laminar in 8 and one side pars, and one side laminar in 4 cases. There was no screw malposition. Neither implant failure nor recurrent instability was observed during the follow-up period. Significant clinical improvement was reported according to the assessments based on JOA and VAS scores.

CONCLUSION: C1-C2 screw fixation is regarded as a more successful and safe method than other fixation methods in surgical treatment of atlantoaxial instability considering the complications, success in reduction, fusion and fixation strength. The C2 laminar screw technique is as successful as the other alternatives in fixation and fusion.

KEYWORDS: Atlantoaxial instability, C1 lateral mass, C2 laminar, C2 pedicle, Screw

INTRODUCTION

C1 and C2 vertebrae are unique among all the other vertebrae in terms of their anatomical and functional differences. In addition to the fact that C1 does not have a real corpus and spinous process, lack of a disc space between C1 and C2, and that C2 has an odontoid process leads to a different and complicated ligamentous structure compared to the other vertebrae. From the functional point of view, the atlantoaxial joint is the most mobile region of the spinal column and covers 50% of cervical rotation (5).

Although atlantoaxial instability is relatively less often reported, thanks to reasons such as the technological developments in diagnostic tools in recent years and easier access to these technological diagnostic tools, it has been more frequently seen in the practice of neurosurgery. Atlantoaxial instability may develop due to many reasons of congenital, infectious, tumor-related, degenerative or rheumatologic, and notably traumatic origin (5,13,24,34,36,44). It is reported in the literature that 3-15% of all cervical spinal traumas involve odontoid fractures and this rate can even be higher for older patients (6,12). Particularly, those of type II according to the

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Anderson and D'Alonzo classification are in general seen together with atlantoaxial instability and generally require surgical treatment.

25% of rheumatoid arthritis patients have atlantoaxial instability that is thought to be associated with chronic inflammation (25). Any other pathology such as Marfan Syndrome and Grisel's Syndrome may also cause instability (9). In the USA, 15-25% of trisomy 21 patients are diagnosed with atlantoaxial dysfunction (35). In all these cases, there may be a need for stabilization procedures, if there is radiological and clinical requirement.

No matter what the reason, atlantoaxial instability is a condition that may result in serious morbidity and mortality if not treated appropriately. Treatment should be determined on the basis of many factors such as the complaint of the patient at the time of consultation, neurological examination, corresponding radiological assessments, co-morbidities, and age. Patients who do not need surgery as a result of the evaluations are treated and followed with suitable external collars or orthoses.

The aim of surgery in atlantoaxial instability should be to protect neural elements, to provide decompression in cases of compression, stabilize the unstable structure by ensuring appropriate vertebral alignment, achieving fusion in the long term, and to do all these in a safe manner. As the atlas and axis are together with and adjacent to very important anatomic structures, the surgical anatomy of the area has many risks for surgeons. Since the 1900s, many researchers have described various methods to achieve stability. Especially the last couple of decades have witnessed very intensive studies in this field, and together with developing technology, serious improvements have taken place not only in diagnosis and planning of the suitable surgical procedure, but also in terms of the materials and implants used in the procedures.

In this study, we aimed to share our experience and to contribute to the literature by retrospectively analyzing the patients we operated on with a screw-rod system for atlantoaxial instability at our clinic.

■ MATERIAL and METHODS

This study was done upon the approval of the Ethics Committee for Clinical Studies of Ordu University numbered 2017/38.

Adult patients who had undergone fixation with C1-C2 screw-rod system at our clinic between January 2006 and January 2016 were scanned regardless of their diagnosis and their files and follow-up data were retrieved. The complaints of all patients at the time of consultation, their diagnoses, pre and postoperative images, Japanese Orthopedic Association (JOA) scores and Visual Analogue Scale (VAS) scores at their first visit and during follow-up, preoperative observations according to the surgical procedure implemented, and the complications were analyzed.

According to the inclusion criteria of the study; adult patients at 18 years of age and above, patients who had fixation with a C1 and C2 screw-rod system and who were followed clinically and radiologically for at least 12 months were included. According to the exclusion criteria of the study on the other hand, patients who had anterior surgery, posterior C1-C2 wiring, hook or transarticular fixation, occipitocervical fixation, patients who had fixation due to tumors and those who were followed clinically and radiologically for a period less than 12 months were excluded from the study.

Starting from the first visit, all the patients were taken into analysis upon wearing the appropriate cervical collar. All patients examined neurologically and recorded were assessed with direct radiographs, cervical magnetic resonance imaging (MRI) and computed tomography (CT). Cases that were identified for surgery as a result of the examinations were assessed with Three Dimensional Computed Tomography (3D CT) and CT Angiogram for the selection of suitable surgical technique, and the screw technique to be employed was determined considering the anatomical position of C1 and C2, and the position of adjacent anatomic structures, mainly vertebral arteries, and some other factors. After we examined the patients neurologically and assessed all radiological findings, all patients were operated upon being appropriately prepared as required. We obtained all routine blood tests and chest radiographs, and all patients were evaluated by the anesthesiologist. If necessary, other disciplines (for example, cardiology, internal medicine or others) examined the patients to ensure safer surgery. All the operations were performed under general anesthesia in the prone position with a Mayfield head frame. A midline incision was made between the inion and the 3rd cervical vertebra. A C1 lateral mass screw was inserted as defined in the literature. Afterwards, pedicle, pars or laminar screws were inserted at C2 according to the previous radiological assessments and intraoperative conditions. Whenever needed, the C-arm scope was used for imaging and the images were recorded. All the operations were performed by the same experienced neurosurgeon.

All patients were evaluated on the postoperative 1st day with control radiographs. Clinical follow-up was performed with JOA and VAS scores. In order to evaluate fusion, all the patients were assessed with direct flexion-extension radiographs and sagittal and coronal reconstruction images on CT at the 12th month. Trabeculation between C1 and C2 on the graft site and mobility of less than 2 mm according to the lateral flexion-extension radiograph was defined as solid fusion.

■ RESULTS

Out of the 28 patients included in the study, 17 were male and 11 were female, and their average age was 44.7 years (21-73 years). According to the Anderson and D'Alonzo classification, 16 (57%) patients had Type 2 odontoid fracture, 5 (18%) patients had basilar invagination, 5 (18%) had C1-C2 instability and 2 (7%) had atlantoaxial subluxation secondary to rheumatoid arthritis, and they underwent fixation with a C1-C2 screw-rod system. Eighteen patients did not have distinct myasthenia, but they had neck pain. The remaining 10 patients had various levels of motor loss and myelopathic findings. The average preoperative JOA score of the patients was 10.6 and the VAS score was 6.3. Upon deciding on the surgical technique as a result of the clinical and radiological assessments, the patients were operated and bilateral lateral mass screws were placed at C1 segment. C2 screws, on the other hand, were bilateral pedicle screws in 12 of the cases, bilateral pars in 4 cases, bilateral laminar in 8 and one side pars, one side laminar in 4 cases. There were no peroperative complications. All patients were checked postoperatively for implant position and reduction through direct radiographs and computed tomography. No screw malposition was observed. One patient with Diabetes Mellitus had wound site infection. The patient was treated problem-free with simple debridement and antibiotherapy. None of the patients had implant failure or recurrent instability during the long-term follow-up. The patients, who were followed up for 24 months on average, had an average postoperative JOA score of 13.1 according to their clinical follow-up, and the average VAS score improved to 1.7. According to the results of the radiological assessments performed at the 12th month on all patients, all of them (100%) achieved fusion. One patient, who was followed up for long term, underwent decompression in the 3rd year due to nerve compression that occurred in the fusion area. None of the patients had injury to nervous tissue or vertebral artery injury associated with the technique. Demographic and clinical data of the patients are summarized in Table I.

Case Illustration

A 51-year-old female patient was under follow-up for 10 years due to Rheumatoid Arthritis. She was admitted to our hospital for the neck pain. There was no neurological deficit. Cervical lateral x-rays (Figure 1A), sagittal CT scan (Figure 1B) and sagittal-T2 weighted MRI (Figure 1C) demonstrated atlantoaxial instability. She was operated on and posterior cervical fixation was achieved by C1 lateral mass (Figure 2A), and C2 laminar screws (Figure 2B). The rest of the clinical

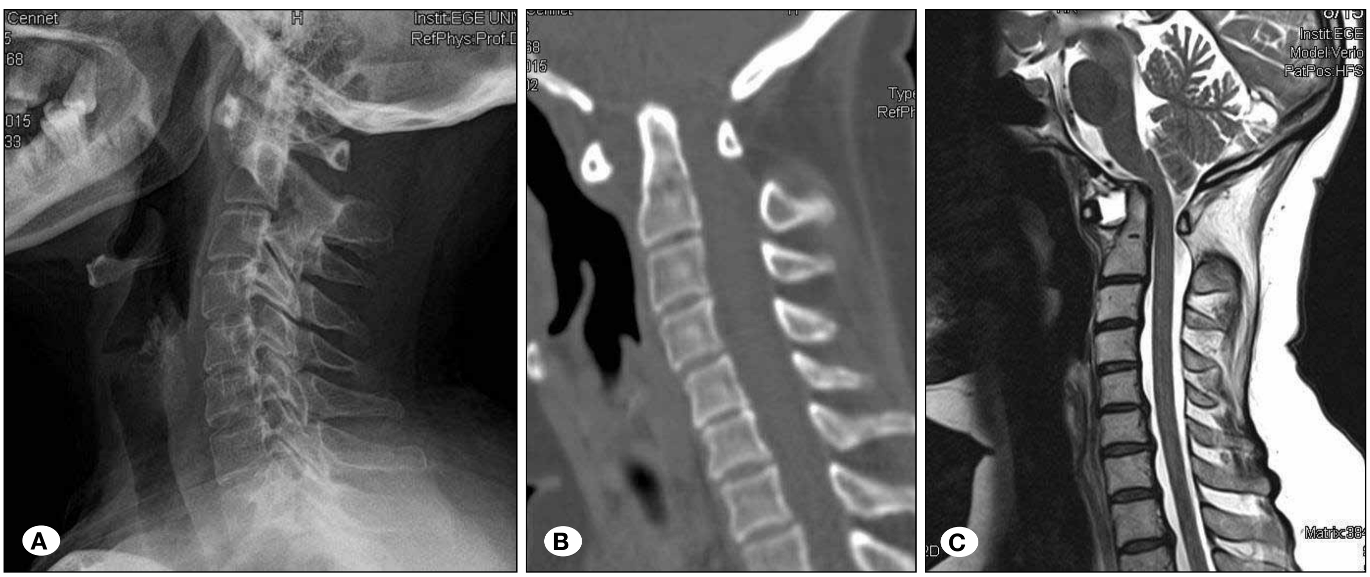

Figure 1: Lateral cervical x-rays **(A)**, sagittal CT scan **(B)** and sagittal T2-weighted MRI **(C)** demonstrate atlantoaxial instability.

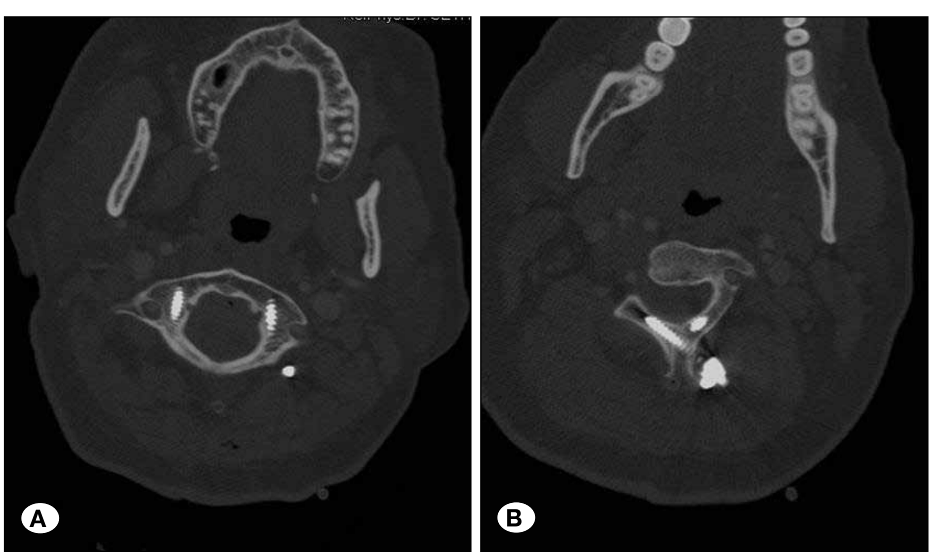

Figure 2: A,B) Postoperative axial CT scans shows precise screw insertion of bilateral C1 lateral mass via the posterior arch combined with bilateral C2 translaminar screws.

Table I: Data of Atlantoaxial Instability Patients

Patient Number	Age (years)	Sex	Diagnosis	C2 Screw Technique	Follow-up (Months)	Preoperative Symptoms
1	62	M	Basilar Invagination	Pedicle	18	Myelopathy-Weakness
2	24	M	Type II Odontoid Fracture	Laminar	15	Neck Pain
3	51	F	Rheumatoid Arthritis	Laminar	24	Neck Pain
4	52	F	Basilar Invagination	Pedicle	18	Neck Pain
5	21	F	Type II Odontoid Fracture	Pedicle	18	Myelopathy-Weakness
6	49	M	Type II Odontoid Fracture	Laminar	48	Neck Pain
7	29	F	Type II Odontoid Fracture	Pedicle	12	Myelopathy-Weakness
8	41	M	Basilar Invagination	Pedicle	60	Neck Pain
9	72	M	Type II Odontoid Fracture	Pars	48	Myelopathy-Weakness
10	60	F	Type II Odontoid Fracture	Laminar	18	Neck Pain
11	20	M	Type II Odontoid Fracture	Pedicle	20	Myelopathy-Weakness
12	50	M	C1-C 2 Instability	Pedicle	36	Myelopathy-Weakness
13	45	F	C1-C2 Instability	Pars	18	Neck Pain
14	72	F	Type II Odontoid Fracture	Pars+Laminar	60	Myelopathy
15	48	M	Rheumatoid Arthritis	Pedicle	14	Myelopathy
16	58	M	C1-C2 Instability	Laminar	16	Neck Pain
17	21	M	Type II Odontoid Fracture	Pedicle	12	Neck Pain
18	23	F	Type II Odontoid Fracture	Pars	18	Myelopathy-Weakness
19	52	F	Type II Odontoid Fracture	Pars	24	Neck Pain
20	73	M	Type II Odontoid Fracture	Laminar	16	Neck Pain
21	21	M	Type II Odontoid Fracture	Pedicle	18	Neck Pain
22	72	M	Basilar Invagination	Laminar+Pars	24	Neck Pain
23	42	M	C1-C2 Instability	Pedicle	18	Neck Pain
24	60	M	Type II Odontoid Fracture	Laminar	15	Neck Pain
25	53	F	Type II Odontoid Fracture	Laminar+Pars	16	Neck Pain
26	21	M	C1-C2 Instability	Laminar	18	Neck Pain
27	26	F	Basilar Invagination	Pedicle	24	Myelopathy
28	36	M	Type II Odontoid Fracture	Laminar+Pars	30	Neck Pain

***M:** Male, **F:** Female.*

course was uneventful and postoperative cervical sagittal T2-weighted MRI was smooth (Figure 3).

■ DISCUSSION

The different and complicated structure of the atlas and axis vis-à-vis all the other vertebrae is an important reason for discussion regarding the suitable and safe performance of the surgical treatment of atlantoaxial instability. However, as mentioned before, no matter what the reason, internal fixation should be performed whenever instability develops in this area if external immobilization methods do not provide sufficient and suitable treatment for the stability. The fixation of C1 and C2 with wire for this purpose was defined by Hadra for the first time in 1891 and for nearly 100 years, many researchers have tried to stabilize this area by modifying wiring techniques (2,8,10,11,17,18). Although every newly defined technique of wiring was reported to achieve higher fusion rates compared

Figure 3: Postoperative cervical sagittal T2-weighted MRI demonstrates that there was no spinal cord compression.

to the previous ones, these rates are far from creating an adequate and safe fusion and the patients have to use rigid external orthoses that would affect their long-term life standards (36). Due to all these reasons, wiring methods are not frequently used nowadays.

Interlaminar clamp technique (Halifax technique), which is recommended for surgical treatment of atlantoaxial instability and which ruled out the risk of spinal cord injury caused by wiring methods, was defined in 1984 by Holness et al., and the ApoFix clamp technique was developed later on (22). Despite their relative ease for use, fusion rates did not reach desired levels, and they had shortcomings particularly in terms of achieving rotational stability (23). In 2009, Hanımoglu et al. developed a technique, a modification of the interlaminar clamp technique, involving the attachment of the claws placed at C1 and C2 to each other by means of a transverse connector. This method was reported to achieve better stability and was recommended as an alternative method (20,23). We do not use wiring or clamp methods in our clinic unless we have to for any reason whatsoever.

Magerl and Seeman defined transarticular atlantoaxial fixation for the first time in 1987 (31). Following studies reported that this technique achieved the most rigid fixation at the atlantoaxial complex and the fusion rate was 100% (10,28). There were even some authors referring to this technique as the gold standard for atlantoaxial instability (33). Nevertheless, many drawbacks were also reported in opposition to its advantages. As a surgical technique, its implementation is not easy and the learning curve is long. Some serious complications such as spinal cord injury, hypoglossal nerve injury and vertebral artery injury can be seen as a result of misplacement of the screw (12,23,36). Vertebral artery injury, in particular, is reported at a rate of 3.7-8.8% in the literature and this complication may lead to vertebrobasilar insufficiency, brainstem infarction, and even death (16,32).

In recent years, there have been surgical technique studies published in the literature that have higher rates of fusion and lower complication rates and therefore that are safer (19,21,37,40). The first of these methods, which are defined as segmental screw fixation systems in general terms, was published by Goel and Laheri in 1994 (19). In this technique, C1 lateral mass screw and C2 transpedicular screw and plate system were used with low complication rates and 100% fusion. In this technique, the C2 ganglion was sacrificed without any clinical problems in order to attain extensive exposure. However, Harms and Melcher modified the technique later on by using polyaxial screw and there was no longer the need to sacrifice the C2 ganglion (21). The lateral mass was used for C1 screw placement in both techniques. In the C1 lateral mass implementation, bicortical placement of the screw passing through the C1 anterior cortex is another topic of debate. Naturally, bicortical screw placement is a desired and recommended technique for strong fixation and fusion. However, due to the risk of causing injury to the hypoglossal nerve and internal carotid artery with the screw during this procedure, it is well known that unicortical screw placement is also possible if there is sufficient bone quality and implemented appropriately (14). The pedicle can also be used for C1 fixation, and as a matter of fact it can allow for longer screws compared to the lateral mass and provides more robust fixation. However, as opposed to the lateral mass screw, far more frequent and more severe complications may be seen. The C1 pedicle screw technique is a difficult technique to implement requiring experience and it brings along a higher risk of vertebral artery injury because of its close proximity (42). In this series of ours, we used C1 lateral mass screw, we tried to place bicortical screws as much as possible, but we used unicortical screws in cases which we deemed more suitable as a result of the assessments we made. We had no complications in any of the patients during or after C1 lateral mass screw placement.

Anatomically, the C2 pedicle is a dense bone structure connecting the inferior articular facet to the C2 vertebra and biomechanically it ensures a more robust fixation than C2 pars and laminar screws, as reported in some studies (27,39). Nevertheless, in the study by Elliot et al., no clinical difference was observed between C2 pedicle screw and pars screw (10,15). Sufficient biomechanical strength was achieved with Goel and Harms' technique by using a C2 pedicle screw. This technique, at the same time, allows preoperative reduction of the atlantoaxial complex (19,21,36). In comparison with transarticular fixation, there is a lower risk of vertebral artery injury with a fusion rate of up to 100% (3,10,36,41). Although there are more frequent reports of vertebral artery injury risk for the transarticular fixation technique compared to the pedicle screw in the literature, there are also studies reporting no difference in this sense (5,43).

The C2 laminar screw technique was first defined by Wright in 2004 (40). In this technique, the screws are inserted into the C2 laminae and they are connected with C1 lateral mass screws by means of rods. Laminar screws are inserted with bicortical placement and biomechanical studies report that this technique achieves more robust fixation than pars screws (13,27). In biomechanical studies, it is similarly stated that C2 laminar screws ensure an equivalent level of rigidity in axial rotation and in flexion-extension vis-à-vis transarticular fixation and pedicle screw fixation, while being less strong in lateral bending (26). As an advantage, its implementation is relatively easy and it can be used as a rescue screw for the problems that may occur during the insertion of the C2 pedicle screw. If isthmus height is ≤ 5 mm and internal height is ≤ 2 mm in preoperative sagittal images, it is defined as a high-riding vertebral artery and its incidence is reported as 18-23% (1,13,30). In addition, studies show that there is vertebral artery dominance in more than 50% of the population, and anatomical variations such as unilateral vertebral artery hypoplasia or occlusion are quite common (7,13). Furthermore, should there be unilateral vertebral artery injury during the surgery, it is contraindicated to insert a pedicle screw to the other side. The laminar screw technique can be a suitable and safe technique in all these cases. The size of the C2 pedicle is another challenge in the placement of pedicle screws. In the study of Smith et al. conducted on 93 patients by evaluating C2 pedicles through radiographic images, it was reported that approximately 25% of the patients did not have a pedicle that was suitable for screw placement (38). In the same study, they underlined the importance of preoperative radiological assessment and stated the necessity of preoperative measurement of the angle of the pedicle for a safe procedure (38).

Despite the abovementioned advantages of the C2 laminar screw technique, there are a couple of issues that need to be considered during its implementation. The most important one is the thickness of the lamina. According to the consensus in the literature, the thickness of the lamina should be more than 4 mm in order to have an appropriate and sufficient laminar screw insertion (4,13). Ma et al. reported the incidence of laminar thickness less than 4 mm as 5% in their study and stated that bilateral laminar screws could be placed safely in 83.3% of the specimens (29). Cassinelli et al., on the other hand, reported an incidence of 92.6% for a thickness of 4 mm and above (4).

Considering the challenging surgical anatomy of the atlantoaxial complex, another fixation method that can be implemented particularly in old patients in a more rapid and safe way, minimizing the risk of vertebral artery injury, is the pars screw fixation (12,15). Dobran et al. reported appropriate and sufficient stabilization and long-term fusion with C1 lateral mass and C2 pars screw fixation in old patients with type II odontoid fractures (12).

In this study, we decided on the technique to be used as on the basis of meticulous and detailed preoperative radiological assessments, and in some cases, on the basis of the requirements emerging during the operation. Out of the 56 screws that we used for the C2 segment, 24 were pedicle, 20 were laminar and 12 were pars screws. We observed no complications such as screw malposition, injury to nervous tissue, injury to major vessels, or hypoglossal nerve injury in any patient. Rajinda et al. stated in their study that a meticulous and careful preoperative assessment, experience of the surgeon on the technique to be used, and ensuring appropriate surgical conditions are the most significant factors in reducing complications (36). We observed the same factors in our study. Considering all the surgical techniques that we have been implementing for atlantoaxial instability in the last 10 years in our clinic, we can conclude as a clinical observation that the laminar screw technique is a technique that we have started to implement more frequently with no different clinical results than the other techniques and safe implementation.

As we compare our study with other relevant series in the literature in terms of clinical outcomes, we see the study of Zheng et al., who implemented stabilization with pedicle screws at C1-C2 on 86 patients in their series published in 2016. Clinical evaluation was done with ASIA and VAS scores and they reported statistically significant recovery and a successful fusion rate of 97.7% (44). Similarly in 2016, Dobran et al. published a series of 21 patients who had stabilization with C1 lateral mass screw and C2 pars screw. In this study, solid fusion rate was reported as 95.24% and clinically significant recovery rates were achieved (12). Furthermore, in a study of Rajinda et al. a fusion rate of 97% and significant recovery in VAS and JOA scores were reported in a series of 60 patients operated with C1 lateral mass and C2 pedicle screw fixation (36). Du et al. stated in their study that laminar screws were a suitable alternative to pedicle screws for C2 and reported high fusion rates and JOA and VAS scores indicating statistically significant recovery without any complications (13). When we consider the clinical outcomes of our study, no complications associated with the technique itself were experienced, significant recovery was observed in VAS and JOA scores, and solid fusion was defined by the 12th month in all patients, which are similar with the literature.

There are some limitations of our study. Being a retrospective study and its relatively low number of cases can be regarded as factors extenuating the scientific value of the study. Still, with this series, we aimed at contributing to the literature by sharing our experiences with our colleagues already performing or planning to perform these surgical procedures.

■ CONCLUSION

C1-C2 screw fixation is regarded as a more successful and safe method than other fixation methods in the surgical treatment of atlantoaxial instability in terms of complications, success in reduction, and fusion and fixation strength. The C2 laminar screw technique is as successful as the other alternatives in terms of fixation and fusion. Its implementation is safer than to the other screw techniques. Preoperative neurological and radiological assessments are crucial in the selection of the most suitable and safe technique. The experience of the surgeon is another vital issue on the success of the surgery. Within this framework, activities such as trainings, courses, and cadaveric practices to increase surgical experience are of great importance.

■ REFERENCES

1. Abou Madawi A, Solanki G, Casey AT, Crockard HA: Variation of the groove in the axis vertebra for the vertebral artery. Implications for instrumentation. J Bone Joint Surg Br 79(5): 820-823,1997
2. Brooks AL, Jenkins EB: Atlanto-axial arthrodesis by the wedge compression method. J Bone Joint Surg Am 60(3):279-284, 1978
3. Calisaneller T, Yilmaz C, Ozdemir O, Caner H: Posterior atlantal lateral mass fixation technique with polyaxial screw and rod fixation system. Turk Neurosurg 18(2):142–148, 2008
4. Cassinelli EH, Lee M, Skalak A, Ahn NU, Wright NM: Anatomic considerations for the placement of C2 laminar screws. Spine (Phila Pa 1976) 31(24):2767-2771, 2006
5. Chakrabarti I, Tredway TL, Khoo LT: Posterior atlantoaxial fusion: Surgical anatomy and technique options. Fessler RG, Laligam S (eds), Atlas of Neurosurgical Techniques Spine and Peripheral Nerve. New York: Thieme, 2006:128-138
6. Chapman J, Smith JS, Kopjar B, Vaccaro AR, Arnold P, Shaffrey CI, Fehlings MG: The AO Spine North America Geriatric Odontoid Fracture Mortality Study: A retrospective review of mortality outcomes for operative versus nonoperative treatment of 322 patients with long-term follow-up. Spine (Phila Pa 1976) 38(13):1098-1104, 2013
7. Cosar M, Yaman M, Eser O, Songur A, Ozen OA: Basilar artery angulation and vertigo due to the hemodynamic effect of dominant vertebral artery. Med Hypotheses 70(5):941-943, 2008
8. Coyne TJ, Fehlings MG, Wallace MC, Bernstein M, Tator CH: C1-C2 posterior cervical fusion: Long-term evaluation of results and efficacy. Neurosurgery 37(4):688-692; discussion 692-693, 1995
9. Dagtekin A, Kara E, Vayisoglu Y, Koseoglu A, Avci E, Talas D, Bagdatoglu C: The importance of early diagnosis and appropriate treatment in Grisel's syndrome: Report of two cases. Turk Neurosurg 21(4):680–684, 2011
10. Dickman CA, Sonntag VK: Posterior C1-C2 transarticular screw fixation for atlantoaxial arthrodesis. Neurosurgery 43(2): 275-280; discussion 280-281, 1998
11. Dickman CA, Sonntag VK, Papadopoulos SM, Hadley MN: The interspinous method of posterior atlantoaxial arthrodesis. J Neurosurg 74(2):190-198, 1991
12. Dobran M, Nasi D, Esposito DP, Iacoangeli M: Posterior fixation with C1 lateral mass screws and C2 pars screws for type II odontoid fracture in the elderly: Long-term follow-up. World Neurosurg 96:152-158, 2016
13. Du S, Ni B, Lu X, Xie N, Guo X, Guo Q, Yang J, Chen F: Application of unilateral C2 translaminar screw in the treatment for atlantoaxial instability as an alternative or salvage of pedicle screw fixation. World Neurosurg 97: 86-92, 2017
14. Ebraheim NA, Misson JR, Xu R, Yeasting RA: The optimal transarticular C1-2 screw length and the location of the hypoglossal nerve. Surg Neurol 53(3):208-210, 2000
15. Elliott RE, Tanweer O, Boah A, Smith ML, Frempong-Boadu A: Comparison of safety and stability of C-2 pars and pedicle screws for atlantoaxial fusion: Meta-analysis and review of the literature. J Neurosurg Spine 17(6):577-593, 2012
16. Elliott RE, Tanweer O, Boah A, Morsi A, Ma T, Frempong-Boadu A, Smith ML: Outcome comparison of atlantoaxial fusion with transarticular screws and screw-rod constructs: Meta-analysis and review of literature. J Spinal Disord Tech 27(1):11-28, 2014
17. Farey ID, Nadkarni S, Smith N: Modified Gallie technique versus transarticular screw fixation in C1-C2 fusion. Clin Orthop Relat Res 359:126-135, 1999
18. Gallie WE: Fractures and dislocations of the cervical spine. Am J Surg 46:495-499, 1939
19. Goel A, Laheri V: Plate and screw fixation for atlanto-axial subluxation. Acta Neurochir (Wien) 129(1-2):47-53, 1994
20. Hanimoglu H, Hanci L, Kaynar MY, Hanci M: Bilateral C1-C2 claw for atlantoaxial instability. Turk Neurosurg 19(4):345-348, 2009
21. Harms J, Melcher RP: Posterior C1-C2 fusion with polyaxial screw and rod fixation. Spine (Phila Pa 1976) 26(22):2467-2471, 2001
22. Holness RO, Huestis WS, Howes WJ, Langille RA: Posterior stabilization with an interlaminar clamp in cervical injuries: Technical note and review of the long term experience with the method. Neurosurgery 14(3):318-322, 1984
23. Huang DG, Hao DJ, He BR, Wu QN, Liu TJ, Wang XD, Guo H, Fang XY: Posterior atlantoaxial fixation: A review of all techniques. Spine J 15(10):2271-2281, 2015
24. Jacobson ME, Khan SN, An HS: C1-C2 posterior fixation: Indications, technique and results. Orthop Clin N Am 43:11-18, 2012
25. Kim DH, Hilibrand AS: Rheumatoid arthritis in the cervical spine. J Am Acad Orthop Surg 13(7):463-474, 2005
26. Lapsiwala SB, Anderson PA, Oza A, Resnick DK: Biomechanical comparison of four C1 to C2 rigid fixative techniques: Anterior transarticular, posterior transarticular, C1 to C2 pedicle, and C1 to C2 intralaminar screws. Neurosurgery 58(3):516-521; discussion 516-521, 2006
27. Lehman RA Jr, Dmitriev AE, Helgeson MD, Sasso RC, Kuklo TR, Riew KD: Salvage of C2 pedicle and pars screws using the intralaminar technique: A biomechanical analysis. Spine (Phila Pa 1976) 33(9):960-965, 2008
28. Low HL, Redfern RM: C1-C2 transarticular screw fixation for atlantoaxial instability: A 6-year experience, and C1-C2 transarticular screw fixation-technical aspects. Neurosurgery 50(5): 1165-1166, 2002
29. Ma XY, Yin QS, Wu ZH, Xia H, Riew KD, Liu JF: C2 anatomy and dimensions relative to translaminar screw placement in an Asian population. Spine (Phila Pa 1976) 35(6):704-708, 2010
30. Madawi AA, Casey AT, Solanki GA, Tuite G, Veres R, Crockard HA: Radiological and anatomical evaluation of the atlantoaxial transarticular screw fixation technique. J Neurosurg 86(6): 961-968, 1997
31. Magerl F, Seemann PS: Stable posterior fusionof the atlas and axis by transarticular screw fixation. In: Kehr P, Weidner A (eds). Cervical Spine 1. New York: Springer-Verlag, 1987:322-327
32. Mummaneni PV, Haid RW: Atlantoaxial fixation: Overview of all techniques. Neurol India 53(4):408-415, 2005

33. Ni B, Zhou F, Guo Q, Li S, Guo X, Xie N: Modified technique for C1-2 screw-rod fixation and fusion using autogenous bicortical iliac crest graft. Eur Spine J 21(1):156-164, 2012
34. Ozer F, Iplikcioglu C, Turkmen C, Sasani M, Sarioglu AC: C1-C2 interfacetal screw fixation in atlantoaxial instability: Case report. Turk Norosir Derg 9(2):43-48, 1999 (In Turkish)
35. Pueschel SM, Scola FH, Perry CD, Pezzullo JC: Atlanto-axial instability in children with Down syndrome. Pediatr Radiol 10(3):129-132, 1981
36. Rajinda P, Towiwat S, Chirappapha P: Comparison of outcomes after atlantoaxial fusion with C1 lateral mass-C2 pedicle screws and C1-C2 transarticular screws. Eur Spine J 26(4):1064-1072, 2017
37. Senturk S, Akyoldas G, Yaman O, Ozer AF: A new technique for the surgical treatment of atlantoaxial instability: C1 lateral mass and C2-3 transfacet screwing. Turk Neurosurg Mar 9, 2017 (Epub ahead of print)
38. Smith ZA, Bistazzoni S, Onibokun A, Chen NF, Sassi M, Khoo LT: Anatomical considerations for subaxial (C2) pedicle screw placement: A radiographic study with computed tomography in 93 patients. J Spinal Disord Tech 23(3): 176-179, 2010
39. Su BW, Shimer AL, Chinthakunta S, Salloum K, Ames CP, Vaccaro AR, Bucklen B: Comparison of fatigue strength of C2 pedicle screws, C2 pars screws, and a hybrid construct in C1-C2 fixation. Spine (Phila Pa 1976) 39(1):E12-19, 2014
40. Wright NM: Posterior C2 fixation using bilateral, crossing C2 laminar screws: Case series and technical note. J Spinal Disord Tech 17(2):158-162, 2004
41. Xie Y, Li Z, Tang H, Li M, Guan Z: Posterior C1 lateral mass and C2 pedicle screw internal fixation for atlantoaxial instability. J Clin Neurosci 16(12):1592-1594, 2009
42. Yan L, He B, Liu T, Yang L, Hao D: A prospective, double-blind, randomized controlled trial of treatment of atlantoaxial instability with C1 posterior arches >4 mm by comparing C1 pedicle with lateral mass screws fixation. BMC Musculoskelet Disord 17:164, 2016
43. Yoshida M, Neo M, Fujibayashi S, Nakamura T: Comparison of the anatomical risk for vertebral artery injury associated with the C2-pedicle screw and atlantoaxial transarticular screw. Spine (Phila Pa 1976) 31(15): E513-517, 2006
44. Zheng Y, Hao D, Wang B, He B, Hu H, Zhang H: Clinical outcome of posterior C1-C2 pedicle screw fixation and fusion for atlantoaxial instability: A retrospective study of 86 patients. J Clin Neurosci 32: 47-50, 2016