15 Axial Instability of Cervical Spine: Posterior Surgical Approach

Alberto Maleci, Pier Paolo Maria Menchetti,
and Nicola Di Lorenzo

Many pathologies can cause instability of the cranio-vertebral junction (CVJ). Among the most common diseases must be considered traumatisms [1], neoplasms [2, 3], inflammation [4], but also congenital malformations [5]. Instability of the CVJ is a potentially life-threatening condition and improper treatment can lead to severe neurological deficits as well as continuous, excruciating pain in the neck. Conservative treatments are often disappointing, and surgery must always be taken in consideration when approaching instability of the CVJ, being in many cases the only therapy that can provide satisfactory results.

Anterior approaches to the CVJ are usually limited to few and selected cases and, with the exception of type II C2 fractures, posterior approach must be considered the first choice to restore stability of the axial cervical spine.

History

Posterior sub laminar wiring of C1 and C2 was attempted in 1910 by Mixter and Osgood [6]. Foerster, in 1927, was the first to describe the use a peroneal graft to treat a trauma of the cranio-vertebral region [7]. However, the first widely used surgical technique to restore stability of the C1–C2 segment was posterior fusion with wires and autograft and was developed by Gallie et al. in 1939 [8].

Gallie's technique gained wide appreciation and has been used for many years; in 1978 Brooks and Jenkins [9] proposed a modification of the original technique. The development of the concept of posterior C1–C2 wiring and grafting is represented by clamps between the posterior arch of C1 and C2 laminae. Integrity of the posterior arch of the atlas was necessary and postoperative immobilization was strongly recommended. When the posterior arch of C1 was interrupted the occiput had to be involved in the fusion leading to a complete abolition of rotatory movements and severe limitation of flexo-extension of the head.

In 1987 Magerl and Seeman proposed the union of C2 to C1 by two screws that, passing through the C2 isthmus, were screwed to the C1 lateral masses [10]. The integrity of the posterior arch of C1 was no longer needed and the construct was so stable that also postoperative course did not require firm immobilization. In 1994 Goel and Laheri [11] published an original technique where two screws were placed in the lateral masses of C1 and two screws in the isthmus of C2. The screws were connected by plates realizing the stabilization of the C1–C2 segment. Some years later Harms and Melcher [12] proposed a modification of this technique that gained great

A. Maleci (✉)
University of Cagliari, Cagliari, Italy

P. P. M. Menchetti
University of Palermo, Palermo, Italy

N. Di Lorenzo
University of Florence, Florence, Italy

P. P. M. Menchetti (ed.), *Cervical Spine*, https://doi.org/10.1007/978-3-030-94829-0_15

popularity in the following years. In 2004 Wright [13] proposed a modification of the Harm's technique which avoided the risk of C2 isthmus perforation; the caudal screws were inserted in the laminae and connected to the lateral mass screws.

Conservative Treatment

Pathologies that can be treated by external immobilization are mainly traumatic: fractures of the atlas, fractures of the dens (reducible fractures type 2 and 3 according Anderson and D'Alonzo) [14]. The goal of an external fixation is to maintain an optimal alignment of the axis for a time long enough to provide healing and fusion (usually 3–4 months). The best way to obtain stability of the cranio-vertebral junction by non-surgical techniques is positioning a halo-cast or halo-vest [15, 16], even though a Philadelphia collar has been proposed to treat C2 fractures [17]. The sternal-occipital-mandibular immobilizer (SOMI)—brace has also been used in the past [18]. The most common traumatic lesion of the axis is the C2 fracture type II. Conservative treatment of this type of lesion has been reported by many authors [19], but a high percentage of non-union has also been reported. Unfavorable results are related to many factors, first of all the presentation of fracture. When translation was larger than 6 mm, the non-union rate was as high as 86% while the results were much better in the cases of dislocation inferior to 4 mm. Another crucial point is the age of the patients: non-union in patients older than 50 [20, 21] is frequently observed. Neurological status is also important; in the presence of progressive neurological deficits or serious impairment of functions as well as in non-cooperative patients, conservative treatment should be avoided. Finally, other lesions involving the cranial and facial bones and thoracic and pulmonary conditions can prevent the correct positioning of a halo vest.

Halo positioning requires insertion of four pins in anterior and posterior position, through the skin and secured to the skull. The direction is vertical, with a 90° angle with the skull, as a differently angled direction decreases biomechanical resistance [22]. The secure zone for the anterior pins insertion is quite small and is represented by an area of about 10 cm^2 1 cm above the orbital ridge on the external part of the forehead in order to avoid the arterial branch of the superficial temporal artery laterally and the supra-orbitary nerve superiorly and medially.

Non-union is the most common but not the only complication following conservative treatments of cranio-vertebral junction. Cutaneous ulcers are quite common [23], but nerve palsy, particularly of the marginal mandibular nerve (terminal branch of the facial nerve) has also been reported [24]. As far as halo is concerned, loosening of the pins is a common complication [25]. Cutaneous infection can follow the positioning of the pins [26] but infections can involve also bone and intracranial structures [21, 27, 28] and subdural as well as epidural hematoma [29].

Presently conservative treatment should be restricted to axis traumatic lesions with minimal dislocations, in young patients without neurological abnormalities; patients with systemic diseases that carry high operative risk should be treated conservatively as well.

In all other cases surgical treatment should represent the first choice.

Biomechanical Analysis of Surgical Treatments

The goal of the surgical treatment is to provide a stabilization of the unstable segment (i.e. the axial part of the cervical spine) as strong as possible. On the other hand, as every posterior stabilization leads to loss of motion, the ideal treatment should be the strongest and the least invalidating.

Many biomechanical studies have investigated the ability of the different treatments of stabilizing the C1–C2 segments. According Sim et al. [30], who measured the range of movement and the neutral zone of cadaver specimens after different techniques of stabilization, posterior wiring (PW), trans-articular screws (TA) and screws in C1 lateral masses combined with C2 screwing (C1LM-C2 PS) are all able to stabilize an unstable axis in flexion–extension. However, posterior wiring couldn't give enough stability at rotational and lateral bending tests, and were therefore considered insufficient. The three-point reconstruction, using TA and PW provided the best results in all the tests, but also the C1LM-C2PS achieved a sufficient stability in the three planes.

A recent review has been published by Du et al. in 2015 [31]. The authors found differences in the results of the single papers, but generally TA, C1LM-C2PS provided good stabilization in the three movements tested, while screwing C1 lateral masses and trans laminar C2 (C1LM-C2TL) were less effective in the lateral bending tests.

Posterior Wiring and Clamps

The original Gallie's technique utilized a single bone harvested from the iliac crest and placed on the C2 spinous process and the posterior arch of C1. The stabilization was then obtained by steel wires which passed below the C1 arch and around the C2 spinous process, keeping at the same time the autograft in place (Fig. 15.1a). In the Brooks and Jenkins technique two single grafts were used, shaped in order to be positioned between the posterior C1 arch and C2 lamina. The wiring was sublaminar both in C1 and C2 (Fig. 15.1b). Dickman et al. [32] furtherly modified the original Gallie's technique using a single graft, not only leaned on the posterior arch of C1, but wedged underneath the spinous process of C2 and C1. The wires to keep in place the graft and to provide stability passed below the posterior arch of C1 and a notch prepared on the spinous process of C2 in order to increase the stability of the construct.

The results of posterior grafting and wiring were satisfactory in a number of cases. Nevertheless, the non-fusion rate was still elevated [33], rotational stability was poor and immobilization for 3–4 months in a halo was mandatory in the postoperative course. Furthermore, sublaminar wires carried the risk of nervous injuries and dural tears.

Interlaminar clamps should decrease this risk: the hooks are placed underneath the posterior

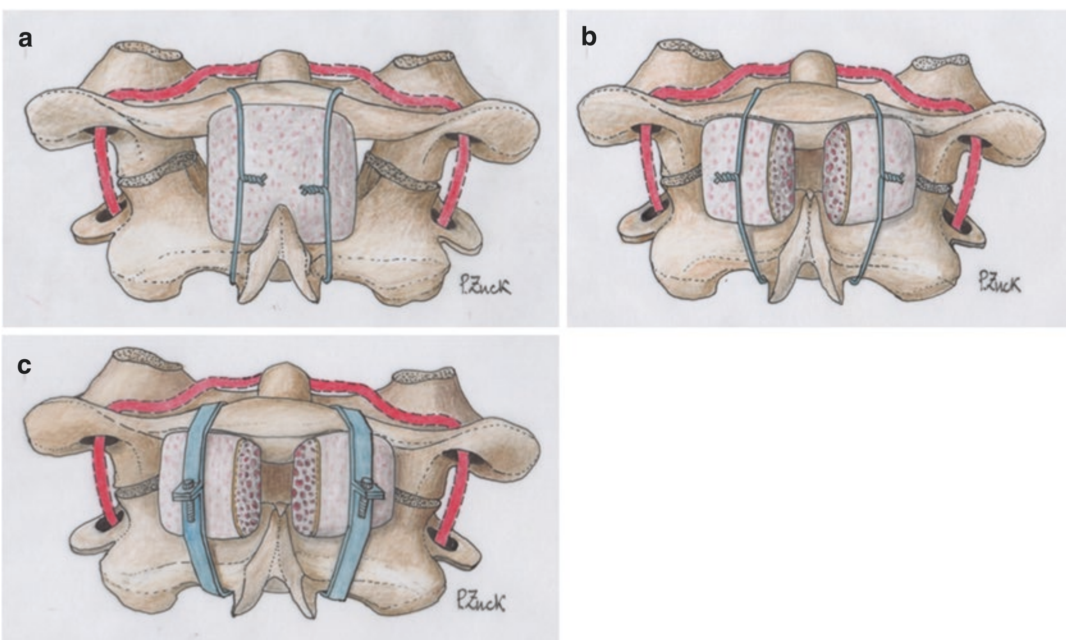

Fig. 15.1 Posterior C1–C2 wiring: (**a**) according to Gallie (**b**) according to Brooks and Jenkings (**c**) according to Dickman

arch of C1 as well as C2 lamina, and then tightened by different mechanism [34]; the autograft, harvested by the iliac crest, is compressed between the posterior aspect of C1 and C2 (Fig. 15.1c). Even though clamps are easier to be positioned than wires, they have good stability only in the flexion and extension movements, while in rotational motion and lateral bending the stability is very poor. Dislocation of the clamps are therefore not uncommon, needing for second surgery (Fig. 15.2). As for all the wiring techniques also clamps require an intact posterior arch of C1.

C1–C2 Trans-articular Screw Technique

This technique, described in 1987 by Magerl [20] gained wide acceptance in the following years, being the most effective technique to stabilize C1–C2 [35], especially if combined with posterior wiring or clamps [36]. This technique can be used also in cases where there is an interruption of the posterior arch of C1 but requires a good alignment of the axis.

Fig. 15.2 Dislocation of Halifax clamps

The patient is placed in the prone position in a three-points head holder: a horse-shoe head holder can also be used, but, in this case, is more difficult to obtain the optimal alignment of the axis. With an external K-wire the ideal trajectory of the screws is identified before the skin incision. The entry point for the drill, in most cases, lies laterally to the spinous process of T1 or T2. The skin incision is on the midline from C0 to C3 and a careful dissection of the muscles is performed. During this step is important to maintain the midline to avoid bleeding from the muscles which are easily detached from the C1 and C2 posterior aspect, especially in young subjects. There is no need to extend dissection too far laterally, but identification of the C2–C3 joint is mandatory. Two small incisions are then made, and two guide tubes are placed along the ideal trajectory from the T2 level up to the C2–C3 joint. The direction is checked with X-rays and the entry point on C2 is identified: it lies just 3 mm medially and superiorly to the center of the C2–C3 joint. After decortication of the dorsal aspect of the joint a guide K-wire is drilled under x-ray control with a sagittal direction toward the anterior C1 tubercle and with a lateral medial inclination of about 0°–10°. If it is not possible to obtain a perfect C1–C2 alignment the trajectory should be a little superior to the anterior tubercle. The drilling is stopped 3–4 mm before reaching the anterior tubercle, preventing penetration of the retro-pharyngeal space and a cannulated screw is then screwed on the K-wire. A special attention must be paid to avoid the advance of the K-wire while the screw is positioned. Some systems have also the possibility to connect two hooks, embracing the posterior arch of the atlas, to the screws, creating a very strong stabilization of the axis (Fig. 15.3a, b). Bone autograft or allograft is finally positioned between C1 and C2. If any doubt arises, a small spatula can be inserted in the C1–C2 joint, after dislocation of the C2 nerve root, to check the presence of the screw crossing the joint.

The main problem of this technique is the risk of lesions to the vertebral artery [37]; a preoperative CT scan with reconstruction should always be performed to investigate the course of

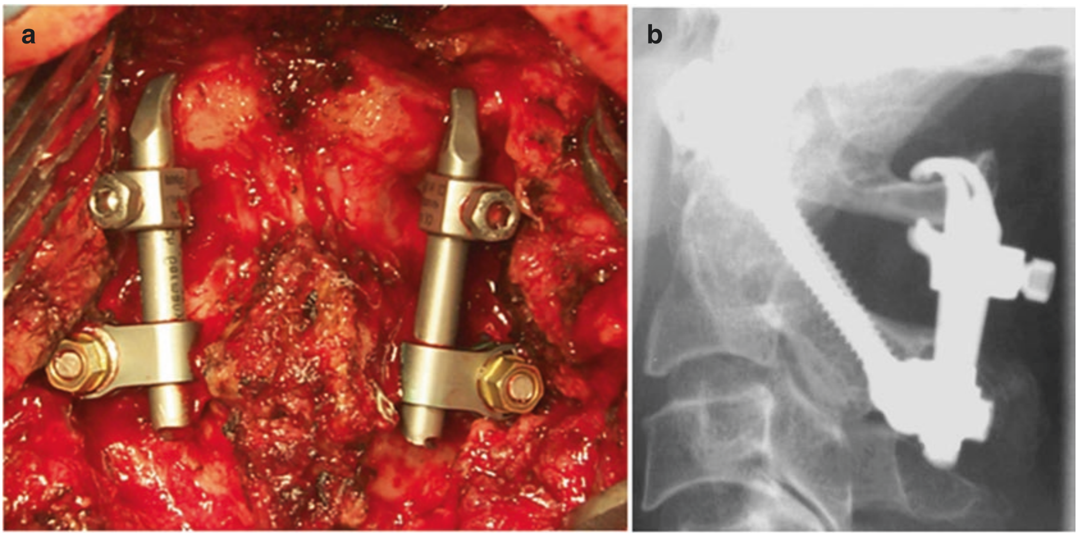

Fig. 15.3 C1–C2 stabilization by transarticular screwing and clamps. (**a**) Operative field (**b**) Post-operative control in LL

vertebral artery. Some studies have shown that anomalies of the vertebral artery anatomy or a large vertebral artery groove are present in more than 20% of the patients [38, 39]. In these situations there are two options: to change technique or to perform an unilateral trans-articular fixation.

C1 Lateral Mass Screws and C2 Pedicle Fixation

This technique was first described by Goel and Leheri in 1994 [11, 40], but gained popularity after its reappraisal by Harms and Melcher [12] some years later. The main advantage of this method is that the integrity of the posterior arch of C1 is not needed and also alignment of the axis is not necessary. With this technique a reduction and alignment of the C1–C2 complex can be obtained also in many cases considered non reducible at the pre-operative studies (Fig. 15.4a–c). At the same time the technique allows good results in terms of primary stability [31] and later fusion [40]. The technique is suitable also in mild cases of basilar invagination: by distraction of C1 and C2 the dens is pulled downward (or the skull is pushed upward), releasing compression on the ventral aspect of the brain stem, so that transoral decompression can be avoided [41].

The patient is in prone position with the head in a three-point or horse-shoe head holder. The skin incision is from C0 to C3 and the muscle of the neck are detached on the midline, exposing the posterior arch of C1 and C2 on both sides. In comparison with the trans-articular technique, the exposition is wider because the lateral mass of the atlas must be fully exposed; some bleeding can rise from the important venous plexus that surrounds the lateral aspect of the spinal cord, the C2 root and the vertebral artery, but it is usually easy to control with gel foam or other hemostatic agents; there is no need to fully expose the vertebral artery. The medial wall of the lateral mass is identified by a smooth dissector and the C2 root is also isolated. The entry point for the C1 screw is in the center of the lateral mass or at the union of the posterior arch with the lateral mass. In order to avoid conflict with the C2 nerve root, a little portion of the inferior aspect of C1 posterior arch can also be removed by drilling or rongeurs (Fig. 15.5). No drilling should be made above the junction of the posterior arch with the lateral mass because this area is too close to the vertebral artery. Under fluoroscopy a hole is drilled with a direction from 0° to 25° medially toward

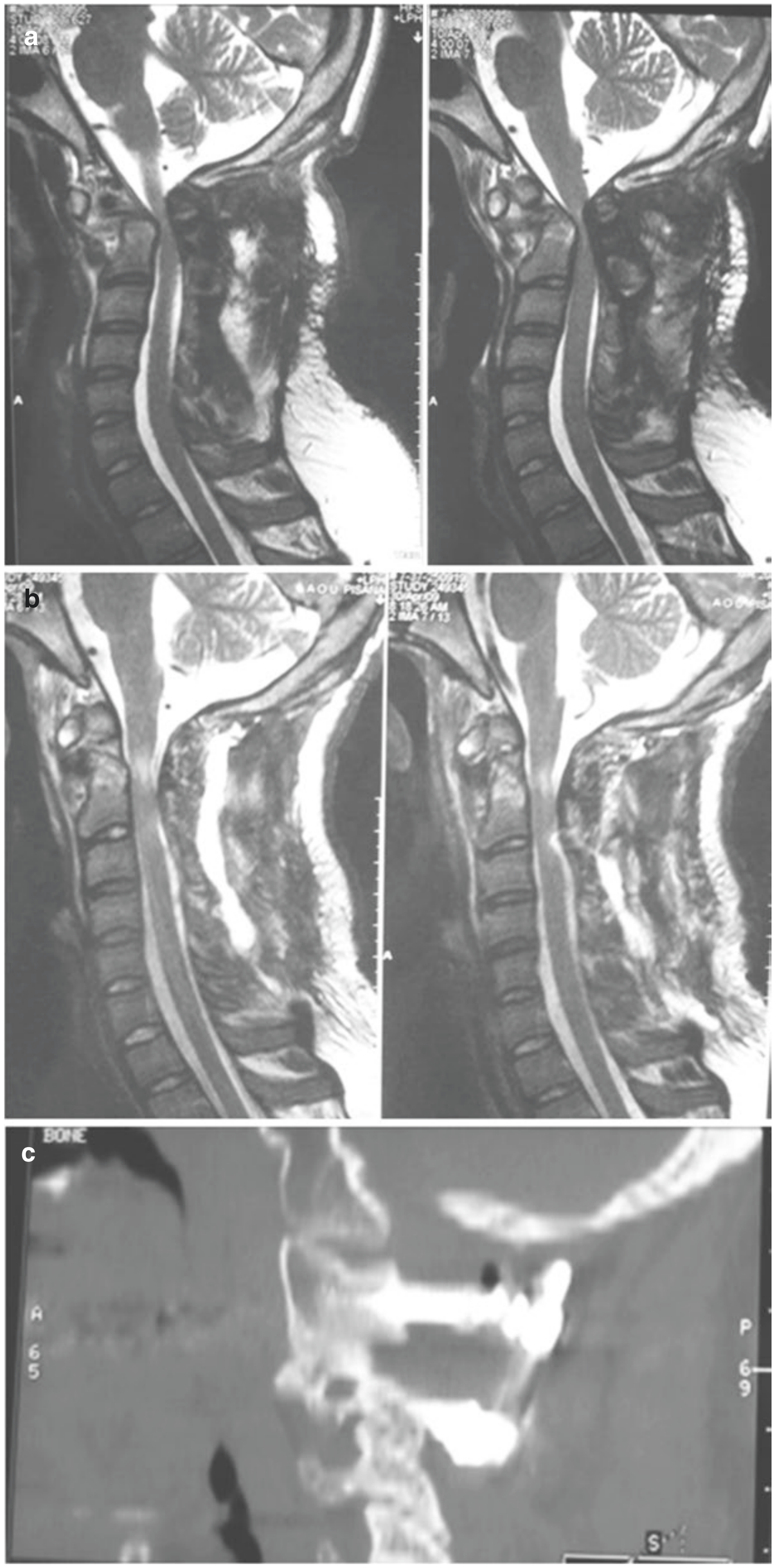

Fig. 15.4 Non-reducible os odontoideum. (**a**) pre-operative MRI (**b**) post-operative MRI following C1–C2 stabilization according to Goel and Leheri (**c**) post-operative CT reconstruction

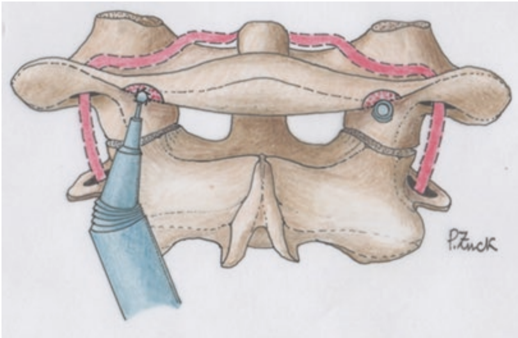

Fig. 15.5 Drilling of posterior arc of C1 before lateral mass screw insertion

the anterior tubercle. After tapping the hole, a screw (3.5 mm) is positioned.

The entry point of the C2 screw depends on the intention to place the screw in the pedicle or in the pars, knowing that there are not real differences from a biomechanical point of view [30, 42, 43]. Conventionally, the pars of C2 is that portion of the vertebra between the superior and inferior surfaces. The entry point and the direction of the screw are about the same as in the trans-articular technique (3 mm medially and 3 mm superiorly to the articular surface of C2 toward the anterior tubercle) with a latero-medial angulation of 15°. The screw is much shorter and the risk of injuries to the vertebral artery is lower. The pedicle of C2 is located anteriorly to the pars and trajectory is a little less angulated (about 20° on a sagittal plane and 15° medially). The entry point of a C2 pedicular screw is very little (about 2 mm) superior and more medial than the entry point for screwing the C2 pars. The C1 and the C2 screws are then connected to bars that allow reduction and stabilize the axis. As in the other techniques bone allograft or autograft are finally inserted between C1 and C2 in order to provide fusion.

Conclusion

Many techniques are available to restore stability of an unstable axis. The choice depends upon the pathology which caused the instability and the severity of damage to bone and ligaments. Posterior wiring and clamps are less demanding from a technical point of view and carry less risks to injuries to the vascular and nervous structures, but give less stability, which means the need for postoperative halo or collars and a significant rate of failures. Trans-articular screwing of C1–C2 is the best performing technique and should be seen as the gold standard, but carries the risk of life-threatening complications and it is not suitable in all cases. C1 lateral mass and C2 (pars or pedicle) screwing has a wider range of feasibility and is a little less risky than trans-articular screwing. The advantages are balanced by less stability.

Mispositioning of the screws, both when Magerl's technique and Goel's technique are performed, is not uncommon and navigation, when available, is recommended; nevertheless, must be said that clinical complications are exceptional also in case of a mistake in screw positioning [37].

References

1. Keen JR, Ayer RE, Taha A, Zouros A. Rigid internal fixation for traumatic carnio-cervical dissociation in infants and young children. Spine. 2019;44(1):17–24.
2. Champagne PO, Voormolen EH, Mammar H, Bernat AL, Krichen W, Penet N, Froelich S. Delayed instrumentation following removal of cranio-vertebral junction chordomas: a technical note. J Neurol Surg B Skull Base. 2020;81(6):694–700.
3. Zuckerman SL, Kreines F, Powers A, Iorgulescu JB, Elder JB, Bilsky MH, Laufer I. Stabilization of tumor-associated craniovertebral junction instability: indications, operative variables and outcomes. Neurosurgery. 2017;81(2):251–8.
4. Wolfs JFC, Arts MP, Peul WC. Juvenile chronic arthritis and the craniovertebral junction in the paediatric patient: review of the literature and management considerations. Adv Tech Stand Neurosurg. 2014;41:143–56.
5. Ropper AE. From anatomic to genetic understanding of developmental craniovertebral junction abnormalities. Neurospine. 2020;17(4):859–61.
6. Mixter SJ, Osgood RB. Traumatic lesions of the atlas and axis. Ann Surg. 1910;51:193–207.
7. Foerster O. Die Leitungsbahnen des Schmerzgefuhls und die chirurgische Behandlung der Schmerzzustaude. Berlin: Urban & Schwarzenberg; 1927. p. 266.
8. Gallie WE. Fractures and dislocations of the cervical spine. Am J Surg. 1939;46:495–9.

9. Brooks AL, Jenkins EB. Atlanto-axial arthrodesis by wedge compression method. J Bone Joint Surg Am. 1978;60:279–84.
10. Magerl F, Seeman P. Stable posterior fusion of the atlas and axis by transarticular screw fixation. In: Kehr P, Weidner A, editors. Cervical spine I. Springer: New York; 1987. p. 322.
11. Goel A, Leheri V. Plate and screw fixation for atlanto-axial subluxation. Acta Neurochir. 1994;129:47–53.
12. Harms J, Melcher RP. Posterior C1-C2 fusion with polyaxial screw and rod fixation. Spine. 2001;26:2467–71.
13. Wright NM. Posterior C2 fixation using bilateral, crossing C2 laminar screws: case series and technical note. J Spinal Disord Tech. 2004;17:158–62.
14. Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. J Bone Joint Surg Am. 1974;56:1663–74.
15. Dunn ME, Seljesko EL. Experience in the management of odontoid process injuries: an analysis of 128 cases. Neurosurgery. 1986;18(3):306–10.
16. Traynelis VC. Evidence-based management of type II odontoid fractures. Clin Neurosurg. 1997;44:41–9.
17. Polin RS, Szabot T, Bogaev CV, et al. Nonoperative management of type II and III odontoid fractures: the Philadelphia collar versus the halo vest. Neurosurgery. 1996;38:450–6.
18. Johnson RM, Hart DL, Simmons EF, Ramsby GR, Southwick WO. Cervical ortosis: a study comparing their effectiveness in restricting cervical motion in normal subjects. J Bone Joint Surg. 1977;59-A:332–9.
19. Greene KA, Dickman CA, Marciano FF, et al. Acute axis fracture, analysis of management and outcome in 340 consecutive cases. Spine. 1997;22:1843–52.
20. Lennarson PJ, Mostafavi H, Traynelis VC, et al. Management of type II dens fractures: a case-control study. Spine. 2000;25:1234–7.
21. Papageloupolos PJ, Sapkas GS, Kateros KT, Papadakis SA, Vlamis JA, Falagas ME. Halo pin penetration and epidural abscess in a patient with a previous cranioplasty: case report and review of the literature. Spine. 2001;26(19):E463–7.
22. Triggs KJ, Ballock RT, Lee TQ, Woo SL, Garfin SR. The effect of angled insertion on halo pin fixation. Spine. 1989;14:781–3.
23. Powers J. A multidisciplinary approach to occipital pressure ulcers related to cervical collars. J Nurs Care Qual. 1997;12(1):46–52.
24. Rodgers JA, Rodgers WB. Marginal mandibular nerve palsy due to compression by a cervical hard collar. J Orthop Trauma. 1995;9:177–9.
25. Botte MJ, Byrne TP, Garfin SR. Use of skin incisions in the application of halo skeletal fixator pins. Clin Orthop. 1989;246:100–1.
26. Glaser JA, Whitehill R, Stamp WG, Jane JA. Complications associated with the halo-vest: a review of 245 cases. J Neurosurg. 1986;65:762–9.
27. Hashimoto Y, Doita M, Hasuda K, Korosue K. Intracerebral pneumocephalus and hemiparesis as a complication of a halo vest in a patient with multiple myeloma. Case report. J Neurosurg. 2004;100(4 Suppl Spine):367–71.
28. Saeed MU, Dacuycuy MA, Kennedy DJ. Halo pin insertion associated brain abscess: case report and review of the literature. Spine. 2007;32(8):E271–4.
29. Medhkour A, Massie L, Horn M. Acute subdural hematoma following halo pin tightening in a patient with bilateral vertebral artery dissecation. Neurochirurgie. 2012;58(6):386–90.
30. Sim HB, Lee JW, Park JT, Mindea SA, Lim J, Park J. Biomechanical evaluations of various C1-C2 posterior fixation techniques. Spine. 2011;36(6):E401–7.
31. Du JY, Aichmair A, Kueper J, Wright T, Lebl DR. Biomechanical analysis of screw constructs for atlantoaxial fixation in cadavers: a systematic review and meta-analysis. J Neurosurg Spine. 2015;22(2):151–61.
32. Dickman CA, Sonntag VK, Papadoupolos SM, Hadley MN. The interior spinous method of posterior atlantoaxial arthrodesis. J Neurosurg. 1991;74:190–8.
33. Dickman CA, Sonntag VK. Posterior C1-C2 transarticular screw fixation for atlantoaxial arthrodesis. Neurosurgery. 1998;43:275–80.
34. Moskovich R, Crockard HA. Atalantoaxial arthrodesis using interlaminar clamps. An improved technique. Spine. 1992;17(3):261–7.
35. Jeanneret B, Magerl F. Primary posterior fusion C1/2 in odontoid fractures: indications, technique and results of transarticular screw fixation. J Spinal Disord. 1992;5(4):464–75.
36. Richter M, Schmidt R, Claes L, et al. Posterior atlantoaxial fixation: biomechanical in vitro comparison of six different techniques. Spine. 2002;27:1724–32.
37. Wright NM, Lauryssen C. Vertebral artery injury in C1-2 transarticular screw fixation: results of a survey of the AANS/CNS section on disorders of the spine and periphera nerves. J Neurosurg. 1998;88:634–40.
38. Madawi AA, Casey AT, Solanki GA, et al. Radiological and anatomical evaluation of the atlantoaxial transarticular screw fixation technique. J Neurosurg. 1997;86:961–8.
39. Paramore CG, Dickman CA, Sonntag VK. The anatomical suitability of the C1-2 complex for transarticular screw fixation. J Neurosurg. 1996;85:221–4.
40. Goel A, Desai K, Mazumdar D. Atlantoaxial fixation using plate and screw method: a report of 160 treated patients. Neurosurgery. 2002;51:1351–6.
41. Guo SL, Zhou DB, Yu XG, Yin YH, Qiao GY. Posterior C1-C2 screw and rod instrument for reduction and fixation of basilar invagination with atlantoaxiall dislocation. Eur Spine J. 2014;23(8):1666–72.
42. Elliot 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. 2012;17(6):577–93.
43. Xu R, Bydon M, Macki M, Belkoff SM, Langdale ER, McGovern K, Wolinski K, Gokalsan ZL, Bydon A. Biomechanical impact of C2 pedicle screw length in an atlantoaxial fusion construct. Surg Neurol Int. 2014;5(Suppl 7):S343–6.