REVIEW ARTICLE

C_2 Nerve Dysfunction Associated with C_1 Lateral Mass Screw Fixation

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The C_1 lateral mass screw technique is widely used for atlantoaxial fixation. However, C_2 nerve dysfunction may occur as a complication of this procedure, compromising the quality of life of affected patients. This is a review of the topic of C_2 nerve dysfunction associated with C_1 lateral mass screw fixation and related research developments. The C_2 nerve root is located in the space bordered superiorly by the posterior arch of C_1, inferiorly by the C_2 lamina, anteriorly by the lateral atlantoaxial joint capsule, and posteriorly by the anterior edge of the ligamentum flavum. Some surgeons suggest cutting the C_2 nerve root during C_1 lateral mass screw placement, whereas others prefer to preserve it. The incidence, clinical manifestations, causes, management, and prevention of C_2 nerve dysfunction associated with C_1 lateral mass screw fixation are reviewed. Sacrifice of the C_2 nerve root carries a high risk of postoperative numbness, whereas postoperative nerve dysfunction can occur when it has been preserved. Many surgeons have been working hard on minimizing the risk of postoperative C_2 nerve dysfunction associated with C_1 lateral mass screw fixation.

Key words: C_2 nerve dysfunction; C_1 lateral mass screw; Atlantoaxial fixation; Atlantoaxial instability

Introduction

Posterior atlantoaxial fixation is widely used to treat atlantoaxial instability. C_1 screw fixation, which includes the C_1 lateral mass technique and C_1 pedicle screw techniques, is the main technique used for atlantoaxial fixation[1–4]. The C_1 lateral mass screw technique was first described by Goel and Laheri in 1944[5], and popularized by Harms and Melcher, who reported on it in 2001[6]. In 2002, Resnick and Benzel were the first to report C_1 pedicle screw fixation[7]. And in 2003, Tan *et al*. introduced the C_1 pedicle screw technique[8]. Since then, many studies have demonstrated the superiority of the C_1 pedicle screw technique[1,2,9]. However, there is widespread agreement that the height of the C_1 pedicle is the factor that most limits achievement of successful C_1 pedicle screw fixation[10–12]. When the height is less than 4.0 mm, the pedicle is not able to accommodate the 3.5 mm-diameter screw that is usually used for C_1 fixation[12]. Thus, C_1 pedicle screw fixation is not feasible in 8%–53.8% of patients[8,13–18]. Hence, the C_1 lateral mass screw technique is still widely used. However, C_2 nerve dysfunction may occur as a complication of C_1 lateral mass screw fixation, comprising the quality of life of affected patients[19–23]. In addition, whether to cut the C_2 nerve root during C_1 lateral mass screw fixation is still controversial. We here review the topic of C_2 nerve dysfunction associated with C_1 lateral mass screw fixation and related research developments.

Anatomy

The C_2 nerve root is located in the space bordered superiorly by the posterior arch of C_1, inferiorly by the C_2 lamina, anteriorly by the lateral atlantoaxial joint capsule, and posteriorly by the anterior edge of the ligamentum flavum (Fig. 1). The height of the C_2 ganglion is 4.97 ± 0.92 mm on the right side and 4.60 ± 0.84 mm on the left side. The C_2 ganglion occupies approximately 50% of the height of the space in the neutral position and approximately 65% in hyperextension with rotation positions[24]. A large venous plexus, which can cause bleeding, surrounds the C_2 nerve root in the space. The C_2 nerve root passes inferolateral to the lateral atlantoaxial joint and can be pulled downward during surgical maneuvering[25].

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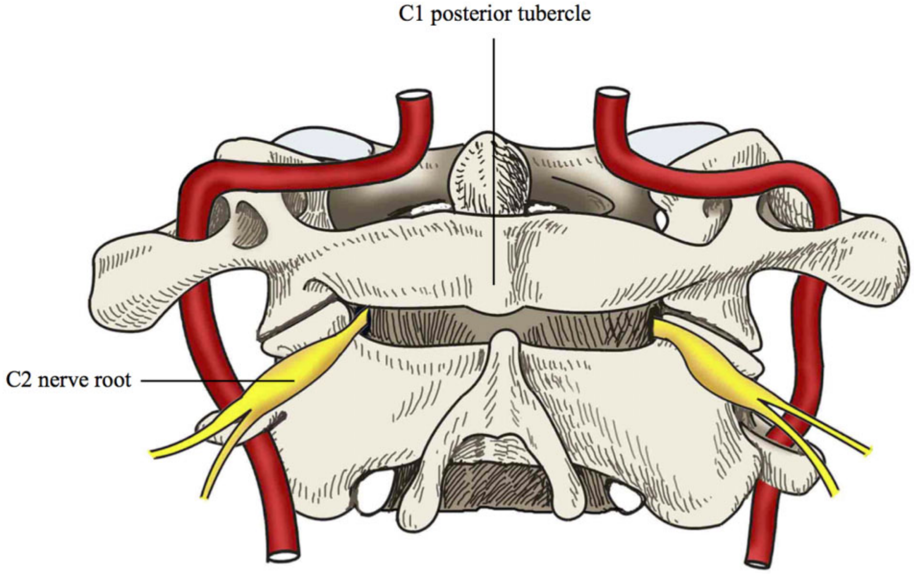

Fig. 1 The C_2 nerve root is located in the space bordered superiorly by the posterior arch of C_1, inferiorly by the C_2 lamina, anteriorly by the lateral atlantoaxial joint capsule, and posteriorly by the anterior edge of the ligamentum flavum.

The dorsal ramus of the C_2 nerve emerges between the C_1 posterior arch and C_2 lamina, below the inferior oblique which it supplies, receives a connection from the C_1 nerve dorsal ramus, and divides in to a large medial and smaller lateral branch. The medial branch, termed the great occipital nerve, ascends between the inferior oblique and semispinalis capitis, pierces the latter and the trapezius near their occipital attachments and is then joined by a filament from the medial branch of the third dorsal ramus. Ascending with the occipital artery, it divides into branches that connect with the lesser occipital nerve and supply the skin of the scalp as far anteriorly as the vertex[26].

Management of the C_2 Nerve Root during C_1 Lateral Mass Screw Placement

Some surgeons suggest cutting the C_2 nerve root during C_1 lateral mass screw placement[27–32], whereas others prefer to preserve it[33–37].

Cutting the C_2 Nerve Root

In their initial study, Goel *et al.* used a screw–plate system for atlantoaxial fixation[38]. To leave enough space for the upper part of the plate, they chose a lower screw entry point than the later Harms technique. Because the screw and plate were placed where the C_2 nerve root and its surrounding venous plexus lie, cutting the C_2 nerve root was unavoidable (Fig. 2).

Subsequently, cutting the C_2 nerve root during C_1 lateral mass screw placement was generally recommended. It was believed that cutting it simplified surgical maneuvering and resulted in less blood loss, shorter operative time and a lower screw malposition rate. Aryan *et al.* reported using a modified Harms technique for atlantoaxial fixation that used a screw–rod system and in which cutting the C_2 nerve root was avoidable; however, they still cut it[27]. In their series, only one of 121 patients developed occipital neuralgia. However, they did not report how many patients had numbness in the region innervated by the C_2 nerve. In their meta-analysis, Elliot *et al.* found that sacrifice of the C_2 nerve root resulted more frequently in postoperative numbness (11.6% vs. 1.3%) but less frequently in neuralgia (0.3% vs. 4.7%), was associated with less blood loss (213 mL vs. 417 mL) and shorter operative time (118 min vs. 132 min) than when the C_2 nerve root was preserved[2]. They concluded that cutting the C_2 nerve root during C_1 lateral mass screw placement resulted in better outcomes,

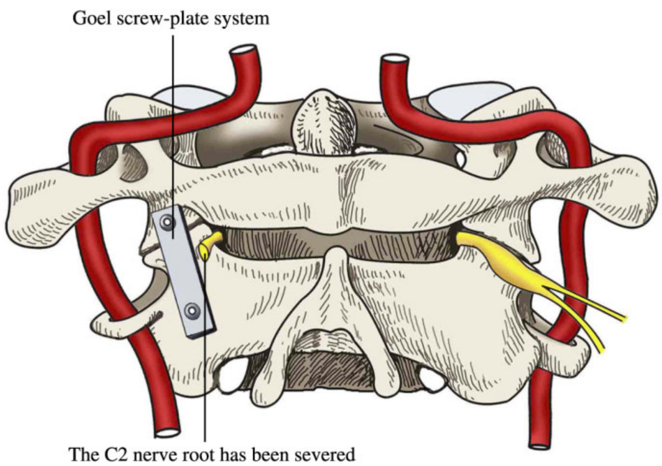

Fig. 2 The Goel technique uses the screw-plate system for atlantoaxial fixation; cutting the C_2 nerve root is unavoidable.

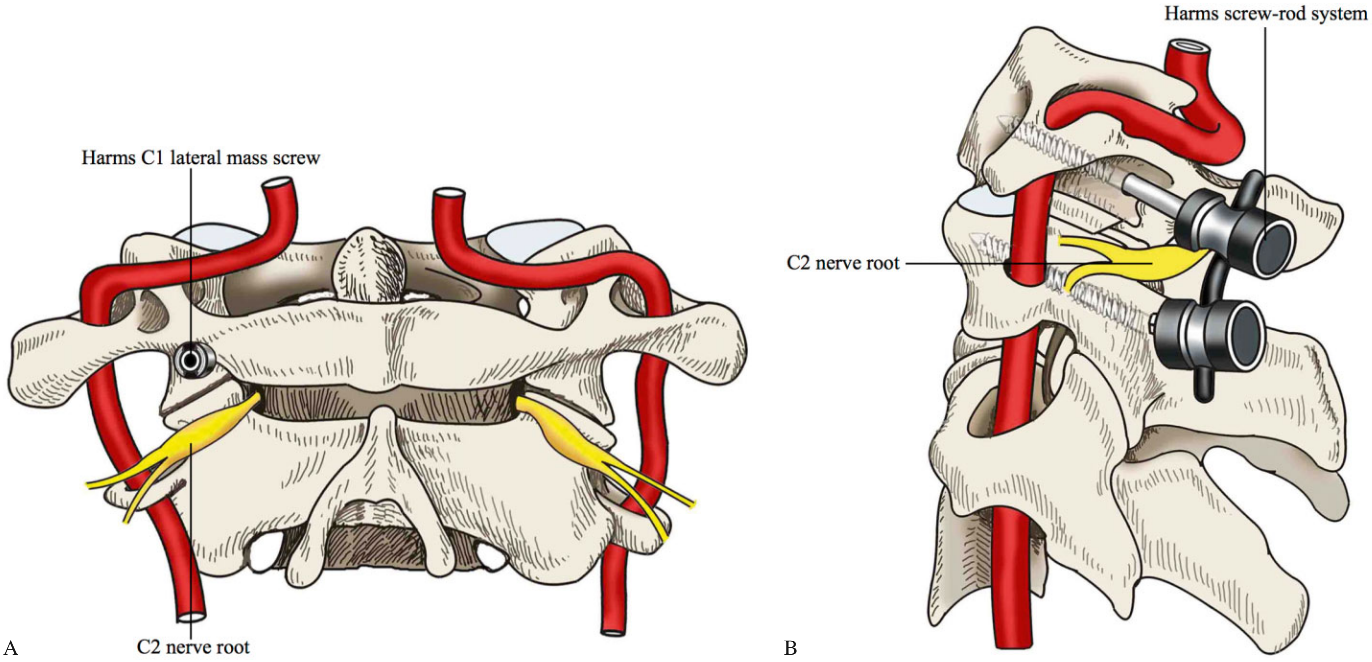

Fig. 3 Harms C_1 lateral mass screw technique (A) A screw–rod system is used, allowing preservation of the C_2 nerve root. (B) The C_2 nerve root passes through the "arch of the viaduct" of the screw–rod system.

even though 11.6% of the patients have postoperative numbness, an outcome that is unacceptable to some patients. Both Squires and Molinari[29] and Hamilton *et al.*[28] reported that, in elderly patients, C_1 lateral mass screw placement with intentional cutting of the C_2 nerve root resulted in satisfactory outcomes, albeit with postoperative numbness. Recently, Patel *et al.* have reported the clinical outcomes of routinely cutting the C_2 nerve root during C_1 lateral mass screw placement in children. None of their 15 cases C_2 developed nerve dysfunction[39].

Preserving the C_2 Nerve Root

If they elect to preserve the C_2 nerve root, surgeons have to face problems such as damage to the C_2 nerve root, severe bleeding from the associated venous plexus and inadequate exposure.

With Harms technique, the entry point for the C_1 screw is the midpoint of the posterior inferior part of the C_1 lateral mass[6]. For atlantoaxial fixation, they use a screw–rod system that looks like a viaduct and allows the C_2 nerve root to pass through the "arch of the viaduct" (Fig. 3). The C_1 screw they use is a partially threaded one: the 8 mm unthreaded portion of the screw stays above the bony surface of the lateral mass, minimizing the risk of irritation to the C_2 nerve root. Since then, many authors have reported their own modified C_1 screw entry points[8,11,13,40]. Modifications that heighten the screw entry point minimize the risk of damage to the C_2 nerve root. With these modifications of the original technique, more and more surgeons are tending to preserve the C_2 nerve root during C_1 lateral mass screw fixation.

C_2 Nerve Dysfunction Associated with C_1 Lateral Mass Screw Fixation

Incidence

The incidence of C_2 nerve dysfunction after atlantoaxial fixation is not clear, reported rates ranging from 0–33%[1,6,38,40]. Goel *et al.* cut the C_2 nerve root during C_1 screw placement; 18/160 patients in their study reported postoperative sensory loss in the distribution of the C_2 nerve[38]. They did not specifically ask about postoperative numbness in the distribution of the C_2 nerve during follow-up. It is possible that patients were so satisfied with their limb function that they ignored anesthesia in the occipital scalp. Thus, the incidence of postoperative C_2 nerve dysfunction is likely greater than the reported incidence. In Harms and Melcher's study, no C_2 nerve dysfunction was reported in a cohort of 37 patients[6]. It may make more sense to discuss the incidence according to the specific circumstances. Elliott *et al.*'s meta-analysis showed that 11.6% of patients in whom the C_2 nerve root has been sacrificed experience postoperative C_2 numbness, whereas only 0.3% experience C_2 neuralgia. However, 4.7% of patients who have undergone C_1 screw placement with preservation of the C_2 nerve root experience postoperative C_2 neuralgia and 1.3% experience C_2 numbness[2].

Clinical Manifestations

The clinical manifestations of C_2 nerve dysfunction are sensory changes in the distribution of the C_2 nerve, including neuralgia, numbness, dysesthesia and paresthesia[1,2,20,27,30,38]. In addition, some patients report indescribable discomfort in the occipital region[28,30].

Causes of Injury to the C_2 Nerve Root

The mechanism of C_2 nerve dysfunction associated with C_1 lateral mass screw fixation is poorly understood[23]. However, possible causes are as follows: (i) transection of the C_2 nerve root; however, the effects of this are unclear[41]; (ii) excessive caudal retraction during exposure of the C_1 lateral mass screw entry point[22]; (iii) damage to the C_2 nerve root during management of bleeding from the associated venous plexus[1]; (iv) reduction of C_1 onto C_2[21,22]; and (v) impingement or irritation from the C_1 lateral mass screw[6,20,23].

Management and Prognosis

There are currently no clear guidelines for the management of C_2 nerve dysfunction associated with C_1 lateral mass screw fixation. Medication is often used[1,20–22]. If the symptoms are severe and do not respond satisfactorily to medication, repeated C_2 ganglion blocks can be tried[21]. In cases with severe or persisting symptoms, some authors recommend extraction of the screw[19,23], which can achieve good results[23], but sometimes fails to do so[22].

Symptoms of C_2 nerve dysfunction often subside spontaneously[19]; however, in some cases medication, C_2 ganglion block, or even screw extraction are needed[21,23]. Of note, even after removal of the instrumentation, the pain still persists in some cases[22].

Prevention

Sacrifice of the C_2 nerve root carries a high risk of postoperative numbness, whereas postoperative nerve dysfunction can occur when it has been preserved. Many surgeons have been working hard on minimizing the risk of postoperative C_2 nerve dysfunction associated with C_1 lateral mass screw fixation.

Gunnarsson *et al*. used partially threaded C_1 screws with smooth shanks to reduce irritation to the C_2 nerve root; however, 3/25 patients still reported postoperative C_2 neuralgia in their case series[20].

In their case report, Rhee *et al*. provided several tips on how to prevent this complication. First, avoid intraoperative hyperextension of the neck[21]. Second, place the head of the C_1 screw sufficiently dorsally to leave enough space in the foraminal area for the C_2 nerve root. Third, use partially threaded C_1 screws with smooth shanks to minimize the chance of irritation to the C_2 nerve root. Fourth, if the surrounding tissue looks tense around the C_1 screw, perform additional mobilization of the C_2 nerve root. Fifth, use a higher entry point and insert the C_1 lateral mass screw via the posterior arch if it can accommodate it. Finally, carefully place fusion materials on the C_1–C_2 posterior arches.

Pan *et al*. reported using a 3–5 mm diameter bone wax column to protect both the venous sinus and the C_2 nerve root during surgical maneuvering[1]. In their study, none of the 22 patients who underwent C_1 lateral mass screw placement with this modified technique developed postoperative numbness, whereas 4/12 patients who underwent screw placement with Harms technique reported postoperative C_2 nerve dysfunction.

In 2013, Lee *et al*. reported a modification of C_1 lateral mass screw insertion, which is also called the notching technique, designed to avoid postoperative C_2 nerve dysfunction[11]. They insert the C_1 screw at the junction of the C_1 posterior arch and the midpoint of the posterior inferior portion of the C_1 lateral mass with a notch at the entry point to facilitate screw insertion. The notch allows the screw to be placed farther away from the C_2 ganglion than with the Harms technique and provides a screw trajectory that is less cranially tilted. Only 1/12 cases had mild postoperative unilateral C_2 neuralgia, which had resolved 6 weeks after surgery.

Recently, Huang *et al*. proposed a preoperative measure, the height for screw index, as a predictor of C_2 nerve dysfunction in patients who undergo C_1 lateral mass screw fixation[3]. The height for screw index is defined as the difference in height between C_2 ganglion and its corresponding foramen and is measured on CT images. This is the first detailed preoperative evaluation designed to prevent C_2 nerve dysfunction; however, this evaluation is not feasible in approximately 46% of patients because of failure to distinguish the C_2 ganglion on CT images. Another recent study by Huang *et al*. showed that if there is a medullary canal in the C_1 pedicle, it is possible to finish C_1 pedicle screw fixation in the atlas, the pedicle height of which is less than 4 mm; this finding has changed the traditional view that C_1 pedicle fixation can be performed only when the C_1 pedicle is more than 4 mm high[4]. In these patients, C_1 pedicle fixation rather than C_1 lateral mass screw fixation can be performed to avoid postoperative C_2 nerve dysfunction.

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