Management of acute odontoid fractures: operative techniques and complication avoidance

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In this article the authors describe the management of Type II odontoid fractures with special attention to operative technique and avoidance of complication. Anterior odontoid screw fixation is a procedure the authors have performed over the last 8 years in cases with acute Type II and rostral Type III odontoid fractures. In cases of Chronic Type II odontoid fractures and in patients with transverse ligament disruption, the authors prefer to undertake posterior transarticular facet screw fixation supplemented by bone graft and interspinous C1–2 wiring.

The technical aspects of these procedures are described with a focus on operative nuances. Selection criteria and techniques that the authors have refined over the years have helped them to optimize success rates and minimize complications.

KEY WORDS • odontoid fracture • cervical spine injury • screw fixation

The management of Type II odontoid fractures has evolved dramatically over the last 15 years. Earlier therapies in which rigid external cervical immobilization was used have given way to newer, more direct approaches of addressing the stabilization of fractures. Although earlier in the 1990s mixed results were reported regarding the efficacy of both anterior and posterior approaches to stabilization of this type of fracture, the authors of more recent studies have demonstrated that Type II fractures are best treated via an anterior approach, although some exceptions exist.^{1,5,23,27,35,45,55} These exceptions include chronic fractures and disruption of the transverse ligament,^{35,45,55} and in these cases a posterior approach is required.

In this report we describe the selection criteria, indications and contraindications, and technical nuances of managing patients with Type II odontoid fractures. We review our 8-year experience with the techniques of anterior odontoid screw fixation and C1–2 transarticular screw fixation.

PATIENT SELECTION: ANTERIOR OR POSTERIOR?

Appropriate patient selection is extremely important to minimize morbidity and to maximize fusion rates. The nonsurgical management of Type II odontoid fractures with either rigid collar immobilization or halo fixation

may be reserved only for application in patients who cannot tolerate general anesthesia or who have sustained other severe concurrent injuries prohibiting surgical intervention. It is our opinion that immediate rigid internal fixation of unstable Type II odontoid fractures may be the most conservative approach to patient care. This belief stems from the relatively short induction period of anesthesia, minimal patient discomfort associated with anterior odontoid fixation, and the relatively poor results observed when prescribing external immobilization alone.

A complete neuroimaging evaluation including CT and magnetic resonance imaging must be thoroughly assessed prior to choosing a surgical approach. Patients selected as candidates for anterior odontoid screw fixation are limited to those with acute Type II fractures in which the transverse ligament is intact. Another prerequisite for the anterior approach is the capacity of the fracture to be reduced into alignment to allow for adequate screw placement as well as a fracture line that is amenable to screw fixation. (Fig. 1A and B) In our experience, there is a higher nonunion rate in cases of chronic fractures, and therefore, we do not consider these patients to be candidates for anterior screw fixation.⁵⁵

Body habitus can also affect the feasibility of anterior screw fixation. Short-necked obese patients—with increased AP chest diameter as seen in those with chronic obstructive pulmonary disease and pulmonary emphysema (barrel chest)—present a challenge to the anterior procedure: the appropriate screw trajectory along the long axis of cervical spine for placement of screws can be difficult or impossible. A significant portion of these patients

Abbreviations used in this paper: AP = anteroposterior; CT = computerized tomography.

Fig. 1. Reconstructed CT studies. *Left:* Sagittal scan demonstrating a Type II odontoid fracture with anterolisthesis of approximately 3 mm. This fracture was easily reduced with gentle extension and posterior translation under fluoroscopic guidance. *Right:* Coronal scan demonstrating a horizontal fracture line well suited for anterior single-screw fixation.

will require alternative posterior fusion techniques in lieu of an anterior approach.

Radiographic evidence demonstrating longitudinal or oblique fractures of the dens are relative contraindications for an anterior single-screw fixation procedure. Oblique fractures slanting ventral to dorsal in a caudal-rostral direction can make the lagging effect of the screw more difficult to align the fracture. Thus, there are some patients with oblique fractures for whom anterior screw fixation is not suitable. Similarly, severe irreducible fracture retro-listhesis is a contraindication to anterior screw fixation. Patients with significant anterolisthesis, however, are not necessarily excluded because the majority of their fractures can be reduced with intraoperative manipulation under fluoroscopy.

SURGICAL TECHNIQUES

Single-Screw Anterior Odontoid Screw Fixation

We prefer to use a cannulated technique for anterior screw fixation.^{6,19,35,55} After fiberoptic intubation with inline stabilization, the lateral C-arm fluoroscope is brought into position and canted under the operating table (Fig. 2). Under fluoroscopic guidance, the patient is placed in the supine position with the neck extended. All attempts are made to minimize displacement of the odontoid to facilitate the ideal trajectory for screw placement into the apex of the odontoid process. A radiolucent mouth gag is used to keep the mouth open to provide a transoral AP view. Because biplanar C-arm fluoroscopy is required to perform this procedure, the second unit is put into the AP position to obtain simultaneous projections prior to preparation of the patient.

A small, transverse midcervical skin incision is made over the level of the cricothyroid junction (the C5–6 interspace). Similar to a standard Cloward-type approach¹⁷ performed for anterior cervical discectomy, blunt dissection is performed down within the avascular plane to the prevertebral area and then extended cephalad to the C2–3 disc space. The trachea and esophagus are retracted medially, and the sternocleidomastoid muscle and the carotid

sheath are mobilized laterally by using a Cloward hand-held retractor. The prevertebral fascia is bluntly dissected from the vertebral bodies of the midcervical spine by using a Kittner dissector. The dissection is then performed cephalad on the midline under fluoroscopic guidance to reach the C2–3 interspace. The hand-held retractors are then replaced by sharp-toothed, transverse self-retaining retractor blades, which are placed at C5–6 to obtain adequate exposure. The C2–3 interspace level is verified using the lateral C-arm fluoroscopic view. The acutely angled superior retractor blade is then placed in the sub-mandibular area and anchored to the lateral retractor system to provide rostral exposure. We have found the Apfelbaum retractor system (Aesculap, San Francisco, CA) to be most suitable for this purpose. In this way, an adequate working channel to the C2–3 interspace is created.

For screw placement we prefer the Universal Cannulated Screw System (Medtronic Sofamor Danek, Memphis,

Fig. 2. Photograph of operating room showing the patient in the supine position prior to anterior odontoid fixation. Note that the lateral C-arm fluoroscope is canted under the table to allow for the second AP C-arm fluoroscope to be well positioned.

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TN). Using biplanar fluoroscopy, a 2-mm threaded K-wire is anchored into the midline of the anteroinferior edge of C-2. By applying a prying motion with the K-wire anchored into C-2 and levered on C-3 in the dorsal-to-ventral direction, the C-2 body is rocked slightly anteriorly, allowing for adequate trajectory to traverse the fracture line and incorporate the superior fragment.

After the drill guide and K-wire are anchored and the trajectory is deemed adequate, the K-wire is then drilled through the fracture line into the distal portion of the fractured dens. The K-wire should be drilled approximately 1 mm beyond the distal odontoid fragment to incorporate the outer cortex. The inner guide tube is then removed, and the K-wire is left in place. A pilot hole is then drilled into the C-2 body with the cannulated drill bit sliding over the K-wire across the fracture line and into the apical cortical surface of odontoid process.

Before the fracture line is crossed, additional head manipulation can be attempted to realign better the odontoid fracture prior to screw placement. Once the pilot hole is made, the depth of penetration of the drill can be determined by reading the markers on the drill bit or K-wire shaft. The drill is then withdrawn, and the drill hole is tapped over the K-wire to cut threads in the interface. A 4-mm nonself-tapping, partially threaded titanium cannulated lag screw is then gradually inserted through the guide tube over the K-wire, under direct fluoroscopic view, and countersunk 2 mm into the C-2 vertebral body. The tip of the screw should barely penetrate the apical cortex of the odontoid process, and it should be just adequately tightened to engage the distal odontoid fragment (Fig. 3). It is important to choose a slightly shorter screw length than is measured by approximately 2 mm because the lag effect derives only from final tightening of the screw to increase compression and to approximate the fracture line. The neck is manually flexed and extended, and alignment and screw placement are verified on biplanar fluoroscopy.

Fig. 3. Lateral fluoroscopic C-arm view of final position of single-screw placement engaging the superior cortex of the odontoid tip.

Posterior C1–2 Transarticular Screw Fixation With Supplemental Tension-Band Fixation

The patient is positioned prone in a rigid three-point pin fixation system. The neck should be slightly flexed in a “military tuck” position, creating posterior translation and reduction, as well as allowing the surgeons to achieve the desired C1–2 trajectory for the instruments. Lateral C-arm fluoroscopy is used to assess planned screw trajectory prior to preparation. The entire posterior cervical region down to the mid-thoracic area is prepared and draped. After a midline incision is made to expose the posterior elements of C1–3, careful attention is directed toward exposure of the C2–3 facet joints. The C-2 pars is exposed and palpated with a Penfield No. 4 dissector, which is used to dissect the C-2 nerve root with gentle sweeping movements in a rostral direction to expose the medial pars. The roof of the C-2 pars is carefully followed into the C1–2 facet joint. After obtaining this rostral dissection, the No. 4 Penfield dissector is directed medially to palpate the medial border of the C-2 pars. This maneuver allows the surgeon to assess the pedicle angulation and screw direction. Venous bleeding can be minimized by centering the dissection on the medial aspect of the pars. Careful dissection and bipolar coagulation of the medial venous complex can also minimize bleeding. Any venous bleeding that is difficult to manage is tamponaded with Gelfoam (Pharmacia Upjohn, Berwyn, PA).

For the drill guide a percutaneous entrance is typically required to achieve the desired trajectory for screw placement. To choose the optimum entry point a long instrument is placed adjacent to the neck, outside of the wound, paralleling the ideal trajectory. This allows the surgeon to judge proper visual alignment of the drill and screw across the C1–2 facet joint with fluoroscopic imaging, and it also demonstrates the optimum entry point for the drill guide through the skin, which is typically two finger-breadths paramedian to the T-1 spinous process. Bilateral stab incisions are made at the paramedian entrance site of the drill guide.

The guide tube is then passed through the stab incision and directed toward the exposed C2–3 facet joint into the open operative site. The tip of the guide tube is docked at the C-2 entry site.

Reduction of C1–2 space must be accomplished prior to drilling the K-wire. In patients with significant subluxation a cable is placed beneath C-1, and the posterior arch is pulled up. Application of manual pressure on the C-2 spinous process can improve alignment. This technique can be used temporarily until the first K-wire is drilled into position, and then the tension can be released. Once the K-wire is placed, often the reduction will remain in place. Alternatively, the interspinous tension band construct can be fixated first to achieve reduction of the fracture prior to undertaking transarticular screw fixation. If the tension band construct is placed prior to implanting the transarticular screws to improve alignment, we recommend only provisional clamping of the cable because the construct can sometime loosen after transarticular screw fixation. After alignment is achieved and the transarticular screws are in place, the posterior tension band then can be permanently tightened.

The inferomedial edge of the C2–3 facet joint is identi-

fied, and the C-2 entry site is marked approximately 3 to 4 mm rostral and 3 to 4 mm lateral to this point (that is, from the inferomedial facet joint, up 3 mm and out 3 mm). Using a high-speed drill and mini-match stick bit, the cortical bone is pierced to mark the K-wire entry site. The K-wire trajectory is visualized on lateral fluoroscopy. Drill angles typically vary from 5 to 15° medial in the sagittal plane. The K-wire is drilled into the C-2 pars and across the C1–2 joint, aimed at the anterior tubercle of C-1. The ideal K-wire tip terminus is a point 3 to 4 mm dorsal to the tip of the anterior C-1 tubercle, barely penetrating the cortical bone of the C-1 lateral mass.

Using a Penfield No. 4 dissector, the articular surfaces of the C1–2 facet joint and the dorsal cortex of the C-1 lateral mass are palpated. Often the K-wire can be visualized as it traverses the C1–2 facet joint. While drilling the K-wire, the surgeon can perceive subtle changes in resistance as the wire traverses the cortical surfaces along its pathway into the C-1 lateral mass. The surfaces include the superior articular surface of C-2, the inferior articular surface of C-1, and the anterior cortex of the C-1 ring. Intermittent pulses with the drill, rather than continuous drilling, will give the surgeon better proprioceptive feedback and control as the K-wire is passed through the C1–2 facet joint. Once the K-wire is drilled into position, a cannulated drill bit is then placed over the K-wire and drilled to the depth of the K-wire fixation point. An assistant holds the K-wire with a needle driver as the drill bit is advanced under fluoroscopic guidance to prevent advancement of the K-wire.

The pilot hole is then tapped over the K-wire into the lateral mass of C-1. A fully threaded 3.5- or 4-mm cortical screw of premeasured length is used. We prefer 4-mm screws, if possible, and attempt to place this sized screw on all of our patients in whom preoperative Stealth scan (Medtronic Sofamor Danek) measurements have been obtained. Screw length can be measured directly from the drill or K-wire inserted under C-arm fluoroscopic control, or it can be premeasured. Screws are typically 38 to 42 mm in length. The technique is repeated on the contralat-

eral side if anatomy permits. It is important to use nonlag screws when performing transarticular screw fixation because the screw functions more as a nail-stabilizing rotation than as a compressive force. Lag screws are not necessary for this construct because the goal of the screws is to prevent rotation at the facet joints. The screws in no way need to lag the facet joints together. In addition fully threaded screws have more surface area and, thus, more screw–bone interface than partially threaded lag screws. Therefore, fully threaded cortical screws increase the rigidity of the total construct compared with lag screws. Data obtained from laboratory investigations have shown equal efficacy and strength of cannulated and noncannulated screws of similar diameter (Dickman, personal communication).

In all cases of transarticular screw fixation we use supplemental posterior tension-band constructs by performing the Sonntag modification of the Gallie-type fusion with Atlas titanium cables (Medtronic Sofamor Danek). This technique provides added stability, particularly in flexion and extension, without the potential morbidity associated with passing sublaminar wires under C-2. We have also used a posterior clamp fixation system (Apofix, Medtronic Sofamor Danek) for tension-band constructs, which has yielded excellent results (Fig. 4). Decortication of the inferior C-1 ring prior to final placement of the graft is critical, as it has been our experience that this region is the region in which a pseudarthrosis will most commonly occur. The graft for the posterior construct is harvested more laterally along the posterior iliac crest, approximately five finger-breadths lateral to the posterosuperior iliac spine. In this region the pelvis takes on an anatomical configuration more suited for the anatomy of the C1–2 region. The curve of this portion of the ilium matches that of the C1–2 interspace. Although the incision necessary for harvesting a more lateral graft (five finger-breadths off of the midline) is slightly more lateral than the standard incision, it is important to stay within 8 cm medial to the postero-inferior iliac crest to avoid injury to the cluneal nerves. A tricortical autologous iliac crest graft is harvested, and the

Fig. 4. Postoperative radiographic studies. *Left:* Lateral cervical spine x-ray film obtained in a patient 2 years after undergoing C1–2 transarticular screw fixation and posterior tension banding with Apofix for treatment of an odontoid fracture with transverse ligament disruption. Note the solid arthrodesis with confluent bone incorporating the posterior graft, as well as the engaged superior cortex of the C-1 lateral mass. *Right:* Cervical spine x-ray film (AP view) obtained in the same patient, demonstrating optimum screw position.

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superior cortex is removed using an oscillating saw. The remaining curved rectangular bicortical graft is placed with medullary bone interfacing both the decorticated inferior surface of C-1 and the decorticated superior surface of C-2.

Postoperative Management

Postoperative management is similar for patients who have undergone either an anterior odontoid screw fixation or a transarticular screw fixation procedure. The patients are monitored closely for neurological and respiratory changes in the recovery room and are then transferred to the ward. Almost all patients are discharged from the hospital within the first few days of surgery regardless of which surgical approach was undertaken.

Patients in whom either of these procedures are performed undergo rigid cervical collar for 12 weeks postoperatively. Outpatient follow up is typically conducted at 6, 12, and 24 weeks as well as at 1 and 2 years postoperatively. Clinical assessment of functional status and postoperative flexion–extension radiographic evaluation are performed during these sessions. We also obtain CT scans with sagittal reconstructions if the adequacy of fusion can not be determined on plain x-ray films.

DISCUSSION

Anterior Technique

Anterior odontoid screw fixation was first reported by Nakanishi⁴² and Bohler.⁹ Since the publication of early reports, multiple authors^{1,5,9,11,19,23,26,33–35,55} have achieved successful outcomes by undertaking this procedure in patients with acute Type II and rostral Type III odontoid fractures. Anterior screw fixation provides immediate spinal stability; preserves normal rotation at C1–2 and is associated with a high fusion rate without requiring the patient to undergo halo immobilization postoperatively; allows the best anatomical and functional outcome for Type II odontoid fractures; and is associated with rapid patient mobilization, minimal postoperative pain, and shorter hospital stays.

However, the anterior approach for direct odontoid process screw fixation has limitations. The high cervical exposure and soft-tissue retraction create anatomical limitations, as does the inability to add graft material to enhance fusion stability. Patients with short necks and barrel-shaped chests may not be surgical candidates for the anterior approach because their anatomy causes the screw trajectories to be inadequate. The transverse ligament must be intact, and the fracture line should be in a horizontal plane. Moreover, this anterior technique should only be performed if adequate alignment can be restored before screw insertion; otherwise, alternative surgical options should be considered.

In the anterior screw fixation procedure, one or multiple screws may be used. The authors of early studies^{1,5,6,10,26,37,46,47} have emphasized the concept of multiple points in fracture fixation and advocated use of two screws whenever possible. Theoretically, two-screw fixation should augment the structural strength of the fusion and prevent rotation of odontoid on the body of C-2. The results of biomechanical studies performed in cadaveric models by

Sasso, et al.,^{47,48} have suggested that the addition of a second screw failed to demonstrate a significant increase in load-bearing capacity compared with a single screw. Moreover, in more recent studies investigators have concluded that no significant difference in fusion rates is associated with a single-screw technique.^{11,14,27,34} Comparing the torsion and bending strength, Graziano, et al.,²⁷ were unable to determine a difference between the one- and two-screw techniques compared with conventional C1–2 posterior wiring techniques. Jenkins, et al.,³⁴ found no difference in fusion rate in the patients treated with single or two odontoid screws. Because the second screw provides no obvious biomechanical advantage, we recommend use of only a single screw.

Similarly, different types of screws are available, including cortical and cancellous bone screws; self-tapping and nonself-tapping screws; lag screws or cannulated screws; and fully or partially threaded screws. Among them, partially threaded lag screws are commonly used to fixate the odontoid fracture. Lag compression is an important concept in odontoid fixation to anneal the fracture line under compressive force. This effect not only provides rigid fixation but also couples the fractured fragments to promote fusion. We believe that cannulated screw systems are better suited for the precise placement of screws. If the trajectory drilled by double-threaded K-wire is not satisfactory, it can be readjusted easily without weakening the screw purchase site. Nonself-tapping screws can be removed and reinserted without a high risk of creating a new screw tract. Although not proven biomechanically,^{36,51} they are supposed to provide a slightly stronger screw purchase in bone compared with that afforded by self-tapping screws, at least in theory.

The screws may be constructed of stainless steel and titanium or its alloy. Titanium has 90% of the strength of steel and is magnetic resonance imaging compatible, allowing postoperative neuroimaging studies of the spine and its contents. We prefer to use a single 4-mm nonself-tapping, partially threaded titanium cannulated lag screw for the anterior odontoid screw fixation procedure.

Management of Other Odontoid Fractures

Most neurosurgeons agree that Type I and Type III odontoid fractures can be successfully managed with conservative therapy alone.^{3,4,29} However, in the management of Type II odontoid fractures, the long-enduring controversy still exists: should one select conservative management with halo immobilization alone or surgical reduction, fixation, and fusion via anterior or posterior approach? This has led some authors to recommend that patients with Type II odontoid fractures be treated initially by trial of halo immobilization,^{2,8,10,38,43,47,53,54,56} whereas others have recommended early surgical stabilization, either in all patients^{32,40,49,50,58} or in only highly selected cases.^{7,15,18,21,22,24,31,44} As a rule, we prefer to manage cases of acute odontoid Type II and some rostral Type III fractures by performing odontoid screw fixation unless the patient cannot tolerate general anesthesia or other concomitant injuries preclude surgery.

Conservative management of Type II fractures with halo immobilization alone is associated with an unacceptable fusion rate compared with newer stabilization tech-

niques. Fractures in young and old patients are even less likely to fuse when immobilized with halo fixation alone.

Factors Affecting Nonunion

A review of the literature has demonstrated multiple factors influencing nonunion of Type II odontoid fractures treated with halo immobilization alone; these include patient age, extent of neurological damage, degree of dens displacement, presence of concomitant C1–2 fracture, preexisting pathological condition and age of fracture.^{16,29} Schatzker, et al.,⁵⁰ and Apuzzo, et al.,⁷ have reported that odontoid fractures with 4 mm or more of anterior subluxation are associated with high incidence of nonunion and require surgical stabilization. Apuzzo, et al., also stated that in patients older than 40 years of age with displaced fractures there is almost an 80% rate of nonunion.

Dunn, and Seljeskog²¹ have reported that in patients older than age 65 years and in those with retrolisthesis there is a high incidence (70–78%) of nonunion when external immobilization is applied. Hadley, et al.,³¹ concluded that, in the conservative management of patients with odontoid fractures the most important factor influencing the union of a fracture was the degree of odontoid displacement. When the displacement was 6 mm or greater in any direction, the nonunion rate was 67% compared with 26% in cases in which displacement was fewer than 6 mm. They also described a subtype IIA with comminuted fracture fragments at the odontoid base and considered it to be remarkably unstable.³⁰ We favor early surgical management in acute cases of Type II odontoid fracture in which there is 6 mm or more of dens displacement. Exceptions are those patients with chronic pathological conditions and anatomical limitation due to short-neck or barrel-chest status. In such cases, alternative surgical options, namely posterior facet screw fixation via transarticular approach, should be selected.

Posterior Approaches

Posterior C1–2 fusion is the approach used for stabilization of Type II odontoid fractures that are not amenable to anterior single-screw fixation. Commonly used techniques involve wedging a bone graft between posterior arches of C-1 and C-2 with sublaminar wiring. The Gallie,²⁵ Brooks,¹² and Sonntag²⁰ approaches have been well-described and are used for C1–2 posterior fusion. The rates of successful fusion have been satisfactory.

The use of posterior C1–2 transarticular screw fixation in which surgeons place unilateral or bilateral screws has been well described.^{19,28,33,39,52} The posterior transarticular approach is an excellent alternative technique, providing excellent rotational spinal stability. This procedure is an indirect method of stabilizing the fracture in which the normal anatomical configuration is disrupted. Damage to the posterior spinal elements may cause more postoperative pain. A precise screw trajectory and preoperative CT evaluation are essential to avoid vascular injury. This procedure can be supplemented with metal plate for occipito-cervical stabilization.^{28,57}

Based on analysis of the combined data obtained from 19 previously published series, the mean reported fusion rate for acute odontoid fracture treated with anterior odontoid screw fixation was 96% (range 75–100%) with an

overall mean rate of complications of 9.5% and no surgery-related deaths. This overall rate is in accordance with results obtained in our published series.⁵⁵

Likewise, Pointillart, et al.,⁴⁵ have also reported a high fusion rate of 95% in cases in which anterior screw fixation was performed. The rates of pseudarthrosis in nonoperatively treated patients who underwent halo immobilization alone, in patients who underwent posterior C1–2 fusion, and in those who underwent anterior screw fixation were 23%, 20%, and 5%, respectively.

CONCLUSIONS

Cases of Type II odontoid fractures can present difficult management issues. Careful attention to the age of fracture (we consider acute fracture to be less than 4 weeks postinjury), patient's body habitus, and position and type of fracture will help the surgeon in choosing the procedure best suited for the patient to maximize fusion rates.

Single-screw anterior odontoid screw fixation has been proven to be an effective and safe procedure in managing patients with acute Type II and some rostral Type III odontoid fractures. This procedure is particularly useful in elderly patients, providing early mobilization and minimizing morbidity. Alternatively, posterior transarticular screw fixation offers excellent fusion rates in patients with Type II odontoid fractures not amenable to anterior fixation.

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