Atlantoaxial Fixation for Odontoid Fracture: Analysis of 124 Surgically Treated Cases

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■ OBJECTIVE: **The authors analyze 124 cases with fracture of odontoid process. All patients were surgically treated by posterior atlantoaxial fixation.**

■ METHODS: **There were 96 male and 28 female patients. The ages of the patients ranged from 12 to 80 years. Apart from Anderson and D'Alonzo type I (6 cases), type II (93 cases) and type III (25 cases), three sub-types of odontoid fractures were included in the classification. In type A (118 cases), there was vertical compression fracture that resulted in malalignment of the fractured odontoid process segments. Type B (49 cases) resulted when the fracture resulted in malalignment of the facets of atlas and axis. Type C (25 cases) included cases in which the fracture line involved the facet of axis. Fractures were divided into acute type when the injury was less than 3 months old (50 cases), delayed type when the injury was between 3 months to one year (34 cases) and chronic type when the injury was more than 1 year in duration (40 cases). All patients were treated with posterior atlantoaxial fixation with the techniques described in 1994 and 2004. Follow-up period ranged from 6 to 156 months (average 72 months).**

■ RESULTS: **All patients improved in symptoms after surgery. There were no significant postoperative complications.**

■ CONCLUSIONS: **Posterior atlantoaxial stabilization forms a safe surgical strategy for all kinds of odontoid fractures. Additional characteristics of odontoid fractures further subclassified them and assisted in surgical decision-making and in formulating the surgical strategy.**

INTRODUCTION

Odontoid fractures are relatively common. Trauma and osteoporosis of bones have been singly and jointly incriminated to be major issues that result in odontoid process fractures. Severe trauma in younger patients and relatively minor injury in older patients is generally associated with odontoid fractures. Anderson and D'Alonzo described a classification system for odontoid fractures that is widely followed and that forms the basis of consideration of surgical treatment.[1,2] Several anterior and posterior approaches have been described for surgical treatment of odontoid fractures.[3-6] We discuss our surgical strategy in this article. Clinical or radiologic evidence of manifest or potential atlantoaxial instability formed the indication of posterior atlantoaxial fixation.

MATERIAL AND METHODS

During the period January 2002 to September 2016, 124 patients having posttraumatic fracture of the odontoid process with or without the association of fracture of the adjoining vertebral body were treated surgically. Two patients were treated earlier with an anterior odontoid screw fixation technique that was not successful. There were 96 male and 28 female patients in the series. Table 1 summarizes the nature of trauma. The trauma was considered "significant" in 109 patients. Cases in which conservative or nonsurgical treatment was done have not been included in the discussion, as clinical, radiologic, and follow-up details were not available for review. Also excluded are cases in which the patients required ventilator-assisted breathing before surgery because of the absence of spontaneous breathing efforts. All these patients could never regain normal respiration and subsequently died. Patients with fractures elsewhere in the cervical spine in general and C2 vertebra in particular were excluded when there was no definite evidence of fracture in the vicinity of the

Key words
- Atlantoaxial instability
- Cervical trauma
- Odontoid fracture

Abbreviations and Acronyms
ASIA: American Spinal Injury Association
MRI: Magnetic resonance imaging

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Table 1. Nature of Injury

Type of Injury	Number of Patients
Fall from height	48
Vehicular/Railway accident	59
Trivial fall	15
Hit by Bull	2

odontoid process. Patients with any kind of tumor, infection, or systemic disorder that could lead to pathologic fracture of the odontoid process were also excluded from the analysis. There were no patients in the study with mental impairment or a history of drug or substance abuse.

Table 2 summarizes the clinical symptoms at the time of presentation. Table 3 shows the ages of the patients. The neurologic status was assessed and interpreted by screening the hospital records, and the clinical condition was quantified as per a 5-point classification described earlier[7] and the American Spinal Injury Association (ASIA) scoring scale[8] (Tables 4 and 5). All patients were evaluated before surgery with computed tomography (CT) and plain radiographs with the head in a neutral position and in flexion and extension position wherever possible. Preoperative magnetic resonance imaging (MRI) was done in 95 cases. After 2008, all patients underwent both CT and MRI examinations. Postoperative evaluation was done with plain radiologic and CT scan examinations.

RESULTS

The cases were divided in to 3 types as per the classification described by Anderson and D'Alonzo.[1,2] Type I included 6 cases in which the fracture involved the substance or body of the odontoid process (Figures 1—3). In type II (93 cases), the fracture line extended along the base or neck of the odontoid process (Figures 4—6). Type II fractures were further subclassified into three types as has been discussed by Grauer et al.[9]: type IIa (59 cases), in which the fracture line was horizontal; type IIb (22 cases), in which the fracture line was anterior oblique; and type IIc (10 cases), in which the fracture line was posterior oblique.[9] Type III (25 cases) included cases in which the fracture of the base of the odontoid process extended into the body of C2 vertebra (Figure 7). In addition to the above classification, we added three additional subtypes (Table 6). Each type I, II, or III fracture was further subclassified in A, B, or C types either singly or in combination. In type A fractures, there was a vertical compression fracture that resulted in malalignment of the fractured odontoid process segments. Type A was further subdivided into subtypes A1 and A2. Type A1 included 115 cases in which there was evidence of compression and fracture of the odontoid process and the 2 fracture segments were vertically malaligned. There were 3 types of compression fracture that depended on the relationship of the odontoid process: anteriorly displaced (64 cases; Figure 5), posteriorly displaced (16 cases; Figures 4 and 6), and centrally displaced (25 cases). Type A2 included 3 patients with distraction that resulted in separation of odontoid fracture segments. In type B fractures (49 cases), the facets of atlas and axis were malaligned. In type C (25 cases), the fracture line involved the facet of axis.

The fractures were divided into acute type when the injury was less than 3 months old (50 cases), delayed type when the injury was between 3 months and 1 year (34 cases), and chronic type when the injury was longer than 1 year in duration (40 cases).

All patients having type II and subtypes A—C odontoid fractures were considered to be suitable candidates for surgery. The indications for surgery in type I and III fractures included any kind of posttraumatic neurologic deficits and persistent neck pain for longer than 3 months. Any evidence of abnormal cord signal, abnormal movements of fractured segments, or atlantoaxial facets on static or dynamic imaging favored the need for surgical treatment.

Surgery

The patients were taken up for the surgical treatment as soon as they were identified as suitable candidates for surgery. During the

Table 2. Presenting Complaints

Presenting Complaints	Number of Patients
Neck pain and restricted neck movements	110
Weakness, spasticity	75
Paresthesias	45

Table 3. Age Distribution of Patients with Odontoid Fractures

Age Group (Years)	Number of Patients
11—20	7
21—30	32
31—40	28
41—50	16
51—60	16
61—70	14
71—80	11

Table 4. Neurologic Status by ASIA Scale

ASIA Grade	Pre-operative	Post-operative
A	—	—
B	4	—
C	39	6
D	31	23
E	50	95

ASIA, American Spinal Injury Association.

Table 5. Neurologic Status by Goel's Clinical Grading

Goel's Clinical Grade	Description	Preoperative (Number of Patients)	Postoperative (Number of Patients)
Grade 1	Independent and normally functioning	50	95
Grade 2	Walks on own but needs support or help to perform routine household activities	8	17
Grade 3	Walks with minimal support and requires help to perform household activities	27	9
Grade 4	Walks with heavy support and unable to perform household activities	23	3
Grade 5	Unable to walk and dependent for all activities	16	—

waiting period, patients wore a firm cervical collar. Preoperative traction was instituted only in the operation theatre. Surgical steps of the operation have been detailed elsewhere, and they are summarized here.[10,11] The patients were placed in prone position with the head end of the operation table elevated by 30 degrees. The traction assisted in maintaining a stable neck posture and acted as a restraint for the fracture segments during the operation. Head end elevation also kept the head in a "floating" position, such that there was no pressure or major contact of the face or eyes on headrest. The head was not fixed to clamps, but it was stabilized with traction and supported with a headrest. Neurophysiologic monitoring was not used. Surgery involved wide exposure of the atlantoaxial joint. Although C2 ganglion resection was done in several cases early in the series, this surgical step was avoided in the later part of the experience. The ganglion was dissected, mobilized, and elevated to achieve the exposure for introduction of screws in the facets of atlas. The atlantoaxial joint was exposed amidst bleeding from venous pool in the lateral gutter. Judicious packing of the venous plexuses in the extradural space and in the region of the lateral gutter with Gelfoam or Surgicel controlled the bleeding. The articular cartilage was widely denuded using chisel and osteotomes and whenever necessary, particularly in cases with acute injury, using power-driven drills. In general, both the atlas and axis screws measured 2.8 mm in diameter and 26–28 mm in length, and the plate measured 12–14 mm in length. Although polyaxial screws and rods can be used, our surgical technique involved the use of monoaxial screws and plates. The direction of the screws depended on local anatomic situation. The insertion of screws in to the axis necessarily avoided vertebral artery course. Bone graft was harvested from the iliac crest. Small bone chips were stuffed into the articular cavity, and manual facet manipulation was done wherever necessary (in types A and B) to bring them into alignment.[12] In patients with type A1 odontoid fractures, the facets of atlas and axis were distracted before insertion of bone graft within the joint cavity. Plate and screw fixation was subsequently completed. During 1988 to 2012, stainless steel implants were deployed for fixation. After 2012, titanium material was used for fixation. In 3 cases,

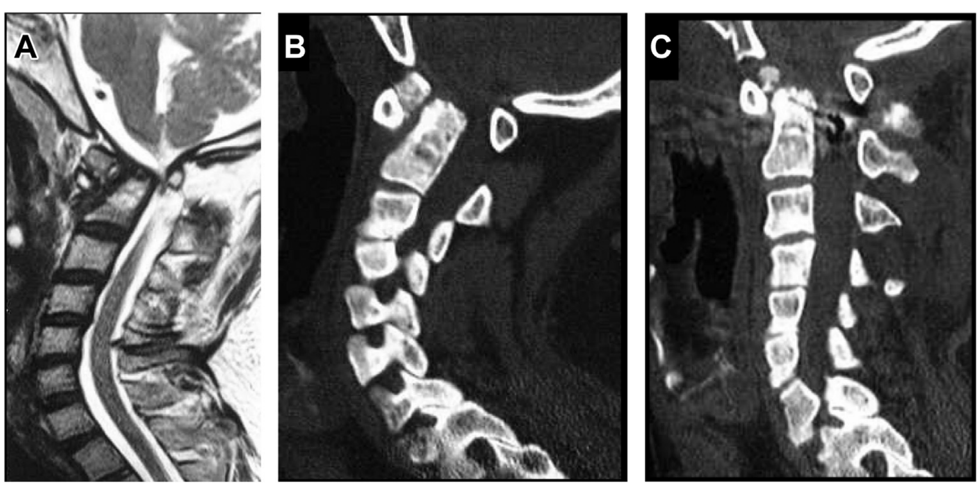

Figure 1. Images of a 50-year-old man with odontoid fracture. (**A**) T2-weighted magnetic resonance imaging showing a type I fracture (delayed) with anterior displacement of the fractured fragment. There is evidence of cord compression. (**B**) Sagittal cut of computed tomographic scan showing the type I fracture. The chronicity of the fracture gives an appearance of os odontoideum. (**C**) Postoperative computed tomography showing the realignment of the odontoid fracture fragments and the fixation.

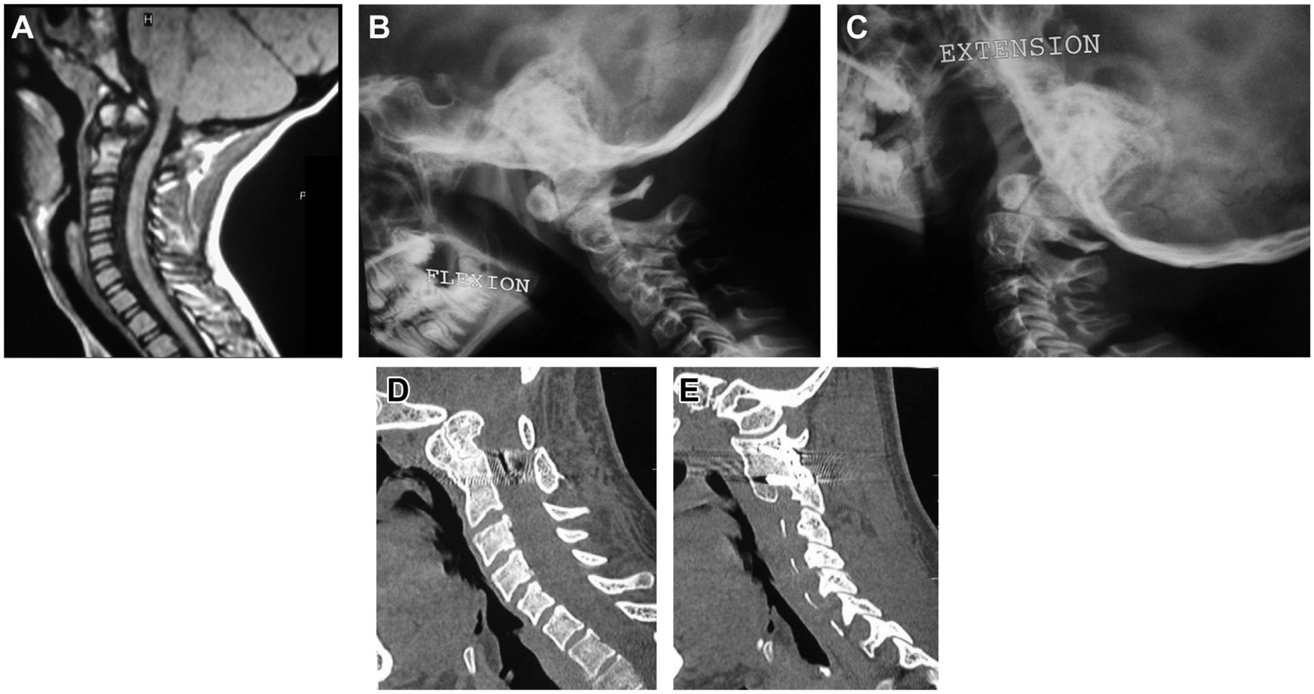

Figure 2. Images of a 12-year-old female child. (**A**) T1-weighted magnetic resonance imaging showing the type I odontoid fracture. (**B**) Radiography of the craniovertebral junction with the head in flexion showing the type I fracture. There is reduction of the fracture segments in this position. (**C**) Radiography of the craniovertebral junction with the head in extension showing the posterior displacement of the fracture fragments. (**D**) Postoperative computed tomographic image, 17 years after surgery, showing fusion of the fractured fragments. (**E**) Computed tomographic cut through the facets showing the implants and atlantoaxial fusion.

intra-articular spacers were introduced into the articular cavity that aimed to distract the facets and provide additional mode of stabilization. We labeled such a mode of joint stabilization as the *joint jamming technique*.[13] Although helpful and probably essential, neuronavigation and fluoroscopy were not used during the operation. After instrumentation for atlantoaxial fixation, bone graft was placed in the midline, over the arch of atlas and lamina of axis, after appropriately preparing the host bone by drilling its outer cortex. All muscle and soft tissue attachment to the spinous process of C2 were widely removed. Traction was removed after turning the patient into supine position. The patient was mobilized as soon as possible, was advised to wear a firm cervical collar for 3 months, and restricted his neck movements during this period. After this period and after confirming bone fusion, the collar was removed and all normal activities were advocated.

Postoperative Outcome

All patients improved after surgery, and the improvement was sustained during the follow-up period (Tables 4 and 5). There were no vascular or neural complications. Postoperative imaging showed reduction of dislocation and of malalignment in all cases. No reoperation for replacing or manipulation of the implant was done. There was no demonstrated instance of pseudoarthrosis or implant failure. There was no infection. Follow-up status of all patients is available after 6 months of surgery. The follow-up period ranged from 6 to 156 months (average 72 months). During the period, all patients are independent and active. Delayed CT scanning after more than 10 years of surgery was possible in 10 patients.

DISCUSSION

Atlantoaxial joint is the most mobile joint of the body. Although the flat and round articular surface of the facets allows wide range of circumferential movements, it also makes this joint susceptible to instability. The odontoid process forms the axis on which the movements of the atlantoaxial joint occur. In our earlier article,[14] we discussed the role of odontoid process in the movements of atlantoaxial region. It was identified that the architectural design of the craniovertebral junction makes the atlantoaxial joint the primary site of movements in the region. The odontoid process acts as a director or conductor of movements and does not actually participate in stability of the atlantoaxial joint. The facets are the fulcrum of all movements that are regulated by a large muscle bulk focused on the strong spinous process of axis. Under such circumstances, it appears that the instability of the atlantoaxial region is related to atlantoaxial joint rather than to odontoid process. Considering this understanding,

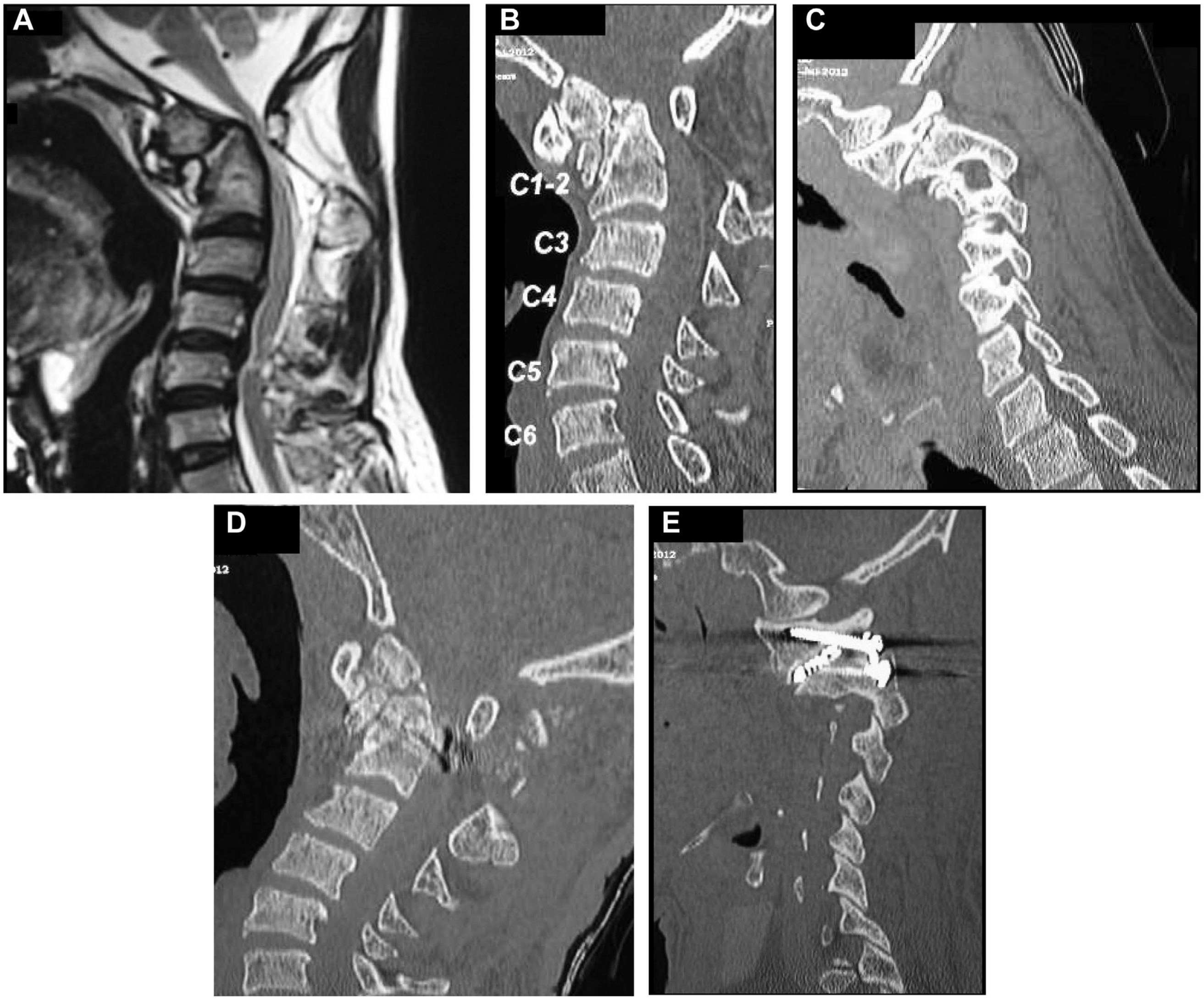

Figure 3. Images of a 47-year-old male patient with a "chronic" odontoid fracture. (**A**) T2-weighted magnetic resonance imaging showing the type I odontoid fracture. The displacement of the fracture segments has resulted in reduction in spinal canal dimension and cord compression. (**B**) Sagittal computed tomographic scan showing the fracture. Multiple small bone pieces resembling osteophytic neoformations are seen around the fracture segments. (**C**) Sagittal computed tomography through the facets showing the facet alignment. (**D**) Postoperative image showing the fixation and realignment of the fractured fragments. (**E**) Postoperative image through the facets showing screws in C1 and C2 facets and a spacer within the atlantoaxial joint.

atlantoaxial stabilization was done whenever it appeared that the odontoid process fracture had resulted in manifest atlantoaxial instability or when there was any clinical or radiologic evidence of potential atlantoaxial instability. Essentially, the aim of surgery was to achieve stabilization and subsequent arthrodesis of the region in the best possible alignment. Decompression of bones or removal of the arch of atlas was not done in any case, even when the complete realignment was not possible.

Odontoid fractures are a relatively frequent posttraumatic event. The general observation is that approximately 15% of cervical fractures involve the odontoid process.[5] The incidence is significantly higher in the older population.[4] High-speed trauma that results in sudden hyperflexion, hyperextension, compression, or distraction movement of the head in relationship to the neck is probably the cause of such fracture. Several series have analyzed cases of odontoid fractures in a geriatric population with a higher incidence of odontoid fracture.[4] In our series, the ages of patients ranged from 12 to 80 years, with an average of 40 years. In 109 patients, the trauma was of significant intensity. We used Goel's clinical grading to evaluate the clinical status of the patients. In

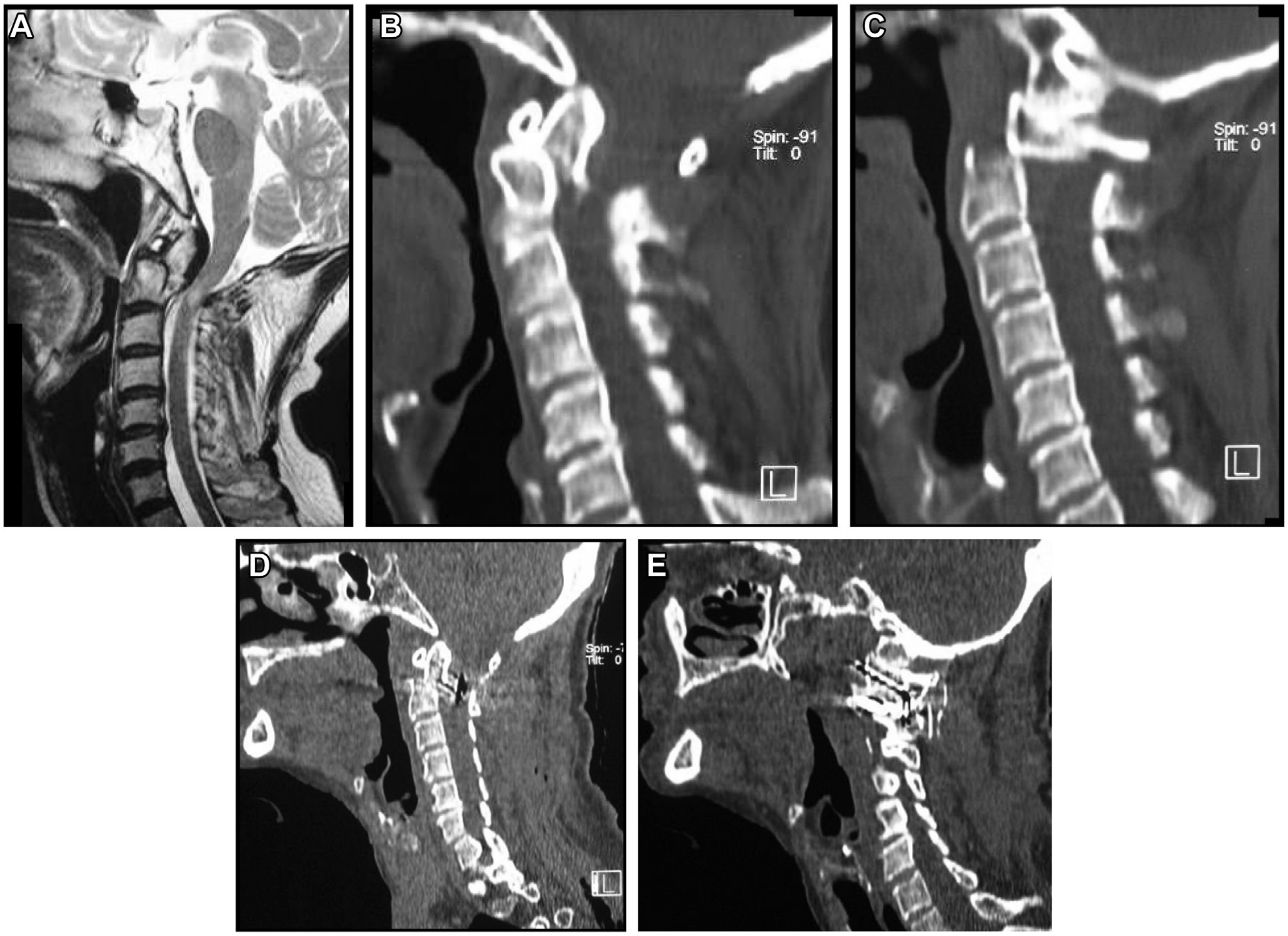

Figure 4. Images of a 55-year-old female patient with acute odontoid fracture. (**A**) T2-weighted sagittal magnetic resonance imaging showing fracture of type IIc A1 + B. (**B**) Sagittal computed tomographic scan showing the type II odontoid fracture with posterior displacement of the fractured fragments. (**C**) Sagittal cut through the facets showing malalignment of the facets. (**D**) Postoperative image showing the fixation and alignment of the fractured fragments. (**E**) Postoperative image with cut passing through the facets showing the realignment of the facets.

addition, we used the more commonly used and validated parameter of ASIA scoring.

Anderson and D'Alonzo discussed a recognized and widely accepted classification system for odontoid fractures that divided them into 3 types.[1,2] We added 3 additional parameters that widened the scope of understanding of the nature of injury and probably in further confirming the need for surgical treatment. Type A odontoid fractures included cases in which there was vertical or compression fracture and the rostral segment of the odontoid fracture was displaced vertically downwards, vertically anterior, or vertically posterior to the inferior fracture fragment. The inclusion of such a fracture in the scheme of classification suggested the mode of injury and in deciding the need of deployment of distraction fixation and realignment of atlantoaxial facets as mode of treatment. In type B odontoid fractures, the facets of atlas and axis are malaligned. Facet malalignment in an anteroposterior perspective is indicative of abnormal atlantoaxial movement or instability. Facet malalignment in the lateral perspective is due to fracture that results in vertical split of the C2 vertebra, and the 2 vertebral segments are laterally displaced, an event that is manifested by lateral location of the facet of axis in relationship with facets of atlas. The mechanism of lateral dislocation of the facets of axis is similar to lateral dislocation of facets of atlas that occurs in patients with bifid arch of atlas, as described previously.[15] In type C, the odontoid process fracture line traversed through the facet of axis. The classification into these additional 3 types suggested the nature and effect of the impact of the injuring forces. Subclassification based on the status of fractured odontoid process segments and alignment of facets assisted in determining the nature of deformity and estimation of the nature and extent of injury. Understanding of the nature of fracture led to appropriate manipulation during

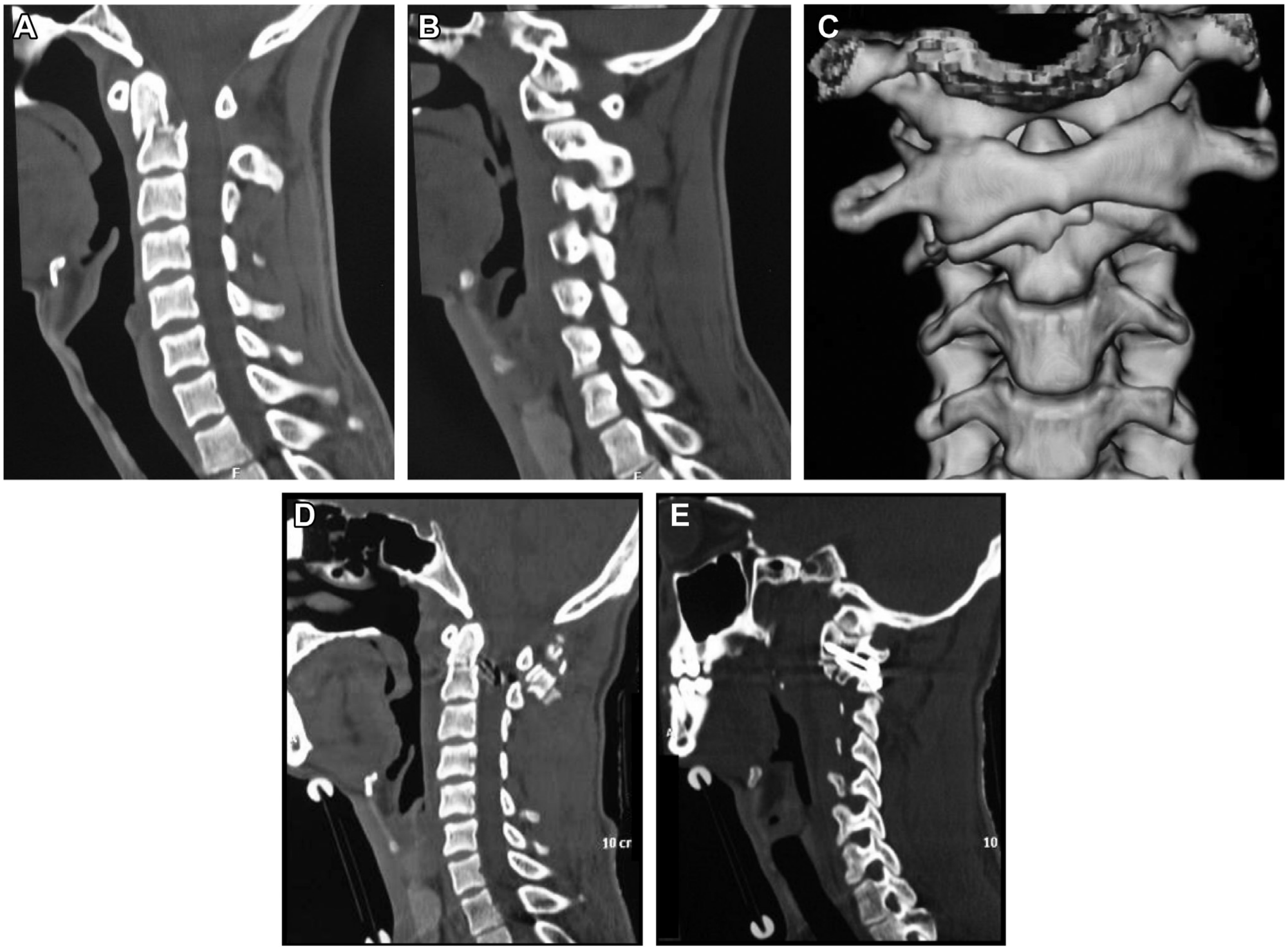

Figure 5. Images of a 15-year-old boy with acute odontoid fracture. (**A**) Sagittal computed tomographic scan showing type IIb+ B odontoid fracture. (**B**) Sagittal computed tomographic cut through the facets showing the facet displacement (type B). (**C**) Three-dimensional reconstructed image showing the type II odontoid fracture. (**D**) Postoperative image showing the fixation and alignment of the fractured fragments. (**E**) Postoperative image showing the implants.

the surgery that aimed to bring the facets in alignment. When the fracture line traversed the facets, special attention was made during surgery to avoid distraction-displacement of the fractured segments during screw implantation. Power-driven guide holes were drilled to traverse both fractured segments before screw insertion. Several patients had chronic fractures (32.2%), with the event of injury being more than 1 year preceding major symptoms that forced the patient to seek medical help. In 21 patients, the injury occurred more than 3 years before admission. Such a delay in treatment could be related to a specified patient population treated by the authors. Illiteracy and difficulty in obtaining specialized medical help in time were possibly the major factors. Delayed diagnosis and presentation allowed assessment of natural history of conservatively treated, untreated, or ignored odontoid fractures. The fractures in such cases had smooth edges and reparative phenomenon in the form of abnormal bone formation in and around the fracture zone, osteophyte formation, and ossification of the posterior longitudinal ligament. The deformity of the region of the fracture and of the atlantoaxial joint and the extent of neural compression and distortion appeared to be more remarkable in such cases. Even in such cases, the atlantoaxial joint appeared to be "active," meaning that it could be manipulated manually and realigned. The smooth edges of fracture made it impossible in some cases to differentiate chronic odontoid fracture from os odontoideum (**Figure 1**).

The need for operative intervention and validity of conservative surgical options has been analyzed in several articles.[4,5,16-18] Currently, the general trend has tilted in favor of surgery. In types I and III odontoid fractures, where it appeared that the atlantoaxial stability of the region was unaffected by odontoid fracture, treatment by conservative and non-surgical observation was adopted. However, whenever there was any doubt about the

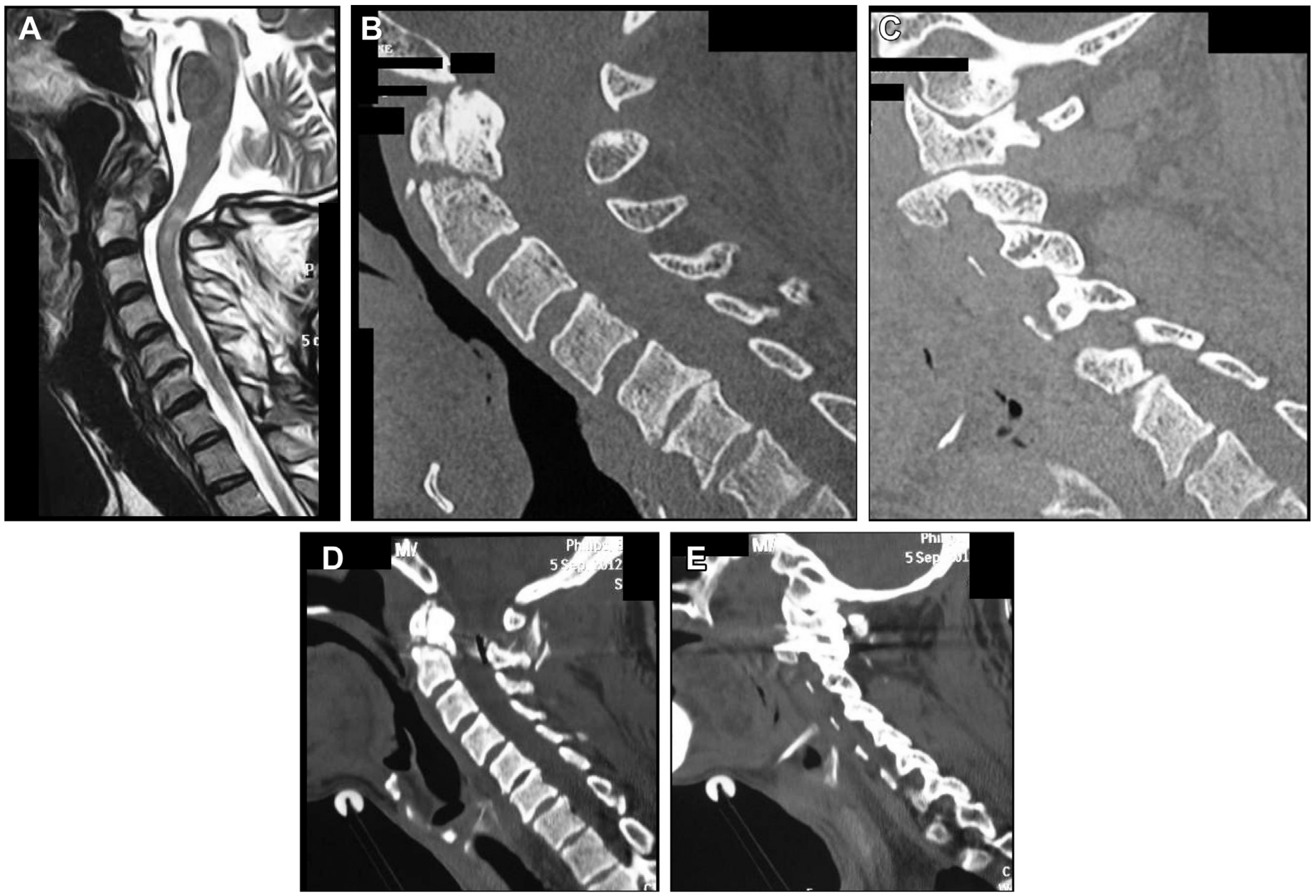

Figure 6. Images of a 47-year-old male patient with odontoid fracture. (**A**) T2-weighted magnetic resonance imaging showing the type IIc + A1 + B delayed odontoid fracture. (**B**) Sagittal computed tomographic scan showing the fracture with posterior displacement of the fractured odontoid fragment. (**C**) Sagittal cut through the facets showing posterior displacement of the facets. (**D**) Postoperative image showing the fixation and alignment of the fragments. (**E**) Postoperative image showing the fixation.

stability of the atlantoaxial joint, or when there was association of fracture subtypes A—C, atlantoaxial fixation surgery was favored. Neurologic deficits and persistent or increasing neck pain were identified to be indicators of instability of the region. Other indicators included the presence of abnormal cord signal changes and excessive or abnormal movements at the atlantoaxial joint. Our experience in the field and standardization of surgical steps has probably tilted the treatment selection toward surgery.

The special vascular architecture of the odontoid process, watershed nature of area of blood supply, and stress of movements of both flexion and extension of neck on the region makes the incidence of pseudoarthrosis prohibitively high, more particularly in the older population. Osteoporosis of the bones and their relative avascularity in the older patient group also makes the bone susceptive to nonfusion. Nonunions are common in conservatively treated patients and in patients treated with anterior screws that traverse across the odontoid fracture line. Apuzzo et al.[16] concluded that in patients older than 40 years with displaced fractures there is almost an 80% rate of nonunion with nonoperative observation.[16]

The surgical approach (anterior versus posterior) has also been a much-debated issue.[3] In a literature survey, there are several reports on the subject in which the anterior odontoid screw fixation was successfully used.[3-6] Bohler first described such anterior screws in 1982.[19,20] The advocated advantage of such a technique is that after the fusion has been achieved, the atlantoaxial joint can function and normal spinal movements can be restored. Moreover, the procedure allows fixation of fracture segments with minimal soft tissue disruption. There is no need to use bone graft in this technique. A number of authors have reported a high clinical and fusion success with the technique.[6] Patients with comminuted fractures and those with chronic fractures of more than 6 months' duration are generally considered unsuitable for such form of treatment. The dictum that was followed in our series was that whenever one is in doubt about the stability, one should fix it. And when one

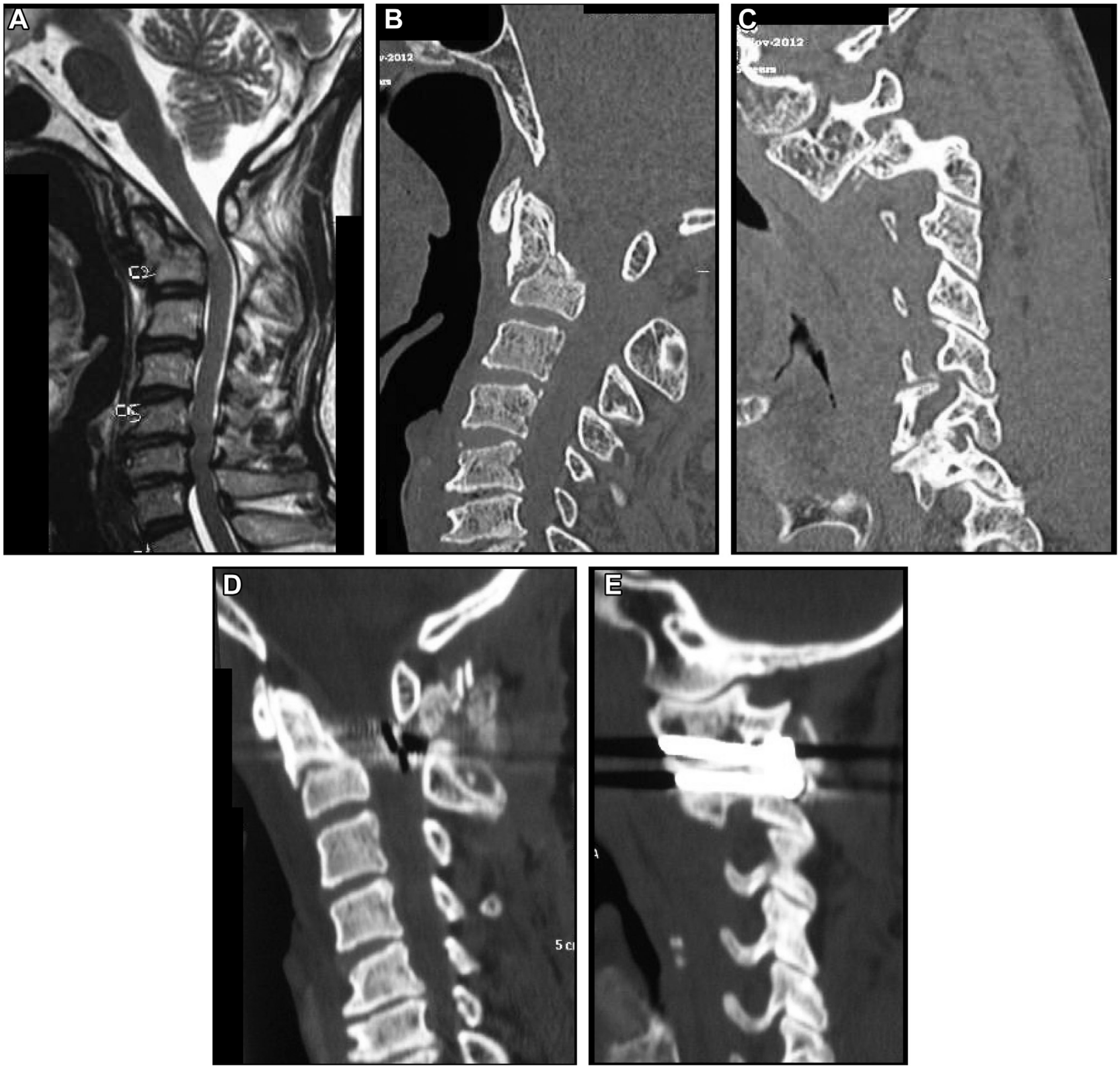

Figure 7. Images of a 46-year-old male patient with a chronic odontoid fracture. (**A**) T2-weighted magnetic resonance imaging showing the type III odontoid fracture with anterior displacement (type A1) of the fractured fragments. (**B**) Sagittal computed tomographic scan showing the type III fracture. (**C**) Sagittal cut of computed tomography through the facets showing the facet displacement suggestive of type B instability. (**D**) Postoperative image showing the realignment of the fractured fragments. (**E**) Postoperative image showing the implants in the C1 and C2 facets.

decides to fix the region, the most versatile and proven method of fixation should be used. In this respect, posterior fusion was identified to provide a stable atlantoaxial fixation and a safer choice when compared with anterior odontoid process screw fixation.[21] As fusion of the joint then became the issue in consideration, nonunion of fracture segments of the odontoid processor and the status of alignment of facets did not form a mode of subsequent evaluation. The surgical treatment was focused on fixation of atlantoaxial joint and was aimed at achieving segmental arthrodesis.

Three-dimensional anatomic understanding of the region, advancements in radiologic imaging, safety of the anesthesia and

Table 6. Classification of Odontoid Fractures

Type of Odontoid Fracture	A1 (Number of Patients)	A2 (Number of Patients)	B (Number of Patients)	C (Number of Patients)
Type I	6	—	—	—
Type II	—	—	—	—
II A	59	2	12	—
II B	22	—	14	—
II C	10	—	10	—
Type III	18	1	13	6

surgical procedure, and biomechanical strength of the construction implant has allowed the adoption of this surgical strategy, even in borderline cases. Despite the fact that the fractured odontoid process segments and facets were in malalignment and the fracture line traversed the facets in a number of cases, there was no need to lengthen the atlantoaxial fixation metal construct to include subaxial bones. Our 100% successful fixation without any demonstrated instance of pseudoarthrosis or implant failure and satisfactory resolution of symptoms in a significantly large number of patients treated over a long duration justifies the surgical strategy. Although neck movements were marginally restricted, segmental nature of fixation limited any significant disability related to movement loss.

CONCLUSION

Comparative data for anterior odontoid screw fixation is not available, because only posterior fusion was performed in all cases. However the successful outcome in the series when compared with an average of 25% failure rate, suitability in only a proportion of cases, and a potential of range of minor and major complications of odontoid process screw implantation and of conservative nonsurgical options suggests the validity of the adopted surgical strategy.

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