Turkish Journal of Clinics and Laboratory

To cite this article: Sandal E, Kinali B, Karadag A, Cagli MS. Surgical management of basilar ınvagination: comparison of clinical and radiographic outcomes utilizing differing surgical approaches. Turk J Clin Lab 2023; 2: 330-338

Research Article

Surgical management of basilar ınvagination: comparison of clinical and radiographic outcomes utilizing differing surgical approaches

Baziler invajinasyonun cerrahi tedavisi: farklı cerrahi yaklaşımların klinik ve radyografik sonuçların karşılaştırılması

Evren Sandal*[1], Burak Kinali[2], Ali Karadag[3], Mehmet Sedat Cagli[4]

[1]Department of Neurosurgery, Medicana İnternational İzmir Hospital, Izmir, Turkey
[2]Department of Neurosurgery, Medicana İnternational Bahçeşehir İstanbul Hospital, İstanbul, Turkey
[3]Department of Neurosurgery, Health Science University, Tepecik Research and Training Hospi-tal, Izmir, Turkey
[4]Department of Neurosurgery, Ege University School of Medicine, Izmir, Turkey

ABSTRACT

Aim: Previous studies have outlined various surgical approaches to treatment of basilar invagination, but none have compared multiple different treatment options using objective clinical and radiological criteria.

Material and Methods: We retrospectively reviewed the records of 30 patients with basilar invagination treated by five different surgical approaches. The surgical outcomes were evaluated and compared using objective clinical (Ranawat score) and radiological parameters (Chamberlain distance, atlantodental interval, and craniovertebral angle).

Results: Our results show a statistically significant improvement in the Ranawat score for patients undergoing 1) anterior decompression with posterior stabilization, 2) posterior decompression with posterior stabilization, and 3) the Goel procedure (posterior decompression, posterior reduction, cage distraction, and posterior stabilization). Of these, the Goel procedure produced the most significant improvement in functional and radiographic outcomes. Neither group without posterior stabilization (posterior decompression alone or endoscopic transnasal odontoidectomy alone) had a significant improvement in Ranawat score or radiographic outcomes.

Conclusion: For surgical management of basilar invagination, a combination of posterior decompression, posterior reduction, cage distraction, and posterior stabilization yielded the best clinical and radiological outcome. There is a risk of craniocervical instability and kyphosis and recurrence of stenosis in patients treated surgically without posterior stabilization. Therefore, when deciding on bacillary invagination surgery without posterior stabilization, it should be carefully considered.

Keywords: Basilar invagination, surgical treatment, craniocervical junction, Goel procedure, spine surgery

Corresponding Author*: Evren Sandal, MD, Department of Neurosurgery, Health Science University, Department of Neurosurgery, Medicana İnternational İzmir Hospital, Izmir, Turkey.
E-mail: drevrensandal@gmail.com.
Orcid: 0000-0001-9268-1744

Doi: 10.18663/tjcl.1281631
Recevied: 12.04.2023 accepted: 08.05.2023

Öz

Amaç: Baziler invajinasyonun cerrahi tedavisine yönelik çeşitli yaklaşımların ana hatları literatürdeki birçok çalışmada araştırılmış ancak hiçbiri objektif klinik ve radyolojik kriterler kullanarak farklı tedavi seçeneklerini karşılaştırmamıştır. Çalışmamızda farklı cerrahi girişimle opera edilen baziller invaginasyonu olan hastaların objektif klinik ve radyolojik parametreler kullanılarak karşılaştırılması amaçlandı.

Gereç ve Yöntemler: 2000-2014 yılları arasında baziler invajinasyon nedeniyle opere edilen hastalar retrospektif olarak incelendi. Sekonder baziler invajinasyon kriterlerini karşılayan romatoid artritin neden olduğu atlantoaksiyal subluksasyonu olan iki olgu da çalışmaya dahil edildi. Çalışmaya beş farklı cerrahi yaklaşımla tedavi edilen baziler invajinasyonlu toplam 30 hasta dahil edildi. Cerrahi sonuçlar objektif klinik (Ranawat skoru) ve radyolojik parametreler (Chamberlain mesafesi, atlantodental interval ve kraniovertebral açı) kullanılarak değerlendirildi ve karşılaştırıldı.

Bulgular: Çalışmamızda posterior stabilizasyonlu anterior dekompresyon, posterior stabilizasyonlu posterior dekompresyon ve Goel prosedürü (posterior dekompresyon, posterior redüksiyon, kafes distraksiyonu ve posterior stabilizasyon) uygulanan hastalarda Ranawat skorunda istatistiksel olarak anlamlı bir iyileşme olduğu saptandı. Bunlardan Goel prosedürü fonksiyonel ve radyografik surveyde en iyi sonuçları gösterdi. Posterior stabilizasyonu uygulanmayan hiçbir grupta (tek başına posterior dekompresyon veya yalnızca endoskopik transnazal odontoidektomi), Ranawat skorunda veya radyografik sonuçlarda anlamlı bir iyileşme olmadı. Anterior dekompresyon ve posterior stabilizasyonun birlikte uygulandığı cerrahi prosedürlerde de başarı oranı yüksek idi.

Sonuç: Baziler invajinasyonun cerrahi tedavisinde posterior dekompresyon, posterior redüksiyon, kafes distraksiyonu ve posterior stabilizasyonun birlikte yapıldığı cerrahi uygulamalar en iyi klinik ve radyolojik sonucu verdi. Posterior stabilizasyonsuz cerrahi tedavi edilen hastalarda, kranioservikal instabilite ve kifoz gelişimi tekrar darlık oluşumu riskleri vardır. Bu nedenle posterior stabilizasyonsuz basiler invaginasyon ameliyatı kararı alınırken titizlikle düşünülmeli bu durumlar göz önünde bulundurulmalıdır.

Anahtar Kelimeler: Basiller invajinasyon, cerrahi tedavi, kranioservikal bileşke, Goel prosedürü, omurga cerrahisi

Introduction

Basilar invagination is an acquired or congenital anomaly of the craniocervical junction in which the odontoid projects through the foramen magnum [1]. The acquired form of basilar invagination, often referred to as basilar impression, typically results from trauma, tumor, infection, or metabolic bone disease [2,3,4]. The congenital form is often associated with other abnormalities of the craniocervical junction, such as platybasia, hypoplasia of the clivus and condyles, and atlas assimilation [5]. Regardless of the cause, the potential neurological complications often necessitate surgical intervention [6].

Surgical treatment aims to decompress neurovascular structures based on correcting and stabilizing the craniocervical junction. Anterior compression of the cervicomedullary junction by the odontoid may lead to odontoid resection, typically performed by either transpharyngeal method (via a transnasal, transmandibular, or transmaxillary approach) or retropharyngeal method (via far-lateral transatlas or far-lateral transcondylar approaches) [6-11] Both approaches can also be performed endoscopically under image guidance [12,13]. Posterior compression may require resection of the posterior elements of the craniocervical junction via midline approach. It is possible to use occipitocervical systems and C1-C2 screw systems for posterior stabilization (PS), as well as C0–C2 implant systems for patients with co-existing atlas assimilation [14,15]. Anterior grafting and stabilization methods are also available for anterior stabilization after anterior decompression (AD). However, PS is most commonly applied and is the recommended approach after AD [16-24].

Various studies have outlined the surgical treatment of basilar invagination, but no study has compared the results of different treatment options by using objective clinical and radiological criteria [14,16,21,24]. This study investigated the clinical and radiological features of patients with basilar invagination treated surgically via five different surgical approaches.

Material and Methods

Study Design

This an IRB approved retrospective study including the patients with basilar invagination who had undergone surgery between 2000 and 2014.

Chart Review

Chart review included review of medical history, physical examination findings, intensive care records, follow-up records, periodic observation notes, operation reports, re-hospitalization records, and radiologic records. The following information was recorded: age, gender, signs and symptoms (including presenting complaints), history, preoperative examination findings, operation performed, discharge examination findings, and details of any complications, morbidity, mortality, or reoperations. The Ranawat Scale[5] was used to standardize the preoperative and postoperative functional status assessments.

Patients were classified into five groups based on surgical approach. Group 1 included patients who underwent posterior decompression (PD), alone. Group 2 patients underwent PD, posterior reduction (PR) and PS. Group 3 patients underwent PD, PR, cage distraction, and PS (Goel procedure). Group 4 patients underwent AD and PS. Group 5 patients underwent endoscopic transnasal odontoidectomy (ETNO).

Radiological examination included the measurements described for cranio-cervical junctional anomalies (Figure 1). The Chamberlain distance was defined as the vertical height of the portion of the odontoid projecting above the Chamberlain line (a line connecting the posterior hard palate with the opisthion on a sagittal view of the craniocervical junction). The atlantodental interval is traditionally defined as the anterior-posterior width of the anterior atlantoaxial joint but was measured in an atlanto-clival direction in most patients due to high atlas assimilation ratios. The craniovertebral angle was measured in the sagittal projection as the angle between a line perpendicular to the posterior cortex of the odontoid and a line perpendicular to the posterior margin of the clivus. Measurements assessing degree of correction of the craniocervical junction (i.e., the Chamberlain distance, atlantodental interval, and craniovertebral angle) were repeated on postoperative images and recorded as the objective indicators of correction of the craniocervical junction and decompression of the foramen magnum. Brain stem decompression was observed in cases subject to AD as a hyper-intense line of cerebrospinal fluid in front of the brain stem in the sagittal plane on T2-weighted MRI, as well as by clinical observation. These subjective parameters were not included in the statistical analyses.

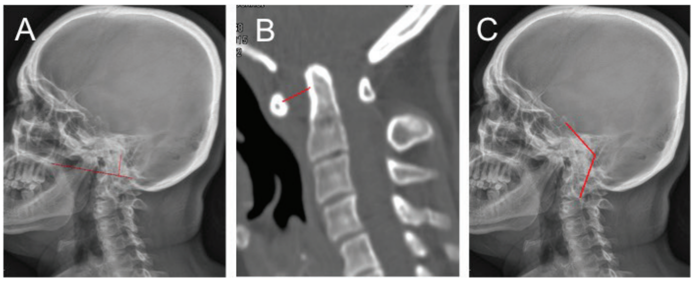


Figure 1. A: The Chamberlain distance measured as the vertical height of the portion of the odontoid projecting above the Chamberlain line (a line connecting the posterior hard palate with the opisthion on a sagittal view). **B:** Anterior atlantodental interval defined as the anterior-posterior width of the anterior atlantoaxial joint. **C:** The craniovertebral angle was measured as the angle between a line perpendicular to the posterior cortex of the odontoid and a line perpendicular to the posterior margin of the clivus.

Statistical Analysis

Data were analyzed by Wilcoxon signed ranks or paired t-tests, as appropriate. Statistical significance was set at $p < 0.05$.

Results

Demographic and clinical characteristics are included in Table 1. The mean follow-up period was 5.6±3.7 months (range 3-11 months). Two cases with atlantoaxial subluxation caused by rheumatoid arthritis meeting the criteria for secondary basilar invagination were also included. A total of 30 patients were included in the study.

An equal number of male and female patients were included with an average age of 37.8±12.2 years (range 18–63 years). The most frequent presenting complaints were paresis and paresthesia. Six patients presented with existing symptoms that deteriorated after minor trauma.

Multiple co-existing abnormalities were identified (Table 2; Figure 2). The most frequent associated finding was atlas assimilation (72.6%). Chiari malformation was present in 52.8% of cases, including seven of the eight patients presenting with cerebellar findings. Chiari malformation was also present in all patients with hydrocephalus or syringomyelia.

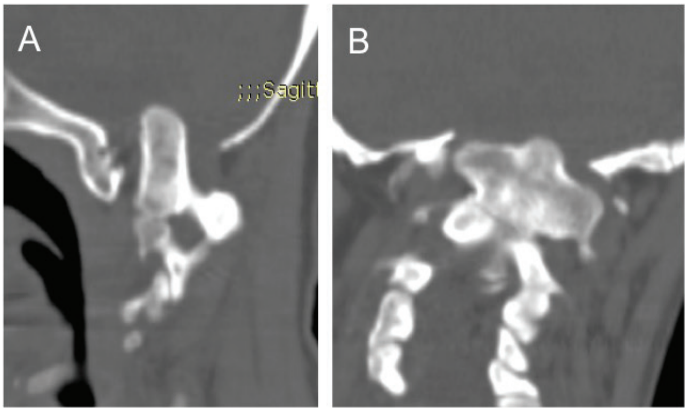
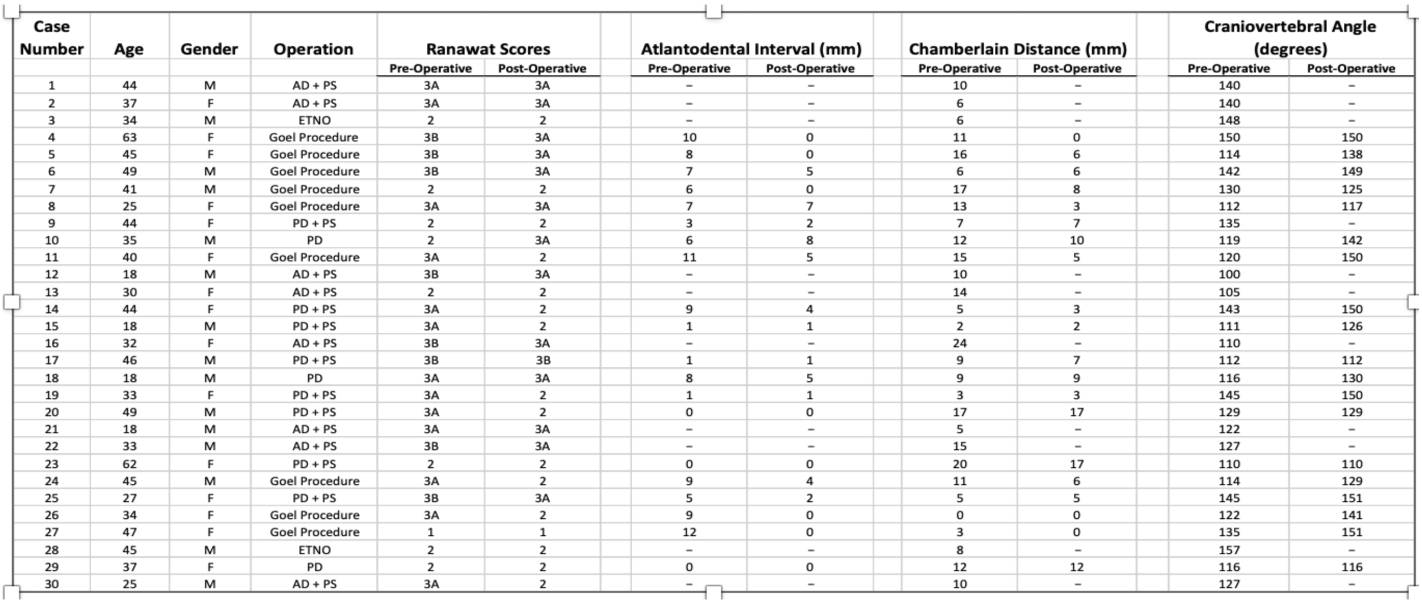


Figure 2. A: A representative case of abnormal fusion of the atlas on the axis, which gives the appearance of two bilateral pedicles on C2. The very fine structure of the real pedicle is seen below. **B**: A representative case of odontoid hypoplasia, condyle hypoplasia, atlas assimilation, Klippel–Feil anomaly, and scoliosis.

Table 1. Summary of Patient Demographics, Treatments, and Radiological and Clinical Analyses.

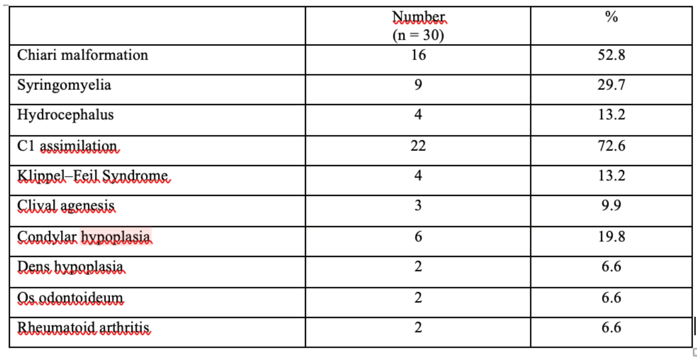


Case Number	Age	Gender	Operation	Ranawat Scores		Atlantodental Interval (mm)		Chamberlain Distance (mm)		Craniovertebral Angle (degrees)	
				Pre-Operative	Post-Operative	Pre-Operative	Post-Operative	Pre-Operative	Post-Operative	Pre-Operative	Post-Operative
1	44	M	AD + PS	3A	3A	–	–	10	–	140	–
2	37	F	AD + PS	3A	3A	–	–	6	–	140	–
3	34	M	ETNO	2	2	–	–	6	–	148	–
4	63	F	Goel Procedure	3B	3A	10	0	11	0	150	150
5	45	F	Goel Procedure	3B	3A	8	0	16	6	114	138
6	49	M	Goel Procedure	3B	3A	7	5	6	6	142	149
7	41	M	Goel Procedure	2	2	6	0	17	8	130	125
8	25	F	Goel Procedure	3A	3A	7	7	13	3	112	117
9	44	F	PD + PS	2	2	3	2	7	7	135	–
10	35	M	PD	2	3A	6	8	12	10	119	142
11	40	F	Goel Procedure	3A	2	11	5	15	5	120	150
12	18	M	AD + PS	3B	3A	–	–	10	–	100	–
13	30	F	AD + PS	2	2	–	–	14	–	105	–
14	44	F	PD + PS	3A	2	9	4	5	3	143	150
15	18	M	PD + PS	3A	2	1	1	2	2	111	126
16	32	F	AD + PS	3B	3A	–	–	24	–	110	–
17	46	M	PD + PS	3B	3B	1	1	9	7	112	112
18	18	M	PD	3A	3A	8	5	9	9	116	130
19	33	F	PD + PS	3A	2	1	1	3	3	145	150
20	49	M	PD + PS	3A	2	0	0	17	17	129	129
21	18	M	AD + PS	3A	3A	–	–	5	–	122	–
22	33	M	AD + PS	3B	3A	–	–	15	–	127	–
23	62	F	PD + PS	2	2	0	0	20	17	110	110
24	45	M	Goel Procedure	3A	2	9	4	11	6	114	129
25	27	F	PD + PS	3B	3A	5	2	5	5	145	151
26	34	F	Goel Procedure	3A	2	9	0	0	0	122	141
27	47	F	Goel Procedure	1	1	12	0	3	0	135	151
28	45	M	ETNO	2	2	–	–	8	–	157	–
29	37	F	PD	2	2	0	0	12	12	116	116
30	25	M	AD + PS	3A	2	–	–	10	–	127	–

* AD = anterior decompression; ETNO = endoscopic transnasal odontoidectomy; PD = posterior decompression; PS = posterior stabilization

** Some patients lacked pre-operative or post-operative measurements due to prior surgeries or procedure performed limiting assessment

Table 2. Anomalies associated with basilar invagination



	Number (n = 30)	%
Chiari malformation	16	52.8
Syringomyelia	9	29.7
Hydrocephalus	4	13.2
C1 assimilation	22	72.6
Klippel–Feil Syndrome	4	13.2
Clival agenesis	3	9.9
Condylar hypoplasia	6	19.8
Dens hypoplasia	2	6.6
Os odontoideum	2	6.6
Rheumatoid arthritis	2	6.6

The distribution of surgical procedures (Table 3) included three (10.0%) patients in Group 1 (PD alone), eight (26.7%) in Group 2 (PD + PR + PS), nine (30.0%) in Group 3 (Goel procedure), eight (26.7%) in Group 4 (AD + PS), and two (6.7%) in Group 5 (ETNO).

Group 1

For patients undergoing PD alone, there was a slight worsening in functional outcome (Ranawat score of 1.33 ± 0.577 pre-operatively to 1.67 ± 0.577 postoperatively); however, this was not statistically significant (p = 0.317). There was also an increase in the atlantodental interval postoperatively by 2.5 mm, not statistically significant (p = 0.18). No significant change was present in the pre-operative and post-operative craniovertebral angle (p > 0.15). Notably, Case 10 had progressive anterior compression and progressed to quadriparesis during the first year after PD.

Group 2

Group 2 patients had a statistically significant improvement in functional outcome with a decrease in Ranawat score from 2.00 ± 0.756 pre-operatively to 1.38 ± 0.741 post- operatively (p = 0.025). Case 17 had presented with neurological worsening after undergoing PD elsewhere, but experienced no further progression of symptoms after subsequent PR and PS.

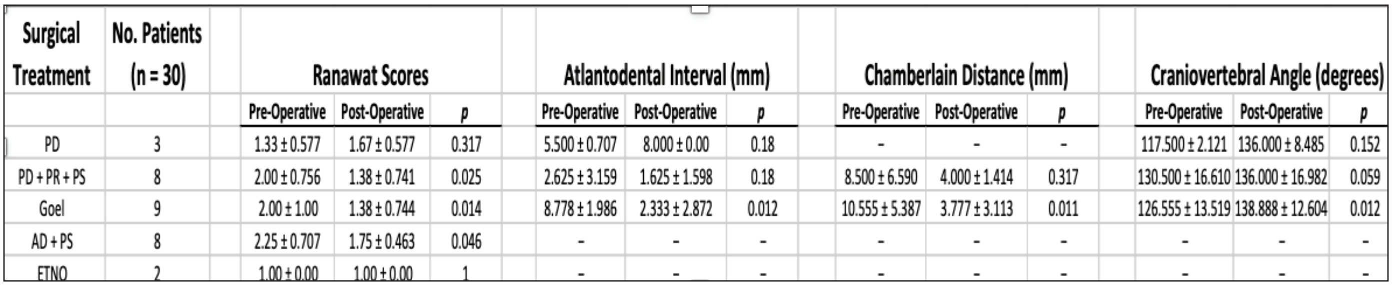
There was 38.1% decrease in the atlantodental interval post-operatively (p=0.18). No significant change in the Chamberlain distance was present; however, there was a trend towards an increase in the craniovertebral angle by an average of 5.5 degrees post-operatively (p=0.059).

Group 3

The most significant functional improvement was found in the patients undergoing the Goel procedure with an average reduction of 62% in Ranawat score (p = 0.014). One case in Group 3 (Case 11) also presented with neurological worsening after undergoing PD elsewhere.

In this group, a cage was placed in the atlantoaxial joint between the condyle and axis in patients with atlas assimilation. This provided direct support at the point where distraction was needed. As such, the greatest improvement in craniocervical alignment was seen in Group 3 with a 73.4% decrease in the atlandodental interval (p = 0.012). Group 3 patients were the only group with a statistically significant decrease in the Chamberlain distance (average decrease of 6.8 mm; p = 0.011) and increased craniovertebral angle (average increase of 12.3 degrees; p=0.012).

Table 3. Relationship between surgical treatment and clinical and radiographic outcomes.



Surgical Treatment	No. Patients (n = 30)	Ranawat Scores			Atlantodental Interval (mm)			Chamberlain Distance (mm)			Craniovertebral Angle (degrees)		
		Pre-Operative	Post-Operative	*p*	Pre-Operative	Post-Operative	*p*	Pre-Operative	Post-Operative	*p*	Pre-Operative	Post-Operative	*p*
PD	3	1.33 ± 0.577	1.67 ± 0.577	0.317	5.500 ± 0.707	8.000 ± 0.00	0.18	-	-	-	117.500 ± 2.121	136.000 ± 8.485	0.152
PD + PR + PS	8	2.00 ± 0.756	1.38 ± 0.741	0.025	2.625 ± 3.159	1.625 ± 1.598	0.18	8.500 ± 6.590	4.000 ± 1.414	0.317	130.500 ± 16.610	136.000 ± 16.982	0.059
Goel	9	2.00 ± 1.00	1.38 ± 0.744	0.014	8.778 ± 1.986	2.333 ± 2.872	0.012	10.555 ± 5.387	3.777 ± 3.113	0.011	126.555 ± 13.519	138.888 ± 12.604	0.012
AD + PS	8	2.25 ± 0.707	1.75 ± 0.463	0.046	-	-	-	-	-	-	-	-	-
ETNO	2	1.00 ± 0.00	1.00 ± 0.00	1	-	-	-	-	-	-	-	-	-

Representative examples of two cases are presented in Figures 3 and 4. Figure 3 shows the results for a patient with basilar invagination presenting with acute quadriparesis. We performed PD, reduction, and condylar–C2 joint distraction (with a cage to the right and an autograft bone to the left) to achieve posterior fusion and occipito-cervical stabilization. As shown in the postoperative images, full reduction of the odontoid was achieved with an increase in the craniovertebral angle and decompression at the level of the foramen magnum. Figure 4 shows a representative case of secondary basilar invagination caused by rheumatoid arthritis. In this case, posterior approach with atlantoaxial joint cage distraction, odontoid reduction, and stabilization with bilateral C2 laminar screw and rod system to the lateral mass of the atlas was performed. This led to full vertical and horizontal reduction of the odontoid and effective decompression of the brain stem.

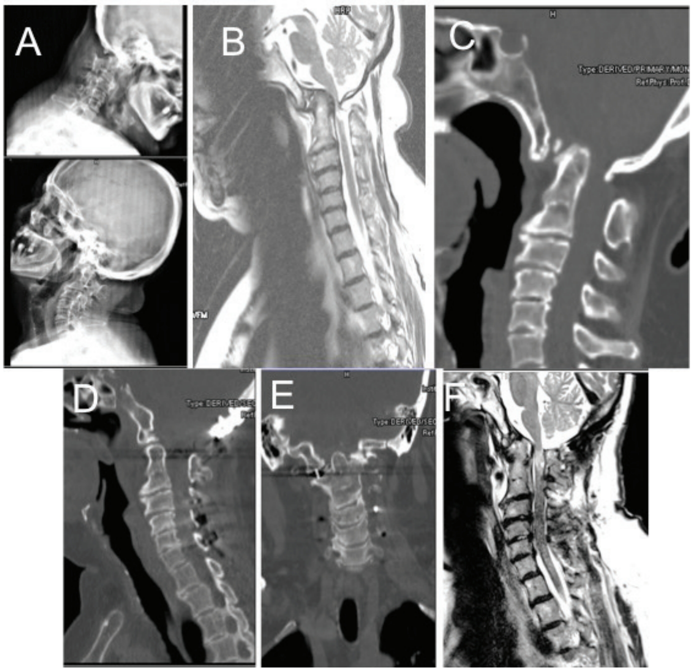


Figure 3. Pre-operative flexion–extension radiographs **(A)**, sagittal T2-weighted MRI **(B)**, and sagittal CT **(C)** show atlas assimilation with basilar invagnation resulting in severe stenosis of the foramen magnum and severe compression of the cervicomedullary junction. Post-operative sagittal **(D)** and coronal **(E)** CT images and T2-weighted MRI **(F)** show marked improvement in alignment at the craniocervical junction with resolution of stenosis at the foramen magnum and reduction in compression on the cervicomedullary junction after Goel procedure.

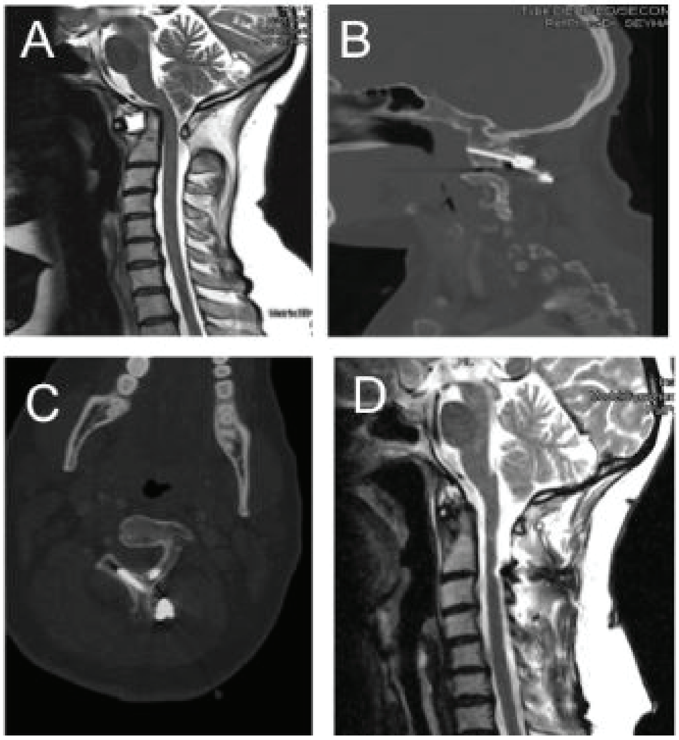


Figure 4. Pre-operative T2-weighted sagittal MRI **(A)** shows substantial widening of the anterior atlantoaxial joint and basilar invagination producing stenosis of the foramen magnum and mass effect on the cervicomedullary junction. Post-operative sagittal **(B)** and axial **(C)** CT and sagittal T2-weighted MRI **(D)** after Goel procedure show marked reduction in the atlantodental interval and reducing in basilar invagination. Compression on the cervicomedullary junction has been resolved.

Some noteworthy events in Group 3 include a died (Case 4) two months after index surgery from central nervous system infection and hydrocephalus despite the treatment with external ventricular drainage and antibiotic therapy. A complication of vertebral artery rupture due to the close relationship with atlantoaxial joint was seen in the opertaion in two patients. The arteries were repaired by primary suture in both patients, and the lumen was preserved as confirmed by postoperative CT angiography. There was no postoperative vertebro-basilar ischemia and no related morbidity. Vertebral artery damage due to screw malposition was not observed in any patient, and there was no early surgical mortality in any of the included patients.

Group 4

The Group 4 patients also showed a slight improvement in functional outcome (average decrease in Ranawat score of 0.5; p = 0.046). There were no notable complications in patients undergoing AD + PS.

Group 5

The ETNO approach was performed in two patients who required AD. There was no significant change in Ranawat score; however, the small sample size limits interpretation. One patient recovered without complication after we achieved sufficient decompression and was discharged after only a brief period of hospitalization. In the second patient, the operation was finalized without sufficient decompression because the hard palate did not permit caudal shifting, as well as a difference between the imaging depth and that observed surgically. There was no surgical complication; however, the patient will undergo repeat surgery in the future.

Discussion

The basic principle of surgical treatment of basilar invagination is to eliminate compression and reduce the stenosis at the level of the foramen magnum. Algorithms dictate that the decompression should be performed based on where the compression is [5, 25,26] . It was found that posterior decompression alone without fusion led to a progression of brain stem compression[25]. However, anterior approaches were technically difficult even in the absence of anatomical irregularities and had serious approach-related complications.[26]

Anterior decompression alone may lead to postoperative instability requiring fixation, therefore, supporting the need for fusion.[27] Dickman, et al.reported that instability developed in over 40% of cases with anterior approaches alone [28,29].

In addition, Goel, et al. reported that various patients with basilar invagination advanced clinically and radiologically during follow up after trans-oral decompression without stabilization [6] .Based on surgical experience and biomechanical studies of AD, it was predicted that instability could be prevented after decompression by protecting the anterior arch of the atlas, the alar ligament, and the transverse ligament when there was no preoperative instability. However, many authors suggested the use of PS since the basilar invagination was already unstable, the percentage of accompanying atlas assimilation was high, and the ability to protect these ligaments during the decompressive surgery was limited [16,22,23,25] There was significant improvement in functional outcome only in patient groups with PS in this study as well.

Our results suggested that the Goel procedure was the most successful method to improve functional status and radiographic alignment compared to the other procedures. Changes in functional status were presumably linked to these radiographic endpoints as the decrease in the Chamberlain distance and atlantodental interval and an increase in the craniocervical angle are all factors that effectively decreased brain stem compression and increased the effective foramen magnum diameter [2,30]. There was no patient with Goel procedure had insufficient decompression and requirement of AD. The average vertical reduction of the odontoid was greater than 5 mm, despite only using distraction cages that were 5 mm thick. Therefore, the Goel method was reported as an effective single-stage procedure, providing both stabilization and AD [31,32].

It is important for the surgeon to be aware of potential complications that may occur from the Goel procedure. In our study, vertebral artery injuries occurred during dissection of the atlantooccipital joint (condylar–C2 joint in atlas assimilation) in two patients as a posterior approach related complicaiton. The risk of this complicaiton is high in this region where the vertebral artery leaves the foramen, encircles the joint, and enters the dura. Before surgery, it is beneficial to know if the fixation point of the atlanto-occipital membrane that covers this trough is ossified and if there is any inherited anatomic variation (e.g., arcuate foramen, ponticulus posticus, or Kimmerle's anomaly) where the vertebral artery and C1 spinal nerve pass through. It has been suggested that such variations can be present in 1.2%–37% of cases [33,34].

Various methods are used to correct the abnormal craniocervical junction and reduce compression including traction, intraoperative distraction, extension, and compression. This is done through horizontal and vertical odontoid reduction, but also through distraction that may be applied by intraoperative maneuvers to the head, surgical manipulations to the lateral atlantoaxial junction, or through a cage placed in the junction gap. PS is added when decompression is applied via reduction [27,35,36,37].

Patel et al. assessed the results of posterior occipito-cervical decompression and fusion operated with intra-operative traction/manipulation and instrumented reduction in cases with BI and intra-operative traction/manipulation, instrumented reduction and posterior occipito-cervical fusion resulted in good correction of radiology, functional performance and clinical neurology as well as excellent fusion rates without adverse effects of trans-oral surgery [38].

Preoperative traction applied for odontoid reduction might be beneficial [39].. In the present series, traction was applied for five days to a patient who presented with severe quadriparesis and resulted in neurological improvement. The patient was operated using the Goel procedure under continued traction, and we were able to achieve full odontoid reduction and brain stem decompression. Another option that is infrequently discussed is AD after PS. We showed that this was possible in a patient who had undergone posterior stabilization at a different center and presented to us after a lack of any clinical improvement. Effective AD was then applied using transnasal endoscopy, which resolved the residual anterior compression.

For PS in our series of patients, C2 fixation was most frequently used when stabilization was applied. Occipitocervical systems for PS are challenging and may predispose to complications such as CSF leak and infection. C1–C2 screw and rod systems and condylar–C2 screw and rod systems may be preferred in the presence of atlas assimilation [25,39-41]. Additionally, C2 pedicle placement is unfavorable when there is a thin pedicle or a high vertebral artery[29] . The laminar screw method defined by Wright is biomechanically sufficient and reduces the risk of neurovascular injury [42,43]. In our patients, there were no cases of channel or vertebral artery penetration nor mechanical complications.

In addition to the standard Goel procedure, other options are available. For example, the transoral atlantoaxial reduction plaque system has promising results by combining AD with PS and fusion in a single-stage procedure [44]. The transoral transpharyngeal path was selected for eight patients who underwent AD, and another two patients were operated via the endoscopic transnasal path. Far-lateral craniocervical approaches have advantages for AD, including the provision of a sterile surgical area and the ability to offer stabilization during the same session[9,10,11,45]. Notably, the endoscopic transnasal and transoral approaches may be superior to classical transoral surgery in terms of outcomes, although the importance of accurate navigation is paramount for these procedures. Caudal shifting and odontoid resection may not be possible for a patient undergoing ETNO because the hard palate may cause an obstruction [10,46]. Endoscopic transcervical odontoidectomy via a retropharyngeal approach gives anterior access to the junction and ensures a sterile surgical area [12].

This our study soughtassesses the outcomes associated with commonly performed employed surgical methods infor the treatment ofin basilar invagination. There wasWe found a significant improvement in functional outcomes associated with: 1) PD + PR + PS, 2) Goels procedure, and 3) AD + PS. Although the sample size was limited small, no significant functional improvement in function was obtained seen by with PD alone nor ETNO. The greatest combination of improvement in function and craniocervical alignment was achieved by seen with the Goel procedure. The literature on publications regarding basilar invagination has been focused on clinical findings or assessment of new technological developments. Some descriptive studies have also been performed, as have those proposing treatment algorithms [25,39-41]. In this study, we were able to compare outcomes amongbetween several common surgical techniques as these naturally evolved in our practice over time.

On rare occasions, PD alone may be the only appropriate treatment option for patients with basilar invagination [21,22,47]. PD may be best suited for patients with no anterior compression, having a normal or near-normal atlantodental interval, no dislocation during flexion-extension examinations [19,47]. PD alone was used for only three patients in our case series; however, two additional patients in our series had received PD alone at a prior institution before presenting with neurological decline necessitating further surgery. Of the three patients in which we performed PD alone, one presented with progressive worsening after surgery and was confirmed to have an increase in anterior compression, craniovertebral angle, and atlantodental interval. In the other two patients, no significant clinical change occurred after surgery.

Conclusion

In the treatment of basilar invagination, a combination of posterior decompression, reduction, cage distraction, and stabilization yielded the best clinical and radiological outcomes. Although the sample size was small, PD alone and ETNO failed to show a significant change in functional or radiographic improvement. Our findings suggest posterior stabilization should be considered in the treatment of basilar invagination, where possible.

Highlights

- This study assesses functional and radiographic outcomes of multiple surgical approaches for treatment of basilar invagination

- Choosing an appropriate pre-operative surgical approach is critical for maximizing outcome
- Patients with posterior stabilization had the best functional outcome with the Goel procedure slightly outperforming other approaches

Conflict of Interest Statemen

The authors have no conflicts of interest to declare.

Conflict-of-interest disclosure

The authors declare no competing financial interests and no sources of funding and support, including any for equipment and medications.

Ethics Committee Approval

This study is retrospective observational research. No human/animal participant is available, so no ethics approve is mandatory. All study is done under Helsinki declarations.

Author Contributions

All the authors declare that they have all participated in the design, execution, and analysis of the paper and that they have approved the final version

References

1. Chamberlain WE. Basilar Impression (Platybasia): A Bizarre Developmental Anomaly of the Occipital Bone and Upper Cervical Spine with Striking and Misleading Neurologic Manifestations. Yale J Biol Med. 1939;11(5):487-496.
2. Goel A, Jain S, Shah A. Radiological Evaluation of 510 Cases of Basilar Invagination with Evidence of Atlantoaxial Instability (Group A Basilar Invagination). World Neurosurg. 2018;110:533-543.
3. MS. G. Neuroradiology. In: MS. G, ed. Handbook of Neurosurgery. NY: Thieme 2010:S126-144.
4. Goel A, Sathe P, Shah A. Atlantoaxial Fixation for Basilar Invagination without Obvious Atlantoaxial Instability (Group B Basilar Invagination): Outcome Analysis of 63 Surgically Treated Cases. World Neurosurg. 2017;99:164-170.
5. Joaquim AF, Ghizoni E, Giacomini LA, Tedeschi H, Patel AA. Basilar invagination: Surgical results. Journal of craniovertebral junction & spine. 2014;5(2):78-84.
6. Goel A, Ellenbogen RG., Abdulrauf SI., Sekhar LN. Craniovertebral Junction: A Reappraisal. In: Principles of Neurological Surgery. 3rd ed. Philadelphia: Elsevier Saunders; 2012:S471-486.
7. Hsu W, Wolinsky JP, Gokaslan ZL, Sciubba DM. Transoral approaches to the cervical spine. Neurosurgery. 2010;66(3 Suppl):119-125.
8. Menezes AH. VT, Albert GW. Developmental and Acquired Abnormalities of The Craniocervical Junction. In: Youman's Neurological Surgery. Philadelphia: Elsevier Saunders; 2011:S2233-2244, S2962-2972.
9. al-Mefty O, Borba LA, Aoki N, Angtuaco E, Pait TG. The transcondylar approach to extradural nonneoplastic lesions of the craniovertebral junction. J Neurosurg. 1996;84(1):1-6.
10. Salas E, Sekhar LN, Ziyal IM, Caputy AJ, Wright DC. Variations of the extreme-lateral craniocervical approach: anatomical study and clinical analysis of 69 patients. J Neurosurg. 1999;90(2 Suppl):206-219.
11. Ture U, Pamir MN. Extreme lateral-transatlas approach for resection of the dens of the axis. J Neurosurg. 2002;96(1 Suppl):73-82.
12. Dasenbrock HH, Clarke MJ, Bydon A, et al. Endoscopic image-guided transcervical odontoidectomy: outcomes of 15 patients with basilar invagination. Neurosurgery. 2012;70(2):351-359; discussion 359-360.
13. Seker A, Inoue K, Osawa S, Akakin A, Kilic T, Rhoton AL, Jr. Comparison of endoscopic transnasal and transoral approaches to the craniovertebral junction. World Neurosurg. 2010;74(6):583-602.
14. Anderson PA, Oza AL, Puschak TJ, Sasso R. Biomechanics of occipitocervical fixation. Spine (Phila Pa 1976). 2006;31(7):755-761.
15. Goel A, Laheri V. Plate and screw fixation for atlanto-axial subluxation. Acta Neurochir (Wien). 1994;129(1-2):47-53.
16. Di Lorenzo N. Craniocervical junction malformation treated by transoral approach. A survey of 25 cases with emphasis on postoperative instability and outcome. Acta Neurochir (Wien). 1992;118(3-4):112-116.
17. Dickman CA, Crawford NR, Brantley AG, Sonntag VK. Biomechanical effects of transoral odontoidectomy. Neurosurgery. 1995;36(6):1146-1152; discussion 1152-1143.
18. Dickman CA, Locantro J, Fessler RG. The influence of transoral odontoid resection on stability of the craniovertebral junction. J Neurosurg. 1992;77(4):525-530.
19. Goel A, Bhatjiwale M, Desai K. Basilar invagination: a study based on 190 surgically treated patients. J Neurosurg. 1998;88(6):962-968.
20. Goel A. Progressive basilar invagination after transoral odontoidectomy: treatment by atlantoaxial facet distraction and craniovertebral realignment. Spine (Phila Pa 1976). 2005;30(18):E551-555.
21. Menezes AH, VanGilder JC, Graf CJ, McDonnell DE. Craniocervical abnormalities. A comprehensive surgical approach. J Neurosurg. 1980;53(4):444-455.

22. Menezes AH. Complications of surgery at the craniovertebral junction--avoidance and management. Pediatr Neurosurg. 1991;17(5):254-266.
23. Naderi S, Crawford NR, Melton MS, Sonntag VK, Dickman CA. Biomechanical analysis of cranial settling after transoral odontoidectomy. Neurosurg Focus. 1999;6(6):e7.
24. Zileli M, Cagli S. Combined anterior and posterior approach for managing basilar invagination associated with type I Chiari malformation. J Spinal Disord Tech. 2002;15(4):284-289.
25. Harkey HL, Crockard HA, Stevens JM, Smith R, Ransford AO. The operative management of basilar impression in osteogenesis imperfecta. Neurosurgery 1990;27:782-6
26. Bertrand J, Luc B, Philippe M, Philippe P. Anterior mandibular osteotomy for tumor extirpation: A critical evaluation. Head Neck 2000;22:323-7.
27. Magama S, Wakao N, Kitoh H, Matsuyama Y, Ishiguro N. Factors related to surgical outcome after posterior decompression and fusion for craniocervical junction lesions associated with osteogenesis imperfecta. Eur Spine J 2011;20 Suppl 2:S320-5.
28. Wei G, Shi C, Wang Z, Xia H, Yin Q, Wu Z. Surgical Outcome and Prognostic Analysis of Transoral Atlantoaxial Reduction Plate System for Basilar Invagination: A Voxel-Based Morphometry Study. J Bone Joint Surg Am. 2016 Oct 19;98(20):1729-1734. doi: 10.2106/JBJS.15.01151. PMID: 27869624.
29. Crockard HA, Sen CN. The transoral approach for the management of intradural lesions at the craniovertebral junction: review of 7 cases. Neurosurgery. 1991;28(1):88-97; discussion 97-88.
30. Botelho RV, Ferreira ED. Angular craniometry in craniocervical junction malformation. Neurosurg Rev. 2013;36(4):603-610; discussion 610.
31. Chandra PS, Kumar A, Chauhan A, Ansari A, Mishra NK, Sharma BS. Distraction, compression, and extension reduction of basilar invagination and atlantoaxial dislocation: a novel pilot technique. Neurosurgery. 2013;72(6):1040-1053; discussion 1053.
32. Goel A. Treatment of basilar invagination by atlantoaxial joint distraction and direct lateral mass fixation. J Neurosurg Spine. 2004;1(3):281-286.
33. Wajanavisit W, Lertudomphonwanit T, Fuangfa P, Chanplakorn P, Kraiwattanapong C, Jaovisidha S. Prevalence of High-Riding Vertebral Artery and Morphometry of C2 Pedicles Using a Novel Computed Tomography Reconstruction Technique. Asian Spine J. 2016;10(6):1141-1148.
34. Yeom JS, Buchowski JM, Kim HJ, Chang BS, Lee CK, Riew KD. Risk of vertebral artery injury: comparison between C1-C2 transarticular and C2 pedicle screws. Spine J. 2013;13(7):775-785.
35. Chandra PS, Prabhu M, Goyal N, Garg A, Chauhan A, Sharma BS. Distraction, Compression, Extension, and Reduction Combined With Joint Remodeling and Extra-articular Distraction: Description of 2 New Modifications for Its Application in Basilar Invagination and Atlantoaxial Dislocation: Prospective Study in 79 Cases. Neurosurgery. 2015;77(1):67-80; discussion 80.
36. 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 atlantoaxial dislocation. Eur Spine J. 2014;23(8):1666-1672.
37. Cobanoglu M, Bauer JM, Campbell JW, Shah SA.Basilar impression in osteogenesis imperfecta treated with staged halo traction and posterior decompression with short-segment fusion. J Craniovertebr Junction Spine. 2018 Jul-Sep;9(3):212-215. doi: 10.4103/jcvjs.JCVJS_63_18
38. Patel R, Solanki AM, Acharya A. Surgical outcomes of posterior occipito-cervical decompression and fusion for basilar invagination: A prospective study. J Clin Orthop Trauma. 2020 Nov 27;13:127-133. doi: 10.1016/j.jcot.2020.11.016. PMID: 33680811; PMCID: PMC7919955.
39. Claybrooks R, Kayanja M, Milks R, Benzel E. Atlantoaxial fusion: a biomechanical analysis of two C1-C2 fusion techniques. Spine J. 2007;7(6):682-688.
40. Harms J, Melcher RP. Posterior C1-C2 fusion with polyaxial screw and rod fixation. Spine (Phila Pa 1976). 2001;26(22):2467-2471.
41. Hartl R, Chamberlain RH, Fifield MS, Chou D, Sonntag VK, Crawford NR. Biomechanical comparison of two new atlantoaxial fixation techniques with C1-2 transarticular screw-graft fixation. J Neurosurg Spine. 2006;5(4):336-342.
42. Wang MY. Cervical crossing laminar screws: early clinical results and complications. Neurosurgery. 2007;61(5 Suppl 2):311-315; discussion 315-316.
43. Wright NM. Posterior C2 fixation using bilateral, crossing C2 laminar screws: case series and technical note. J Spinal Disord Tech. 2004;17(2):158-162.
44. Xia H, Yin Q, Ai F, et al. Treatment of basilar invagination with atlantoaxial dislocation: atlantoaxial joint distraction and fixation with transoral atlantoaxial reduction plate (TARP) without odontoidectomy. Eur Spine J. 2014;23(8):1648-1655.
45. Magerl F. SP. Stable posterior fusion of the atlas and axis by transarticular screw fixation. In: Cervical Spine. Austria: Springer Verlag; 1987:S322-327.
46. Menezes AH, VanGilder JC. Transoral-transpharyngeal approach to the anterior craniocervical junction. Ten-year experience with 72 patients. J Neurosurg. 1988;69(6):895-903.
47. Shah A, Goel A. Clival dysgenesis associated with Chiari Type 1 malformation and syringomyelia. J Clin Neurosci. 2010;17(3):400-401.