ORIGINAL ARTICLE

Role of effective canal diameter in assessing the pre-operative and the post-operative status of patients with bony cranio-vertebral anomalies

Anant Mehrotra, Arun Srivastava, Rabi N. Sahu, Raj Kumar

Department of Neurosurgery, Sanjay Gandhi Post Graduate Institute of Medical Sciences, Rai Bareilly Road, Lucknow, Uttar Pradesh, India

ABSTRACT

Introduction: The effective canal diameter (ECD) for the cranio-vertebral junction is measured from the posterior surface of the dens to the nearest posterior bony structure (foramen magnum or the posterior arch of the atlas). The ECD is the space which is occupied by the buffer space (which can be compromised without producing any signs or symptoms) and the cord itself. We intend to study the role of the ECD (especially in patients with markedly reduced ECD) in producing the symptoms and also the outcome of surgery in patients with bony cranio-vertebral junction (CVJ) anomalies.

Materials and Methods: A total of 67 consecutive patients from the period of January 2009 through June 2010 were prospectively included in the study. These patients were operated by a single experienced surgeon (the senior author) at the Sanjay Gandhi Post Graduate Institute of Medical Sciences, Lucknow. The ECD and the pre-operative Kumar and Kalra score (K and K score) (4) was calculated for all patients. The K and K score was also calculated at the time of discharge, at three months and six months follow-up. The patients were divided into three groups based on the ECD into 5 mm to 10 mm group, 10 mm to 15 mm group, and >15 mm group.

Results: There were 53 male (79.1%) patients and 14 female patients (20.9%) with mean age of presentation 27.10 years (±15.01 years) with range of 4-59 years. The duration of symptoms in our series varied from 1-120 months with mean of 23.79 months. The mean effective canal diameter was 9.027 mm (±2.23 mm) with range of 5-16 mm. The mean pre-operative K and K score was 19.27 (±4.19). There were 39 patients who had an ECD between 5 mm to 10 mm, 24 patients with ECD between 10 mm to 15 mm, and 4 patients with ECD more than 15 mm. The correlation coefficients between the effective canal diameter and the pre-operative and the post-operative Kumar and Kalra score at the time of discharge, 3 months and 6 months were 0.404 ($P < 0.001$), 0.320 ($P < 0.008$), 0.0302 ($P < 0.013$), and 0.284 ($P < 0.020$), respectively. The ECD and the pre-operative score were most significantly and strongly related to each other in patients with ECD between 5-10 mm.

Conclusion: The ECD is significantly related to the pre-operative status (K and K score) of the patient. This correlation was strongest in the group with ECD of 5-10 mm. It was also observed that as the follow-up increased, the correlation between the ECD and the post-operative K and K score became less stronger though they remained significantly related to each other.

Key words: Cranio-vertebral junction, effective canal diameter, Kumar and Kalra score

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Address for correspondence:
Dr. Raj Kumar, MCh, Professor and Head, Department of Neurosurgery, Sanjay Gandhi Post Graduate Institute of Medical Sciences, Rai Bareilly Road, Lucknow, Uttar Pradesh - 226 014, India. E-mail: rajkumar1959@gmail.com

Introduction

The cranio-vertebral junction (CVJ) refers to the bony structures at the foramen magnum region which are composed of occipital bone, atlas, and axis. The bony enclosure surrounds the medulla oblongata, cervico-medullary junction, and the upper part of the cervical spinal cord. Any anomaly, congenital, or acquired defect can produce symptoms by neural compression, vascular compromise and abnormal cerebrospinal fluid (CSF) dynamics.[1,2] The space available for canal is measured at the level of the first cervical vertebrae and this space is divided into three compartments.[3] One compartment is occupied by the odontoid, another by the cord, and the remaining third is the free space with each occupying one-third space. The free space acts as a buffer in which displacement can occur without producing any neurological deficit. The effective canal diameter (ECD) is the space which is present between the posterior surface of the odontoid and the nearest posterior bony structure (foramen magnum or the posterior arch of the atlas). The ECD is the space which is occupied by the cord along with the buffer space for movement of the neck. As the CVJ has a complex anatomy and a poorly understood biomechanics and kinematics, it is not known how important is the ECD in producing the symptomatology. We intend to study the role of the ECD (especially in patients with markedly reduced ECD) in producing the symptoms and also the outcome of surgery in patients with bony CVJ anomalies.

Materials and Methods

A total of 67 consecutive patients from the period of January 2009 through June 2010 were prospectively included in the study. These patients were operated by a single experienced surgeon (the senior author) at the Sanjay Gandhi Post Graduate Institute Of Medical Sciences, Lucknow. There were a total of 77 patients out of which 67 patients were included in the study as these patients fulfilled the inclusion criteria decided at the beginning of the study.

Inclusion criteria

1. Bony CVJ anomalies (congenital or acquired); and
2. Follow-up of atleast six months.

Exclusion criteria

1. Associated soft tissue anomaly eg. Chiari malformation, syringomyelia;
2. Follow-up of less than six months;
3. Compression over the cord/thecal sac at a level in addition to CV junction;
4. Re-surgery; and
5. Cord signals changes.

All patients had initially come to our Out Patient Department (OPD) with features suggestive of thecal sac compression/ myelopathy. Our institute being a tertiary care institute, 21 patients had visited our OPD with magnetic resonance imaging (MRI) already done. Those patients in whom there were features of myelopathy or cord compression a non contrast MRI of the CVJ was advised [Figure 1] (except in those patients who had already undergone MRI). In patients who were known cases of inflammatory joint diseases/infective etiology (e.g., rheumatoid arthritis, pott's spine), a gadolinium enhanced MRI was advised. If the clinical features or radiology was suggestive of CV junction anomaly a plain X-ray of the CVJ in lateral neutral, flexion and extension view and in an anterior-posterior view was advised. If on plain X-ray there were findings suggestive of bony CVJ anomalies, then the patient was asked to undergo Computerized Tomography (CT) of the CVJ with 2 mm cuts with flexion, extension, and neutral view. We have a protocol of having sagittal and coronal views and 3-D reconstruction films of the CVJ as well. Based on the radiological investigations, the diagnosis of either mobile/fixed Atlanto-axial dislocation (AAD) with or without Basilar Invagination (BI) was established. Associated bony anomalies like occipitalized atlas fused cervical bodies etc., were similarly diagnosed. Incentive spirometry and limb physiotherapy was initiated from the OPD itself. At the time of admission, particulars of the patient like name, age, sex, and occupation were noted, and a detailed history including the symptoms and there durations and clinical examination along with K and K[4] scoring was done and recorded. In patients of fixed AAD or BI, traction was applied 24-48 hours prior to surgery. A plain X-ray of the CVJ was done after application of the traction to look for any reducibility of the atlanto-dental interval (ADI). If there was no reduction of the ADI, a trans-oral decompression and posterior stabilization was planned (by either contour rod or sublaminar wiring). However, if there was reduction of the ADI, then only posterior fusion was planned.

The ECD was measured from the posterior surface of the dens [Figure 2] to the nearest posterior bony structure i.e. either

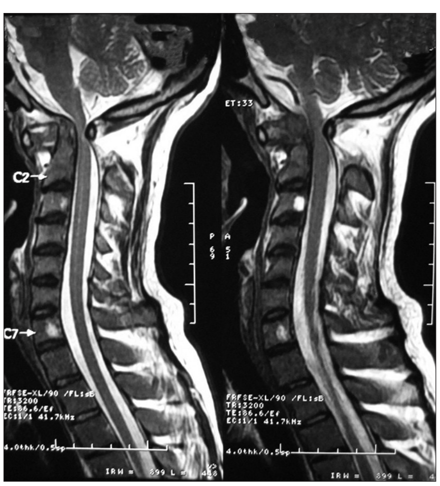

Figure 1: MRI showing severe narrowing at CVJ

Figure 2: CT CVJ showing method to calculate ECD

the posterior rim of the foramen magnum or the posterior arch of the first cervical vertebra whichever was the minimum at this region [Figure 2]. The ECD was measured on CT CVJ in neutral view. In patients with inflammatory joint disease (three patients) and CVJ tuberculosis (one patient), the ECD was calculated from the posterior aspect of the inflammatory soft tissue. The patients were categorized into three groups based upon the ECD. Group 1 was patients with ECD between 5-10 mm, Group 2 was patients with ECD between 10-15 mm, and Group 3 was patients with ECD more than 15 mm. The pre-operative and the post-operative clinical status of the patient was assessed by the K and K myelopathic scoring system[4] [Table 1]. The score was recorded in the pre-operative period, at the time of discharge, at three and six months follow-up. The correlation between the ECD (group-wise and in total as well) and the pre-operative and the post-operative K and K score was done. The SPSS version 16.0 was used for statistical analysis.

The patients were mobilized as early as possible depending upon the K and K score (usually the day after the surgery). A plain X-ray of the CVJ was done in the immediate post-operative period to ascertain the adequacy of odontoidectomy and posterior fixation as applicable. The patients were allowed orally (in case of trans-oral procedure) next day morning. The patients were discharged on the 7th post-operative day and were followed-up in OPD. The patients were followed-up at 1.5, 3, and 6 months and yearly thereafter.

Results

There were 53 male (79.1%) patients and 14 female patients (20.9%) with mean age of presentation 27.10 years (±15.01 years) with range of 4-59 years [Table 2]. The duration of symptoms in our series varied from 1-120 months with mean of 23.79 months [Table 2]. Majority of the patients had motor and sensory symptoms. Spasticity and motor weakness was present in 55 patients (82.1%) and 54 patients (80.6%), respectively. Total 80% of patients had sensory symptoms. Other major symptoms included sphincteric involvement in 32 patients (47.8%), neck tilt/restriction of neck movement 30 patients (44.8%), and respiratory difficulty in 27 patients (40.3%).

The mean pre-operative K and K score (4) was 19.27 (±4.19). Out of 67 patients, 24 patients had BI with fixed AAD (35.8%), 14 (21%) had only fixed AAD, 20 (29.9%) had mobile AAD, 5 (7.5%) patients had os odontoideum, and 3 (4.5%) had fracture odontoid [Table 3]. The mean effective canal diameter was 9.027 mm (±2.23 mm) with range of 5-16 mm. three patients had inflammatory joint disease (one each of Juvenile Idiopathic Arthritis, Rheumatoid arthritis and Still's disease), one patient had Down's syndrome, and one patient had CVJ tuberculosis (on anti-tubercular treatment for three months).

Radiologically, 26 patients had occipitalized atlas, and out of these 26 patients, 10 had partially occipitalized atlas. Among these 26 patients, 12 patients had associated C2-C3 fusion. 5 patients had only C2-C3 fusion. 1 patient had bifid C2, 1 patient had clival segmentation defect, 1 had hypoplastic C1 arch, and 1 patient had combination of C2-C3 and C5-C6 fusion. 2 patients had C3-C4 fusion. 11 patients had cord intensity changes at the CVJ [Table 4].

Pre-operatively, skull traction was applied in 44 patients (65.7%). Total of 24 patients underwent only post fusion (35.9%). Out of these 24 patients, 18 patients (26.9%) underwent post-fusion by sublaminar wiring and remaining 6 (9%) patients by contour rod. 43 (64.1%) patients underwent combined approach of trans-oral decompression and posterior fusion (TOPF). Out of these 43 patients, 27 patients (nearly 40%) underwent sublaminar wiring for posterior fusion and examining 16 patients underwent contour rod fixation for posterior fusion (23.9%) [Table 5].

Fifty nine (88.06%) patients had significant improvement in their symptoms, whereas seven patients had no improvement and one patient expired during the post-operative period. Five patients had wound dehiscence (one had oral wound involvement and four had posterior wound dehiscence). Out of the four patients who had posterior wound dehiscence,

Table 1: Kumar and Kalra scoring system

Score	1	2	3	4	5
Motor power	Contraction without movement or plegia	Movement with gravity	Movement against gravity	Movement against resistance	Normal power
Gait	Wheel chair bound or bedridden	Restricted mobility despite aid	Mobility using aid	Slight disturbance, no aid required	Normal
Sensory involvement	Total loss of function	Restriction of function of daily living	Significant (>25%) but no dysfunction of daily living	Insignificant	No sensory loss
Sphincteric involvement	Retention requiring indwelling catheter	Occasional CIC required with hesitancy	Hesitancy with residual urine not requiring catheter	Hesitancy but no residual urine	Normal
Spasticity	Affected part rigid in flexion or extension	Passive movements difficult	Passive movements easy	Slight increase , a catch felt	No increase in tone
Respiratory difficulty	Requires assisted respiration	Dyspnoea at rest	Dyspnoea on mild exertion	Dyspnoea on moderate exertion, unable to do active work	Normal

Table 2: Age and duration of symptoms

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Age (years)	67	55	4	59	27.10	15.069
Duration of symptoms (months)	67	119	1	120	23.79	26.368

Table 3: Diagnosis

Diagnosis	No. of cases (*n*=67)	Percentage
Mobile AAD	20	29.9
Fixed AAD	14	20.9
Basilar invagination with fixed AAD	24	35.8
Fracture odontoid	3	4.5
Os odontoideum	5	7.5
Mobile AAD with BI	1	1.5

AAD – Atlanto-axial dislocation; BI – Basilar invagination

Table 4: Associated bony anomalies

Associated bony anomalies	Frequency	Percentage
Occipitalised atlas	14	20.89
Occipitalised atlas+C2-C3 fusion	12	17.91
Only C2-C3 fusion	5	7.46
C3-C4 fusion	2	2.98
Bifid C2	1	1.49
C2-C3+C5-C6 fusion	1	1.49
Clival segmentation	1	1.49
Hypoplastic C1 arch	1	1.49

Table 5: Procedures performed

Surgery	No. of cases (*n*=67)	Percentage
Post fusion with wire	18	26.9
Post fusion with rod	6	9.0
TOPF (wire)	27	40.3
TOPF (rod)	16	23.9

TOPF – Trans-oral decompression and posterior fusion

Table 6: Complications

Complications	Frequency	Percentage
Wound dehiscence	5	7.46
Posterior wound	4	5.97
Oral wound	1	1.49
CSF leak	2	2.98
Meningitis	1	1.49
Death	1	1.49

CSF – Cerebrospinal fluid

Table 7: Correlation between K and K score and ECD

	Mean K and K score	Correlation coefficient	*P* value
Pre-operative	19.27 (+/–4.190)	0.404	0.001
At time of discharge	21.87 (+/–4.217)	0.320	0.008
3 months follow-up	23.33 (+/–4.391)	0.302	0.013
6 months follow-up	23.46 (+/–4.258)	0.284	0.020

ECD – Effective canal diameter

two had CSF leak, and among these two patients, one had meningitis (and this patient eventually expired) [Table 6].

The mean post-operative K and K score (4) at the time of discharge, three months and six months follow-up are 21.87 (±4.217), 23.33 (±4.391), and 23.46 (±4.258), respectively. There was more marked improvement in the intial post-operative period and with the passage of time the improvement stabilized as seen by only minimal change in the mean of the post-operative K and K score at three months and six months. The correlation coefficients between the effective canal diameter and the pre-operative and the post-operative K and K score at the time of discharge, three months and six months were 0.404 ($P < 0.001$), 0.320 ($P < 0.008$), 0.0302 ($P < 0.013$), and 0.284 ($P < 0.020$), respectively [Table 7].

The ECD and the pre-operative score was significantly related to each other indicating that the ECD plays a major role in determining the severity of the presentation [Table 7]. The strength of correlation between the ECD and the post-operative scores reduced as the follow-up increased indicating that the ECD is more strongly related to the post-operative improvement in the early post-operative period and with passage of time the ECD might play a lesser, though significantly important, role in governing the post-operative improvement [Table 7]).

There were 39 patients who had an ECD between 5 mm to 10 mm, 24 patients with ECD between 10 mm to 15 mm, and 4 patients with ECD more than 15 mm. The mean pre-operative K and K score and mean K and K score at the time of discharge, at three months and six months follow-up is given in Table 7. The ECD was significantly correlated with the pre-operative score [Tables 8 and 9] indicating that the ECD played an important role in determining the pre-operative score. The strength of correlation reduced as the follow-up increased [Tables 8 and 9]. In Table 9, the rows indicate the correlation coefficient alternately with the *P* value and the three columns are the three groups of the patients. The ECD and the pre-operative score were most significantly and strongly related to each other in patients with ECD between 5-10 mm. With increasing ECD i.e. in group of patients with ECD between 10-15 mm and >15 mm, the strength and significance of correlation between the ECD and the pre-operative K and K score reduced (though it still remained significant) [Tables 8 and 9]. The correlation between the ECD and the post-operative score at the time of discharge, at three months and six months follow-up reduced as the follow-up increased across the three groups [Table 9].

Discussion

The CVJ anatomy consists of various neural structures like the cervico-medullary region, the cerebellum, fourth ventricle,

Table 8: Mean K and K score in each group

ECD	Mean K and K score pre-operatively	Mean K and K score at discharge	Mean K and K score at 3 months follow-up	Mean K and K score at 6 months follow-up
5-10 mm	18.81	21.09	22.89	23.01
10-15 mm	19.46	22.21	23.53	23.66
>15 mm	19.54	22.31	23.57	23.71

ECD – Effective canal diameter

Table 9: Correlation between ECD and K and K score at pre-operative period and various follow-ups

Pearson correlation ECD	Pre-op	*P* value	Post-op (at discharge)	*P* value	Post-op (at 3 months follow-up)	*P* value	Post-op (at 6 months follow-up)	*P* value
5-10 mm	0.421	0.002	0.341	0.008	0.303	0.012	0.297	0.019
10-15 mm	0.401	0.007	0.311	0.014	0.296	0.022	0.278	0.029
>15 mm	0.357	0.012	0.291	0.023	0.257	0.025	0.234	0.028

ECD – Effective canal diameter

and the lower cranial and upper cervical nerves and also includes important vessels like vertebral and posterior inferior cerebellar artery. Any lesion in this region can therefore produce signs or symptoms by compression of any of the neural structure(s) or vascular compromise and abnormal CSF dynamics.[1,2] The effective canal diameter is measured from the posterior surface of the dens to the nearest posterior bony structure (foramen magnum or the posterior arch of the atlas). The ECD is the space which is occupied by the buffer space (which can be compromised without producing any signs or symptoms) and the cord itself. If there is any breach in the "Safe zone of Steel", then there is likelihood of production of signs and symptoms of cervico-medullary compression. It appears logically that any compromise in the ECD would lead to the production of the symptoms and more severe the compression more severe would be the symptoms. The bony CVJ anomalies commonly encountered are mobile and fixed AAD, basilar invagination, os odontoideum, and fracture odontoid. Although pathologies of bony CVJ anomalies may vary, their presentations are more or less similar.

In our study, the ECD and the pre-operative score was significantly related to each other indicating that the ECD plays a major role in determining the severity of the presentation. The relation was strongest in the group where the ECD was between 5 and 10 mm, and in the remaining two groups the association was not as strong (though it was significantly related to the pre-operative K and K score[4]). The relation between the ECD and the pre-operative score although was significant, but there appears to be other factors which might play an important role in determining the pre-operative K and K score (reflecting the severity of the symptoms), especially if the ECD is on the higher side. Duration of the symptoms might be one of the factors apart from ECD which might govern the severity of the symptoms. Interestingly, there were few patients in our study who had short duration of history but had a low K and K score (without any history of trama) and vice versa.

With flexion the cord becomes longer and thinner and with extension movements the cord becomes thicker and shorter. In one study, the author performed cadaveric dissection and studied the dynamic air myelography of patients and he observed overall spinal cord length changes of 45 to 75 mm during flexion and extension movement of the cord.[5] This was further substantiated by MRI studies by Condon *et al*.[6] The tensile forces produced by the cervical flexion are carried primarily by the dura and the pia-arachnoid rather than the cord and the nerve roots and is balanced by the tensile forces not from the filum terminale but rather from the nerve roots.[7,8] Repeated movement might cause some trauma to the cord in a compromised canal. Occupation of the patient might be another factor. For instance, lower K and K score (despite relatively higher ECD) was seen in patients who were laborers and better score (despite lower ECD) was seen in housewives. Perhaps repeated unnoticed trivial trauma to the cord in an already compromised canal diameter in a laborer might be responsible for the disparity. Associated anomalies, especially fusion of vertebrae at other cervical region, might have some protective role in preventing recurrent trivial trauma to the cord due to restricted movement at that joint or alteration in the kinematics and biomechanics of the region. Due to fusion, this mobility might be altered and reduce the severity of the symptoms. In a study by Dickman *et al*. they found that after transoral odontoidectomy in patients with congenital bone malformations and pre-existing fusions or assimilations of the joints had only 50% risk of instability compared to patients with <90% rate of instability in patients with rheumatoid arthritis.[9] Other factors might be history of repeated trauma to the head –neck region (leading to mono/para/quadriparesis), associated diseases like rheumatoid arthritis, genetics (folate metabolism abnormalities) etc.

In our study, we found that the strength of correlation between the ECD and the post-operative scores reduced as the follow-up increased indicating that the ECD is more strongly related to the post-operative improvement in the early post-operative period and with passage of time the ECD might play a lesser, though significantly important, role in governing the post-operative improvement. In the early post-operative period, the compression over the thecal sac was relieved (increased ECD) and that would lead to improvement in the symptoms. With increasing follow-up, the relation between the ECD and the K and K score (4) reduced, though it was significantly positive.

With increasing follow-up, other factors might play an important role in determining the outcome. In a study conducted by Dickman *et al.* they found that immediately after fixation by cable techniques the motion at C1-C2 in all directions was controlled only 20%-50% depending upon the technique used.[10] Therefore, by post-fusion absolute immobilization is not achieved and so with passage of time, this difference in the ablity to immobilize might explain the reduced significance of association between the ECD and the improvement. In two patients with similar pre-operative ECD and post-operative decompression, they might have different immobilization and as proper immobilization is necessary for fusion they might have some differences in their outcomes.

Fusion also depends upon the nutritional status of the patient. For immobilization, we advice Philadelphia collar to all our patients in the post-operative period. As patients might have differences in compliance, they might have different fusion rates and this might be another factor explaining the reduced significance of ECD.

The ECD appears to be related significantly to the pre-operative severity of the symptoms and is also significantly related to the post-operative improvement. The relation between the ECD and the pre-operative severity was maximum in the group of patients who had ECD between 5 and 10 mm. As the follow-up increased, the strength of the relation reduced but was still significantly positive.

To properly establish the role of ECD in determining the pre-operative neurological status and its effect on post-operative score a larger sample size would be needed. Moreover, in our study, although we have used the K and K scoing system[4] which includes respiratory component, but in our study, no objective assessment of respiratory function was done by pulmonary function tests (PFT). As respiration is apparently an important factor in assessing the post-operative morbidity, it would be advisable to include PFT in future studies on ECD (currently a prospective study is underway in our department to correlate the ECD with PFT).

Conclusions

The ECD is the space occupied by the cord along with the buffer space and any compromise in the ECD is likely to cause neurological deterioration. In our study, we found that the ECD is significantly related to the pre-operative status of the patient. This correlation was strongest in the group of patients with ECD of 5-10 mm. It was also observed that as the follow-up increased, the correlation between the ECD and the post-operative score became less stronger though they remained significantly related to each other. It appears that there are factors other than ECD that govern the post-operative course of the patient.

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