Received:
21 April 2017

Revised:
6 July 2017

Accepted:
6 August 2017

<https://doi.org/10.1259/bjr.20170286>

Cite this article as:

Erdem Toslak I, Lomasney LM, Jones NS, Wojewnik B, Aziz A, Alsabban K, et al. A practical radiographic visual estimation technique for the prediction of developmental narrowing of cervical spinal canal. *Br J Radiol* 2017; **90**: 20170286.

FULL PAPER

A practical radiographic visual estimation technique for the prediction of developmental narrowing of cervical spinal canal

¹ICLAL ERDEM TOSLAK, MD, ¹LAURIE M LOMASNEY, MD, ²NATHANIEL S JONES, MD, ³BARTOSZ WOJEWNIAK, MD, ⁴AMANY AZIZ, MD, ⁵KHALID ALSABBAN, MD and ⁶WILLIAM ADAMS, MA

¹Department of Radiology, Loyola University Medical Center, Maywood, IL, USA

²Department of Primary Care Sports Medicine, Loyola University Medical Center, Maywood, IL, USA

³Department of Orthopedic Surgery, Loyola University Medical Center/Loyola University Medical Center, Maywood, IL, USA

⁴Department of Surgery, Loyola University Medical Center, Maywood, IL, USA

⁵Department of Internal Medicine, University Hospitals Cleveland Medical Center, Cleveland, OH, USA

⁶Division of Biostatistics, Clinical Research Office, Loyola University Medical Center, Maywood, IL, USA

Address correspondence to: Dr Iclal Erdem Toslak

E-mail: driclalerdem@yahoo.com

Objectives: To determine if visual spinal canal percentage of facet overlap could be used as a rapid visual pre-screening test to detect developmental bony spinal canal narrowing on lateral cervical radiographs.

Methods: Lateral cervical spine radiographs with radiology report documenting developmental narrowing of the spine canal were retrospectively identified. Cohort was supplemented with additional images without such documentation. Utilizing a radiology work station, one reader (Orthopaedics) calculated the Torg ratio at C3–C6. Two readers (Radiology, Primary Care Sports Medicine) visually estimated percentage (≥ 80 , ≥ 90 , 100%) of spinal canal overlaid by facet articulations C3–C6 for all cases independently. Statistical analysis included accuracy tests and kappa test for comparing the gold standard and inter-, intra-observer reliability, respectively.

Results: 96 lateral images were included; 25 had abnormal radiology reports. High specificity (range, 91–93%) and true negative predictive values (range, 88–93%) achieved consistent statistical significance for relationship between facet/canal overlap and Torg ratio for both combined and individual data points. Sensitivity values (range, 59–75%) showed a trend toward association, with statistical significance for only the C3 level at 80% overlap. Interobserver agreement was substantial. Intra-observer reliability was moderate to perfect.

Conclusion: Visual estimation of percentage of facet overlap of the spinal canal is a valid tool to identify individuals with potential developmental narrowing of the spinal canal as a screening prompt to select which patients may need formal calculation utilizing accepted metrics.

Advances in knowledge Visual estimation of percentage of facet overlap from lateral radiographs can predict developmental narrowing of cervical spinal canal.

INTRODUCTION

Narrowing of the sagittal bony canal diameter of the cervical spine, including developmental narrowing, has been shown to have a strong relationship to neurological injury after trauma.¹ Long-term follow-up studies to determine the association between the canal diameter and long-term development of symptoms have shown that even asymptomatic individuals can develop neurological symptoms due to superimposed degenerative/proliferative changes that result in narrowing of the spinal canal.²

Pavlov et al calculated a ratio (Torg-Pavlov ratio or Torg ratio) by dividing the sagittal diameter of the spinal canal to

the sagittal diameter of the corresponding vertebral body to describe developmental spinal canal stenosis which proved to be reliable for determining cervical spinal stenosis.³ This study and others further proved that this ratio was closely related to increased risk of acute cervical spinal cord injury after minor trauma to the cervical spine.^{4,5} However, formal calculations should be done for every patient, a task that can be impractical depending on technical proficiency, clinical encounter time limits and/or technologic resources. Recently, a different method of measuring the lateral mass-to-canal diameter ratio was reported as an indicator of developmental cervical stenosis and was said to be useful as a screening tool to prompt cross-sectional

imaging or surgical referral.⁶ In contrast to the Torg ratio, they obtained multiple ratios including the spinolaminar line-to-lateral mass distance, lateral mass-to-posterior vertebral body distance, spinal canal (spinolaminar line-to-vertebral body) diameter and vertebral body diameter. Of these measures, however, the authors found only the ratio of lateral mass-to-posterior vertebral body distance to spinal canal (spinolaminar line-to-vertebral body) diameter to be an indicator of developmental cervical stenosis and, this tool was found to be applicable to only C5 level. Similar to the Torg ratio, this tool also requires numerical calculation.⁶ Studies describing MRI techniques have also been presented with alternative grading systems, and some of these include visual estimation of cervical spinal canal narrowing.⁷ However, utilization of MRI fails the definition of screening being a very expensive secondary imaging modality that is not applicable to all patient populations.⁸ Therefore, there is a need for an inexpensive, rapidly applied screening tool applicable to all patient populations to quickly stratify probability of developmental canal narrowing to prompt a more precise calculation in an at risk population. Since the facet articulations share a roughly similar geographic location as the spinal canal on lateral radiographs of the cervical spine, it would be convenient if a relationship could be established between these two elements to serve as a prompt for formal calculation of the Torg ratio.

Figure 1. Sample Torg ratio measurements on true lateral cervical spine radiograph for C3 level in a 32-year-old female presenting with neck pain after motor vehicle crash. Line A represents mid-sagittal diameter of the spinal canal and line B represents mid-sagittal diameter of the vertebral body drawn from anterior to posterior surfaces. The Torg ratio of C3 level was recorded as 0.97% (non-narrowed); the remaining levels were above the threshold for canal narrowing.

The purpose of this study was to determine if visual percentage of facet overlap of the spinal canal could be used as a rapid visual pre-screening test to detect developmental bony spinal canal narrowing on lateral cervical radiographs and to evaluate the efficiency and reproducibility of this method.

METHODS AND MATERIALS

Study population

This retrospective study was pre-approved by the IRB Committee; individual patient consent was waived. Radiology information system database was searched from January 2011 to November 2015 for key words (developmental narrowing, developmental bony narrowing, developmental stenosis) on upright cervical spine radiographic series completed on patients from 18 to 49 years regardless of patients' symptoms and diagnosis. To enhance power of analysis, additional consecutive images from a similar patient population were collected that did not include the key words in the radiology report. The ratio of enrollees with developmental narrowing to non-narrow individuals was allowed to exceed the incidence in the natural population to assure sufficient quantity of positive interpretations to adequately challenge the concept with statistical confidence.

Exclusion criteria included technical failure (motion artefact, incomplete visualization, oblique positioning), previous posterior cervical spine surgical procedures, underlying segmentation

Figure 2. True lateral cervical spine radiograph of 36-year-old female presenting with stiff neck for 3 days. Both readers rated C3 (top lines) and C4 as ≥ 90 and ≥ 80 % overlying facet coverage, C5 (bottom lines) and C6 levels as ≥ 80 % overlying facet coverage. Torg ratio was below 0.8 for all levels.

anomalies, improperly positioned or rotated films, inadequate visualization of C3 through superior endplate C7 vertebra and presentation for major trauma such as motor vehicle crashes, motorcycle crash or fall greater than 20 feet (minor sports-related injuries were not excluded). Of the original identified 130 images, 34 were excluded due to presence of corpectomy, obscuration of the canal due to the instrumentation, and rotated images. Of the remaining 96 patients, 25 patients were identified from review of imaging records, and an additional 71 patients through sequential imaging events. The images selected represent a true clinical population with representative heterogeneity of race, gender, age and clinical presentation.

Radiography and image analysis

True lateral cervical radiographs in an upright position were taken using a digital radiography system with the head neutrally positioned and the shoulders depressed. All digital data were transferred to a server (Inteleviewer by Intelera version 4.11.1, Canada), anonymized and randomized.

Two board-certified physicians (Radiology, 22 years experience; Primary Care Sports Medicine, 7 years experience) blinded to

Figure 3. True lateral cervical spine radiograph of 36-year-old female referred for clinical diagnosis cervical stenosis. Both readers rated C3 as complete (100%) facet coverage (square), C4 and C6 levels as ≥ 90 and $\geq 80\%$ overlying facet coverage, C5 level as $\geq 80\%$ overlying facet coverage (lines). Torg ratio measurements revealed value of below 0.8 for all levels.

the clinical data and colleague interpretation independently reviewed the images to assess inter-observer reliability on Radiology workstations (Barco 6MP; Duluth, GA) with full ability to manipulate images (windowing, magnification), but restricted from measuring. Physicians from different disciplines participated in image analysis to establish consistency and reproducibility of the technique despite differences in medical training and area of expertise. Visual estimates with regard to percentage of facet articulation overlap of the bony spinal canal at each level, C3–C6, were performed subjectively and entered into an electronic survey form. Any visually detected canal narrowing was categorized as ≥ 80 , ≥ 90 and/or 100%. One of the physicians re-reviewed 25 images 2 months after the first reading session to assess intra-observer reliability. Consensus was then subsequently reached between the two physicians for data points in which there was reader disagreement from the original reading.

Torg ratio measurements

Torg ratio measurements were accepted as gold standard in our study to predict at risk individuals. Measurements were performed using the distance measurement tool present in the picture archiving and communication system for each level from C3 to C6 for each patient by an orthopaedic spine surgeon (5 years experience) blinded to the clinical data using the Torg ratio method (Figure 1). According to this method, the sagittal diameter of the spinal canal was divided by the sagittal diameter of the corresponding vertebral body, and the ratio for every level was recorded.³ Lateral cervical spine radiographs were categorized as normal or narrow on the basis of Torg ratio measurements such that any ratio lower than 0.8 was accepted as a narrow canal (Figures 2 and 3). Then, Torg ratio measurements and consensus results of visual assessment were compared.

Statistical analysis

Data were analysed using SAS v. 9.4 (SAS Institute Inc., Cary, NC, USA). Descriptive statistics included frequency, percentage, mean, SD.

The consensus visual ratings for the two readers were also compared with the gold standard and accuracy statistics were estimated for every level of a targeted area. Using the gold standard as a reference, the sensitivity, specificity, negative predictive value and positive predictive value of the physicians' visual ratings were estimated using exact 95% CI for the level and degree of stenosis. All differences associated with a chance probability of .05 or less were considered statistically significant.

Inter-observer reliability between physicians for percentage of facet articulation overlap of the bony spinal canal at each level was estimated using weighted kappa to count disagreements separately due to the ordinal nature of the assessments on lateral cervical radiographs. Similar analyses were performed to assess for intra-observer reliability. Kappa estimates were interpreted as poor agreement (≤ 0), slight agreement (0–0.20), fair agreement (0.20–0.45), moderate agreement (0.45–0.60), substantial agreement (0.60–0.80) or as near perfect agreement (0.80–0.99).⁹

Table 1. Accuracy tests of visual assessment of cervical canal narrowing according to the levels and $\geq 80\%$ degree of facet overlap of spinal canal

Vertebrae level	<i>n</i>	Point estimate	95% CI		Exact p-value
			Lower	Upper	
C3	96				
Sensitivity		0.7500	0.5090	0.9134	0.04
Specificity		0.9211	0.8360	0.9705	<0.001
True positive probability		0.7143	0.4782	0.8872	0.08
True negative probability		0.9333	0.8512	0.9780	<0.001
C4	96				
Sensitivity		0.6522	0.4273	0.8362	0.21
Specificity		0.9315	0.8474	0.9774	<0.001
True positive probability		0.7500	0.5090	0.9134	0.04
True negative probability		0.8947	0.8031	0.9534	<0.001
C5	96				
Sensitivity		0.6000	0.3605	0.8088	0.50
Specificity		0.9211	0.8360	0.9705	<0.001
True positive probability		0.6667	0.4099	0.8666	0.24
True negative probability		0.8974	0.8079	0.9547	<0.001
C6	96				
Sensitivity		0.5909	0.3635	0.7929	0.052
Specificity		0.9054	0.8148	0.9611	<0.001
True positive probability		0.6500	0.4078	0.8461	0.26
True negative probability		0.8816	0.7871	0.9444	<0.001

n, the number of valid patients being rated; CI, confidence interval.

RESULTS

Ultimately, 96 patients (48 female, 48 male; age range 18 to 49; mean age 39 ± 8) were included in the analyses. Overall, $\geq 80\%$ of the spinal canal coverage on lateral cervical spine radiographs was shown to have high specificity for narrowing ranging from 91 to 93% as well as high negative predictive values for ranging from 88 to 93% as defined by the Torg ratio (Table 1). Specificity of consensus reading at all levels, sub-categories combined ranged from 0.91 to 0.93 at all levels C3-C6, with strongest values at C4 (Table 2). Statistical significance was retained for

sub-categories of percentage of canal coverage. True negative predictive values ranged from 0.88 to 0.93, with strongest value at C3. Statistical significance was retained for all sub-categories of percentage coverage (Table 2). Values for sensitivity and true positive predictive value were lower, below threshold for statistical significance except for the 75% sensitivity at the C3 level ($p = .04$) and for the 75% true positive value at the C4 level ($p = .04$) (Table 3). Values mostly closely reached statistical significance at the C3 level, especially for percentage overlap ≥ 80 percent (Table 1).

Table 2. The summary of true negative probability and specificity results of visual assessment of facet overlap of spinal canal for the diagnosis of canal narrowing

% of coverage	$\geq 80\%$ coverage		$\geq 90\%$ coverage		100% coverage	
	True probability (%)	Specificity (%)	True probability (%)	Specificity (%)	True probability (%)	Specificity (%)
C level vertebra						
C3	93	92	86	96	83	100
C4	90	93	83	100	76	100
C5	90	92	85	96	81	100
C6	88	91	83	93	77	99

Table 3. The summary of true positive probability and sensitivity results of visual assessment of facet overlap of spinal canal for the diagnosis of canal narrowing^a

	≥80% coverage		≥90% coverage		100% coverage	
C level vertebra	True + probability (%)	Sensitivity (%)	True + probability (%)	Sensitivity (%)	True + probability (%)	Sensitivity (%)
C3	71	75	73	40	100	20
C4	75	65	100	35	–	–
C5	67	60	70	35	100	10
C6	65	60	61	36	–	–

^aTrue positive probability and sensitivity are not estimable for some levels for 100% stenosis.

There was substantial agreement between the two physicians on all levels with the kappa values ranging from 0.61 to 0.72 within 95% CI (Table 4). Intraobserver agreement was moderate to perfect agreement with the kappa values ranging from 0.48 to perfect within 95% confidence interval on the vertebral levels from the first to second observation (Table 4).

DISCUSSION

Mathematical calculations of spinal canal diameter are important for identifying individuals at risk for spinal cord injury in athletic and low-impact trauma settings. The width of the cervical canal, defined by its mid-sagittal diameter or cross-sectional area, has been shown to be an important factor in the occurrence and severity of a number of disorders including neurological injury after cervical trauma, neuropathy and degenerative cervical spinal disorders.^{1,4} A variety of tools have been used by different investigators to evaluate the cervical spinal canal diameter. One of the most popular and maybe the oldest one is the Torg ratio which is obtained from lateral cervical radiographs by measuring the spinal canal to vertebral body ratio.^{1,4,5,10} All of these studies proved the correlation between the canal diameter obtained by Torg ratio method and the neurological outcome although they reached different thresholds for Torg ratio as the indicator of spinal stenosis. Pavlov et al calculated 0.82 as the threshold level

and designated the ratio as 0.8 for an easier recall.³ Similarly, Kang et al whose study had the largest population to compare neurological outcome of cervical spinal trauma and sagittal measurements of the cervical spine, calculated the ratio as 0.82 for complete and 0.84 for incomplete canal related injuries.¹⁰ Once cervical spinal stenosis is identified and confirmed with more advancing imaging, a variety of management options may be considered for individual patients ranging from observation to restriction from contact sports to surgical decompression.

In a clinical setting, it would be useful to identify a rapid screening technique to select specific cases that require more precise numerical calculation. This study was performed to assess the effectiveness of a rapid visual assessment of cervical canal stenosis on lateral cervical radiographs compared to the clinically accepted Torg ratio. Specifically, this study evaluated the efficacy of identifying patients at risk for developmental narrowing of the spinal canal based on visual characterization of the percentage of the bony spinal canal overlapped by the facet articulation.

When comparing consensus ratings of visual assessment level with the Torg ratio measurements in this study, strongest results were noted for the ≥80% degree of facet overlap,

Table 4. Inter- and intraobserver reliability analyses in interpreting the percentage of overlap of the spinal canal by facet articulations

Rating	Comparison		n	Weighted kappa	95% CI		Exact-p
					Lower	Upper	
C3	Physician 1	Physician 2	96	0.6080	0.4528	0.7633	<0.001
C4	Physician 1	Physician 2	96	0.6805	0.5456	0.8154	<0.001
C5	Physician 1	Physician 2	96	0.7175	0.5913	0.8437	<0.001
C6	Physician 1	Physician 2	96	0.7197	0.6007	0.8386	<0.001
Physician 2 C3	Time 1	Time 2	25	0.5509	0.1629	0.9389	0.04
Physician 2 C4	Time 1	Time 2	25	0.4792	0.1321	0.8262	0.001
Physician 2 C5	Time 1	Time 2	25	Perfect agreement			
Physician 2 C6	Time 1	Time 2	25	0.7283	0.3991	0.9999	0.01

n, the number of valid patients being rated; CI, confidence interval.

particularly for C3 level with a 75% sensitivity, 92% specificity, 71% +PV and 93% -PV within a narrow 95% CI (Table 2). There is a trend to have higher levels of specificity for all levels and +PV for some levels with the higher degrees of stenosis; values were the most accurate for all four parameters at $\geq 80\%$ overlap at C3.

Recently, Horne et al⁶ calculated a radiographic index using the lateral mass measurement divided by the canal diameter to screen for developmental cervical stenosis and they compared their ratios with the true canal diameter measured on a CT midline sagittal cut at the cortical margins of the points of the mid-vertebral-body posterior cortex. However, even though they measured C3 through C6 levels, their measurements were only accurate at C5 on radiographs compared with the true canal diameter measured from CT. This assessment is also dependent on formal calculation and measurement using a secondary imaging modality, and thus is less readily applied to routine clinical practice. Ultimately, we had overall higher accuracy estimates on the basis of comparison with the Torg ratio with 75% sensitivity, 92% specificity, 71% +PV and 93% NPV for the C3 level as compared to their ratios on the basis of the comparison with the true canal diameter measured on a CT midline sagittal cut with 83% sensitivity, 74% specificity, 44% +PV and 95% -PV for C5 level. Also, our study allows more granularity of analysis evaluating each level independently in comparison to the Horne study that presented estimated stenosis at any level (C3–C6) except for C5 as the only level presented individually.⁶

As an additional measure of a screening tool, it is important to confirm that clinical teams can consistently apply the new visual technique. The results of this study show that inter-observer repeatability for visual assessment of cervical spinal canal from lateral cervical radiographs was substantial even though the

two physicians were from different clinical disciplines. Further, intra-observer reliability analysis yielded moderate to perfect agreement within this sub-group of patients ($p < .05$) supporting the potential for reproducibility of method within the same reader.

Although important results have been presented, these must be interpreted in light of limitations. As a retrospective study, sample bias can play a role in our finding. However, the images selected represent a true clinical population with representative heterogeneity. Another limitation of our study is utilization of the Torg ratio as a gold standard. The Torg ratio may have inherent bias with regard to both the spinal-canal size and vertebral-body size since the larger vertebral bodies of the athletes could result in low Torg ratios.^{11,12} We did not evaluate the vertebral body size of the individuals. In addition, the ratio of enrollees with developmental narrowing to non-narrow individuals in our study exceeded the incidence in the natural population. However, this study was not designed to establish incidence. A sufficient quantity of positive interpretations would be needed to adequately challenge the concept with statistical confidence. Further, the positive population must be embedded within a larger control population to assure accuracy.

CONCLUSIONS

In conclusion, visual estimates of percentage of ≥ 80 spinal canal overlay by facet articulations on lateral cervical radiographs is a reproducible, easily applicable and inexpensive technique for identification of cases likely to be associated with developmental narrowing of the bony spinal canal and abnormal Torg ratio measurements. Due to its high diagnostic performance, we suggest utilizing this technique to identify patients that may benefit from formal calculation of the Torg ratio to define underlying developmental narrowing of the spinal canal and thus an at risk population for secondary pathology or injury.

REFERENCES

1. Song KJ, Choi BW, Kim SJ, Kim GH, Kim YS, Song JH. The relationship between spinal stenosis and neurological outcome in traumatic cervical spine injury: an analysis using Pavlov's ratio, spinal cord area, and spinal canal area. *Clin Orthop Surg* 2009; **1**: 11–18. doi: <https://doi.org/10.4055/cios.2009.1.1.11>
2. Gore DR. Roentgenographic findings in the cervical spine in asymptomatic persons: a ten-year follow-up. *Spine* 2001; **26**: 2463–6. doi: <https://doi.org/10.1097/00007632-200111150-00013>
3. Pavlov H, Torg JS, Robie B, Jahre C. Cervical spinal stenosis: determination with vertebral body ratio method. *Radiology* 1987; **164**: 771–5. doi: <https://doi.org/10.1148/radiology.164.3.3615879>
4. Castro FP, Ricciardi J, Brunet ME, Busch MT, Whitecloud TS, Stingers WTS. Stingers, the Torg ratio, and the cervical spine. *Am J Sports Med* 1997; **25**: 603–8. doi: <https://doi.org/10.1177/036354659702500503>
5. Aebli N, Wicki AG, Rüegg TB, Petrou N, Eisenlohr H, Krebs J. The Torg-Pavlov ratio for the prediction of acute spinal cord injury after a minor trauma to the cervical spine. *Spine J* 2013; **13**: 605–12. doi: <https://doi.org/10.1016/j.spinee.2012.10.039>
6. Horne PH, Lampe LP, Nguyen JT, Herzog RJ, Albert TJ. A novel radiographic indicator of developmental cervical stenosis. *J Bone Joint Surg Am* 2016; **98**: 1206–14. doi: <https://doi.org/10.2106/JBJS.15.01231>
7. Muhle C, Metzner J, Weinert D, Falliner A, Brinkmann G, Mehdorn MH, et al. Classification system based on kinematic MR imaging in cervical spondylitic myelopathy. *AJNR Am J Neuroradiol* 1998; **19**: 1763–71.
8. Kang Y, Lee JW, Koh YH, Hur S, Kim SJ, Chai JW, et al. New MRI grading system for the cervical canal stenosis. *AJR Am J Roentgenol* 2011; **197**: W134–W140. doi: <https://doi.org/10.2214/AJR.10.5560>
9. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977; **33**: 159–74. doi: <https://doi.org/10.2307/2529310>
10. Kang JD, Figgie MP, Bohlman HH. Sagittal measurements of the cervical spine in subaxial fractures and dislocations. An analysis of two hundred and eighty-eight patients with and without neurological deficits. *J Bone Joint Surg Am* 1994; **76**: 1617–28. doi: <https://doi.org/10.2106/00004623-199411000-00004>

11. Tierney RT, Maldjian C, Mattacola CG, Straub SJ, Sitler MR. Cervical spine stenosis measures in normal subjects. *J Athl Train* 2002; **37**: 190–3.
12. Herzog RJ, Wiens JJ, Dillingham MF, Sontag MJ. Normal cervical spine morphometry and cervical spinal stenosis in asymptomatic professional football players. Plain film radiography, multiplanar computed tomography, and magnetic resonance imaging. *Spine* 1991; **16**(Suppl. 6): S178–86.