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ORIGINAL ARTICLE

Occipitocervical measurements: correlation and consistency between multi-positional magnetic resonance imaging and dynamic radiographs

Rattanaporn Chamnan[1,2] · Kunlavit Chantarasirirat[1,3] · Permsak Paholpak[1,4] · Kevin Wiley[1] · Zorica Buser[1,5] · Jeffrey C. Wang[1]

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Abstract

Purpose To evaluate the reliability and validity of the multi-positional magnetic resonance imaging in measuring occipitocervical parameters using the standard cervical dynamic radiographs as a reference.

Methods Patients were included if they underwent both dynamic radiograph and cervical multi-positional MRI within a 2-week interval from January 2013 to December 2016. Twelve occipitocervical parameters were measured on both image modalities in all positions (neutral, flexion and extension): Posterior Atlanto-Dental Interval, Anterior Atlanto-Dental Interval (AADI), Dens-to-McRae distance, Dens-to-McGregor distance, Occipito-atlantal Cobb angle (C01 angle), Occipito-axis Cobb angle (C02 Cobb angle), Atlas-axis Cobb angle (C12 angle), Redlund-Johnell, Modified Ranawat, Clivus canal angle, Occiput inclination, and Occiput cervical distance. Pearson correlation and linear regression analysis were used to evaluate the correlation of both modalities for each parameter. A p value of <0.05 was considered statistically significant.

Results Cervical images of 70 patients were measured and analyzed. There was a significant positive correlation between dynamic X-ray and multi-positional MRI for all parameters ($p<0.05$) except AADI. Dens-to-McGregor distance and Redlund-Johnell parameter demonstrated a very strong correlation in the neutral position ($r=0.72$, $r=0.79$ respectively) and moderate to very strong correlation($r>0.4$) for Modified Ranawat, Clivus canal angle, C02 Cobb angle and C02 distance in all neck position. The intra-class correlation (ICC) of intra- and inter-observer showed good to excellent reliability, and ICCs were 0.67–0.98.

Conclusions Multi-positional MRI can be a reliable imaging option for diagnosis of occipitocervical instability or basilar invagination compared to standard dynamic radiographs.

Keywords Occipitocervical parameters · Occipitocervical instability · Multi-positional MRI · Dynamic radiograph

✉ Zorica Buser
zbuser@usc.edu

[1] Department of Orthopaedic Surgery, Keck School of Medicine, University of Southern California, 1450 Biggy Street, NRT-4513, Los Angeles, CA 90033, USA

[2] Department of Orthopaedic Surgery and Physical Medicine, Faculty of Medicine, Prince of Songkla University, Hat Yai, Songkhla, Thailand

[3] Department of Orthopaedic Surgery, Somdech Phra Pinklao Hospital, 504 Taksin Road, Bukkalo Thonburi, Bangkok, Thailand

[4] Department of Orthopaedics, Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand

[5] Department of Orthopaedic Surgery, Keck School of Medicine, University of Southern California, 1450 San Pablo St., HC4 – Suite 5400A., Los Angeles, CA 90003, USA

Introduction

Occipitocervical area has a complex structural anatomy which composes occiput, atlas and axis. There are many types of imaging modalities used to evaluate this area including radiograph, computerized tomographic scan (CT scan) and magnetic resonance imaging (MRI) with different advantages and limitations [1–4].

Dynamic radiograph is accepted as one of the most generalized and inexpensive tools used to determine occipitocervical range of motion and pathology such as instability, spinal cord compression and basilar invagination. Dynamic radiograph and several parameters such as Anterior Atlanto-Dental Interval (AADI) of more than 5 mm and Posterior Atlanto-Dental Interval (PADI) of less than 13 mm have been used to diagnose occipitocervical compression or instability in patients with inflammatory or congenital diseases such as rheumatoid arthritis, Down's syndrome, Chiari malformation type I and Ehlers Danlos syndrome. Additionally, radiograph can define basilar invagination by parameters using the position of Dens correlation to McGregor line and Redlund-Johnell distances [5–8]. Nevertheless, plain radiographs lack visibility of soft tissue pathology, providing only two dimensions and is ionizing radiation that is harmful and accumulates in case of serial follow-up X-ray for example in long-term treatment for scoliosis [9]. Occipitocervical diseases are chronic conditions; therefore, accumulated doses of radiation can escalate overtime. Hence, choosing a less harmful, non-ionized radiating imaging tool should be considered [10].

MRI is used as a gold standard imaging tool for cervical spine because it is a non-invasive modality and provides clear evaluation of soft tissue pathologies such as ligament disruption or hypertrophy, disc herniation, spinal cord compression, etc. Thereafter, multi-positional magnetic resonance imaging (multi-positional MRI) was developed as dynamic weight bearing multi-positional MRI including neutral, flexion and extension position able to provide dynamic information. Multi-positional MRI has been used to evaluate functional relationship between the pathological structure changes and cervical movement [11, 12]. Morishita et al. measured 289 symptomatic patient MRIs in flexion, neutral, and extension postures. They found in case of severe cord compression moderate disc degeneration level tended to have less motion than severe disc degeneration level. Thus, the result was inferred that the spinal cord could have a potential protective role avoiding excessive cervical motion. In additional, some literature focused on changes in ligamentum flavum with change in posture [13]. Zhong et al. reported that multi-positional MRI can identify dynamic spinal cord compression with missed ligamentum flavum bulge (LFB) which only exist in the extension position. The frequency of missed LFB was the highest at C4–C5 and C5–C6. Angular variation, translational motion, disc herniation and disc degeneration were significantly associated with missed LFB at C4–C5 and C5–C6 [11]. In addition, there are a large number of studies focusing on cervical rheumatoid arthritis (RA) using radiograph and MRI of the upper cervical spine [14–17]. For occipitocervical area, occipitocervical parameters were used for diagnosis of several pathologies including instability: AADI and PADI, basilar invagination: Dens-to-McRae distance, Dens-to-McGregor distance, Redlund-Johnell distance, Modified Ranawat distance, Occiput inclination and Clivus canal angle. Additionally, Cobb angle of occiput-atlas, occiput-axis, and atlas-axis were used for range of motion assessments. These parameters are usually measured by dynamic radiograph. However, to the best of our knowledge, there is no literature on correlation of occipitocervical parameters between multi-positional MRI and dynamic radiograph.

The aim of this study was to understand if the measurement of occipitocervical parameters with multi-positional MRI can be used as a valid, reliable, predictable and accurate substitute for cervical dynamic X-ray in neutral, flexion and extension positions.

Materials and methods

Patients who underwent both multi-positional MRI and dynamic radiograph that included occipitocervical junction within a 2-week interval from January 2013 to December 2016 were retrospectively studied. Images included in the study had to be good-quality images especially the hard palate had to be identified in both multi-positional MRI and dynamic radiograph in all weight barring positions (neutral, flexion and extension). Patients who had deformity of the cervical spine (more than 10° in coronal, sagittal and frontal plane), previous cervical spine surgery, congenital cervical anomaly, inflammatory disease of the cervical spine, cervical spine infection and cervical spine tumor were excluded from the study. According to all of the inclusion and exclusion criteria, 70 patients (37 men and 33 women) with an average age of 45.4 years (range 23–67 years) were included in the study. Twelve occipitocervical parameters were measured on both multi-positional MRI and dynamic radiograph in all positions (neutral, flexion and extension): Posterior Atlanto-Dental Interval (PADI), Anterior Atlanto-Dental Interval (AADI), Dens-to-McRae distance, Dens-to-McGregor distance, Occipito-atlantal Cobb angle (C01 Cobb angle), Occipito-axis Cobb angle (C02 Cobb angle), Atlas-axis Cobb angle (C12 Cobb angle), Redlund-Johnell distance, Modified Ranawat distance, Clivus canal angle, Occiput inclination and Occiput cervical distance. This study was approved by the institutional review board at the University of Southern California, USA.

Multi-positional MRI of the cervical spine was conducted using a 0.6 T MRI scanner (Up-right Multi-Position, Fonar Corp., New York, NY, USA). The MR unit was equipped with two electromagnets to generate a horizontal magnetic field which scans patients in the upright position, in additional the use of both solenoidal and planar receiver coils, allowing patients to be examined in upright weight-bearing positions. The image protocol included T1- and T2-weighted sagittal fast spin-echo images that were obtained using a flexible surface coil with the patient seated in neutral (0°), flexion (40°) and extension (−20°) positions. The following protocols were used: T1-weighted sagittal spin echo images (repetition time 671 ms, echo time 17 ms, thickness 4.0 mm, field of view 30 cm, matrix 256 × 224, number of excitations 2) and T2-wighted fast spin echo images (repetition time 3000 ms, echo time 140 ms, thickness 4.0 mm, field of view 30 cm, matrix 256 × 224, number of excitations 2).

The lateral dynamic plain radiographs were taken in neutral, flexion and extension positions. The angles in flexion, and extension position for dynamic plain radiographs were similar to the multi-positional MRI angles. Both dynamic plain radiographs and multi-positional MRI were viewed and measured using the eRAD PACS system (version 7.2.38.0, SC, USA).

Inter-observer measurement was done by two spine surgeons who measured independently both multi-positional MRI and dynamic plain X-ray. Intra-observer measurement was performed for both multi-positional MRI and dynamic radiograph with 1 month interval between two measurements.

Angular parameters' measurement

Posterior Atlanto-Dental Interval (PADI): Distance measured from posterior border of C2 to posterior arch of C1 (Figs. 1a, 2a).

Anterior Atlanto-Dental Interval (AADI): Distance measured from posterior rim of anterior arch of C1 to anterior rim of Dens (Figs. 1b, 2b).

McRae's line: The line was drawn from the tip of the basion to the tip of the opisthion [7].

Dens-to-McRae distance: Distance from the odontoid tip to McRae line (Figs. 1c, 2c).

McGregor's line: Drawn from tip of posterior margin of hard palate to undermost surface of occiput [5].

Dens-to-McGregor distance: Distance from tip of dens to McGregor's line (Figs. 1d, 2d).

Occipito-atlantal Cobb angle: Measured by the angle between McGregor's line and mid-axis of C1 in sagittal plane (Figs. 1e, 2e).

Occipito-axis Cobb angle: Measured by the angle between McGregor's line and along the inferior end plate of C2 (Figs. 1f, 2f).

Atlas-axis Cobb angle: Measured by the angle between mid-axis of C1 and along the inferior end plate of C2 in sagittal plane (Figs. 1g, 2g).

Redlund-Johnell distance: Minimum distance measured from the midpoint of the C2 base to the McGregor's line (Figs. 1h, 2h) [6].

Modified Ranawat distance: Minimum distance measured from the midpoint of the base and along the long axis of C2 to mid-axis of C1 in sagittal plane (Figs. 1i, 2i) [16].

Clivus canal angle: Angle formed at posterior border of clivus and posterior vertebral C2 line (Figs. 1j, 2j).

Occiput inclination angle: Measured by the angle between McGregor's line and posterior border of C2 (Figs. 1k, 2k).

Occiput cervical distance: Distance from spinous process of C2 to undermost surface of occiput (Figs. 1l, 2l).

Statistical analysis

All parameters on multi-positional MRI and dynamic plain X-ray images were measured independently by two spine surgeons. Inter-observer and intra-observer reliability values were analyzed using 20 patients and intra-class correlation coefficients (ICCs) statistics. The intra-observer and inter-observer agreements for each parameter both modalities were analyzed. The ICC values were assessed using the following criteria: 0–0.2 indicated slight agreement, 0.21–0.4 indicated fair agreement, 0.41–0.6 indicated moderate agreement, 0.61–0.8 indicated substantial agreement, and 0.81–1 indicated excellent agreement [18]. Pearson correlation statistic was used to evaluate the correlation between multi-positional MRI and dynamic radiograph in each parameter. A Pearson correlation coefficient (r) of 0.00–0.09 was considered very low correlation, r of 0.10–0.29 was considered low to moderate correlation, r of 0.30–0.49 was considered moderate to substantial correlation, r of 0.50–0.69 was considered substantial to very strong correlation, r of 0.70–0.89 was considered very strong correlation, and r of 0.90–0.99 was near perfect correlation [19]. Linear regression analysis was used to confirm correlations. Normality test for normal distribution of all parameters was done using Shapiro–Wilk test. For statistical analysis, SPSS 23.0 (Chicago, IL) was used; a p value of less than 0.05 was considered a statistically significant finding.

To test the correlation between two independent groups, the sample size of 29 in each group was determined using the effect size of 0.79 (calculated by the difference between mean and standard deviation of occiput inclination parameter in flexion position in both groups), alpha value of 0.05, and beta value of 0.20.

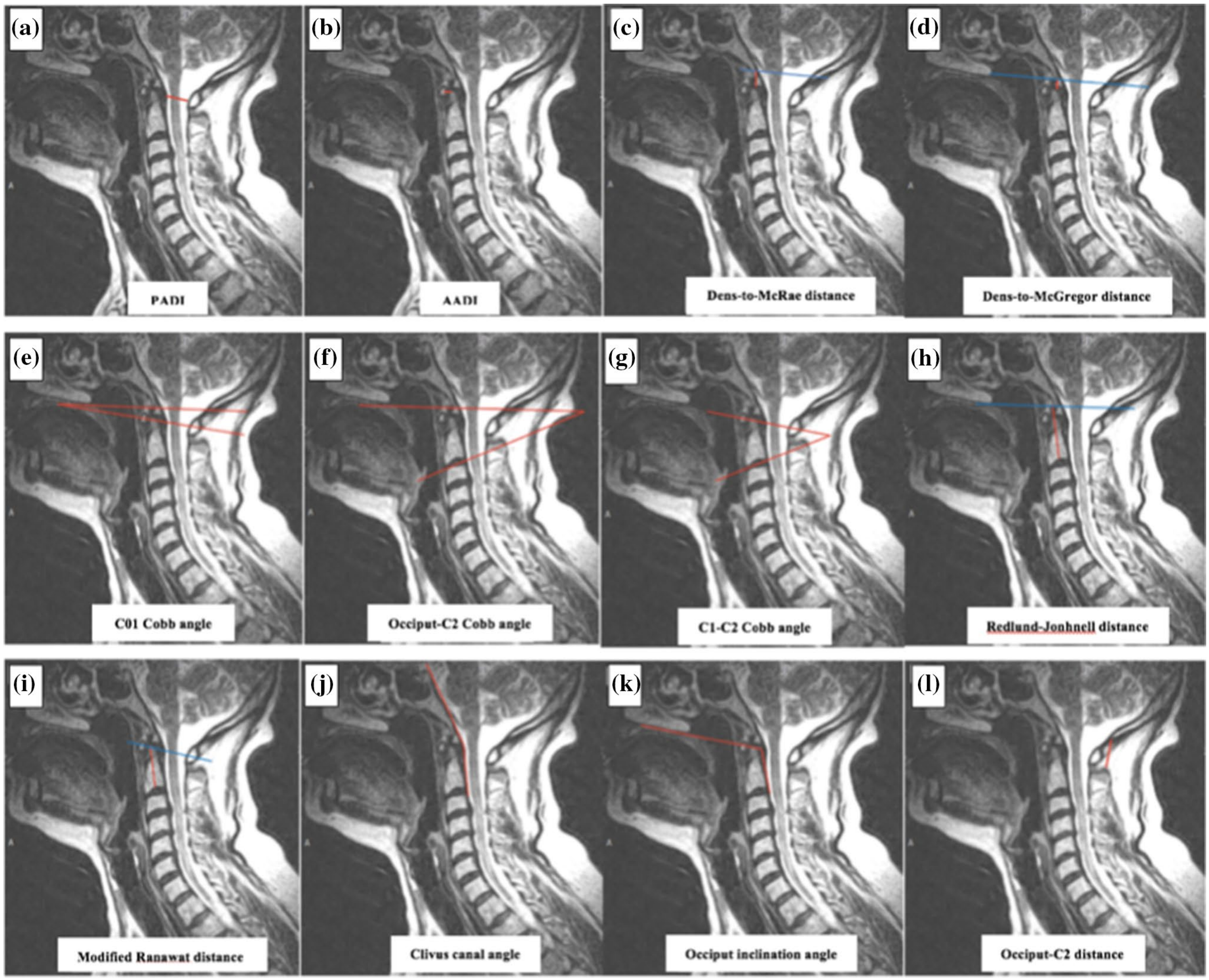

Fig. 1 Occipitocervical parameters in multi-positional MRI; **a** PADI, **b** AADI, **c** Dens-to-McRae distance, **d** Dens-to-McGregor distance, **e** C01 Cobb angle, **f** C02 Cobb angle, **g** C02 Cobb angle, **h** Redlund-Johnell distance, **i** Modified Ranawat distance, **j** Clivus canal angle, **k** Occiput inclination angle, **l** Occiput-C2 distance

Results

From 1273 patients who underwent both dynamic plain X-ray and multi-positional MRI, 210 patients had both imaging modalities within 2 weeks. Seventy patients (37 men and 33 women) with an average age of 45.4 years (range 23–67 years) based on the inclusion and exclusion criteria were included in the study. The Pearson correlation coefficient results showed statistically significant positive correlation between dynamic radiograph and multi-positional MRI for all parameters and in all three positions ($p < 0.05$) except AADI parameter. Dens-to-McGregor distance and Redlund-Johnell parameter showed very strong correlation range in the neutral position ($r = 0.72$, $r = 0.79$, respectively) and moderate to very strong correlation in flexion ($r = 0.49$, $r = 0.63$, respectively) and extension ($r = 0.62$, $r = 0.71$ respectively). The Pearson correlation coefficient showed substantial to very strong correlation in the following parameters ($r > 0.5$); modified Ranawat, occiput cervical distance, the flexion position of C12 Cobb angle, the neutral position of C01 Cobb angle, C02 Cobb angle and occiput inclination. Parameters that presented moderate to substantial correlation (r from 0.3 to 0.49) were: PADI, Clivus canal angle, the flexion position of Dens-to-McRae distance, C01 Cobb angle, C02 Cobb angle, occiput inclination, the extension of C01 Cobb angle, C02 Cobb angle, C12 Cobb angle, occiput inclination and the neutral position of C12 Cobb angle. The least

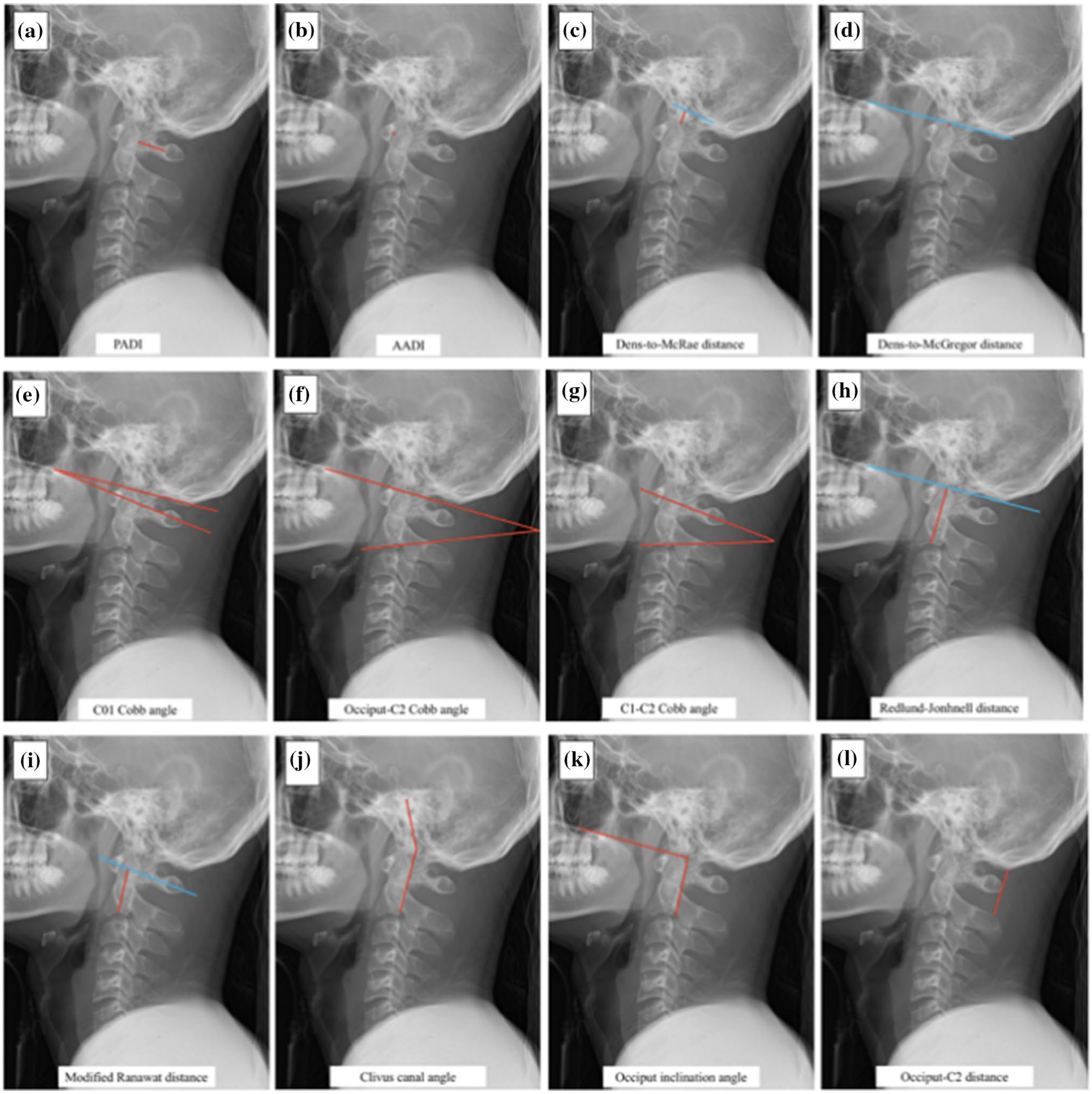

Fig. 2 Occipitocervical parameters in plain radiograph; **a** PADI, **b** AADI, **c** Dens-to-McRae distance, **d** Dens-to-McGregor distance, **e** C01 Cobb angle, **f** C02 Cobb angle, **g** C02 Cobb angle, **h** Redlund-Johnell distance, **i** Modified Ranawat distance, **j** Clivus canal angle, **k** Occiput inclination angle, **l** Occiput-C2 distance

correlation in the neutral position was for Dens-to-McRae distance ($r < 0.29 <$ Table 1). Linear regression analysis also showed statistical significant correlation between dynamic radiograph and multi-positional MRI R^2 results (Table 1).

The intra-class correlation (ICC) of intra- and inter-observer between two spine surgeons showed good to excellent reliability in almost all measured parameters; the ICCs were 0.67–0.98 (Table 2).

Table 1 Occipitocervical parameters measurement values from dynamic radiograph and multi-positional MRI, the Pearson correlation coefficients, statistical significant, and the R^2 value of regression analysis

Parameters	X-ray	Kmri	Pearson's correlation coefficient	*p* value	R^2
PADI					
Neutral	21.03 ± 0.24	15.78 ± 0.20	0.42	< 0.001[t]	0.18
Flexion	20.22 ± 0.25	15.65 ± 0.18	0.41	< 0.001[t]	0.17
Extension	20.51 ± 0.25	15.54 ± 0.19	0.38	0.002[t]	0.14
AADI					
Neutral	1.60 ± 0.05	2.20 ± 0.08	− 0.10	0.408	0.01
Flexion	1.70 ± 0.05	2.41 ± 0.08	0.41	< 0.001[t]	0.17
Extension	1.34 ± 0.05	1.89 ± 0.64	− 0.12	0.894	0.00
Dens-to-McRae distance					
Neutral	8.09 ± 0.32	8.04 ± 0.32	0.24	0.042[t]	0.06
Flexion	7.78 ± 0.32	7.94 ± 0.31	0.40	0.001[t]	0.16
Extension	8.87 ± 0.33	8.93 ± 0.36	0.35	0.003[t]	0.12
Dens-to-McGregor distance					
Neutral	0.36 ± 0.26	1.64 ± 0.33	0.72	< 0.001[t]	0.52
Flexion	0.07 ± 0.29	1.14 ± 0.32	0.49	< 0.001[t]	0.24
Extension	1.77 ± 0.33	2.85 ± 0.35	0.62	< 0.001[t]	0.39
Redlund-Johnell distance					
Neutral	37.08 ± 0.60	32.73 ± 0.51	0.79	< 0.001[t]	0.63
Flexion	36.86 ± 0.60	31.87 ± 0.52	0.63	< 0.001[t]	0.40
Extension	39.22 ± 0.66	34.52 ± 0.55	0.71	< 0.001[t]	0.50
C02 Cobb angle					
Neutral	18.80 ± 0.88	17.72 ± 0.84	0.57	< 0.001[t]	0.33
Flexion	14.56 ± 0.88	13.30 ± 0.80	0.40	0.001[t]	0.16
Extension	34.41 ± 1.07	32.40 ± 1.08	0.45	< 0.001[t]	0.20
C12 Cobb angle					
Neutral	28.73 ± 0.71	26.92 ± 0.77	0.37	0.001[t]	0.14
Flexion	23.49 ± 0.85	22.39 ± 0.96	0.57	< 0.001[t]	0.32
Extension	34.44 ± 0.78	35.47 ± 0.93	0.43	< 0.001[t]	0.19
C01 Cobb angle					
Neutral	− 9.05 ± 0.91	− 9.04 ± 0.29	0.58	< 0.001[t]	0.33
Flexion	− 8.44 ± 0.87	− 9.71 ± 0.77	0.35	0.003[t]	0.12
Extension	− 0.92 ± 0.77	− 3.36 ± 0.73	0.31	0.008[t]	0.10
Clivus canal angle					
Neutral	162.19 ± 0.89	155.91 ± 1.07	0.40	0.001[t]	0.16
Flexion	159.65 ± 1.06	149.91 ± 1.12	0.40	0.001[t]	0.16
Extension	172.19 ± 0.87	166.33 ± 1.06	0.40	0.001[t]	0.16
Modified Ranawat distance					
Neutral	30.18 ± 0.37	25.30 ± 0.33	0.48	< 0.001[t]	0.23
Flexion	29.96 ± 0.38		0.55	< 0.001[t]	0.30
Extension	30.78 ± 0.38	25.68 ± 0.37	0.54	< 0.001[t]	0.29
Occiput inclination angle					
Neutral	96.87 ± 0.83	93.54 ± 0.94	0.58	< 0.001[t]	0.33
Flexion	93.08 ± 0.80		0.44	< 0.001[t]	0.20
Extension	111.27 ± 1.01	105.48 ± 1.18	0.30	0.013[t]	0.09
Occiput cervical distance					
Neutral	20.80 ± 0.64	17.11 ± 0.56	0.64	< 0.001[t]	0.41
Flexion	23.29 ± 0.61		0.59	< 0.001[t]	0.35
Extension	13.06 ± 0.68	11.75 ± 0.55	0.55	< 0.001[t]	0.31

[t]Statistically significant (*p* value of less than 0.05)

Table 2 Inter- and intra-observer reliability

Parameters	Intra ICC 95% CI (min–max)		Inter ICC 95% CI (min–max)	
	Dynamic X-ray	kMRI	Dynamic X-ray	kMRI
PADI	0.77–0.92	0.81–0.84	0.81–0.91	0.80–0.88
AADI	0.82–0.90	0.79–0.92	0.89–0.90	0.73–0.83
Dens-to-McRae distance	0.78–0.82	0.79–0.89	0.73–0.86	0.84–0.93
Dens-to-McGregor distance	0.81–0.96	0.84–0.87	0.90–0.91	0.83–0.85
C01 Cobb angle	0.81–0.98	0.87–0.97	0.90–0.99	0.86–0.94
C02 Cobb angle	0.87–0.95	0.84–0.86	0.73–0.89	0.80–0.86
C12 Cobb angle	0.80–0.90	0.83–0.88	0.81–0.85	0.69–0.90
Redlund-Johnell distance	0.95–0.98	0.87–0.92	0.87–0.98	0.79–0.90
Modified Ranawat distance	0.90–0.94	0.85–0.92	0.77–0.84	0.80–0.93
Clivus canal angle	0.80–0.83	0.82–0.93	0.67–0.81	0.80–0.86
Occiput inclination angle	0.94–0.97	0.78–0.84	0.78–0.90	0.67–0.90
Occiput cervical distance	0.95–0.98	0.86–0.87	0.85–0.93	0.88–0.93

All parameters were statistically significant (*p* value of less than 0.05)

Discussion

Occipitocervical parameters measured in both dynamic radiograph and multi-positional MRI had a significant positive correlation for all parameters except AADI. Dens-to-McGregor distance, Redlund-Johnell parameter, Modified Ranawat and clivus canal angle C02 Cobb angle and C02 distance had moderate to very strong correlation. Additionally, our study also found good to excellent inter- and intra-observer reliability for all parameters. These findings suggested that occipitocervical parameters which demonstrated moderate to very strong level of correlations can be used reciprocally between two modalities.

Occipitocervical area has various anatomical landmarks and parameters such as range of motion, PADI to determine upper cervical spine stenosis and Dens-to-McGregor, Dens-to-McRae, Redlund-Johnell, etc., to diagnose basilar invagination. Paholpak et al. reported that for C2–7 Cobb angle and cervical segmental Cobb angles multi-positional MRI and dynamic radiograph can be reliably interchangeably used if there is at least moderate correlation. C2–7 and cervical segmental Cobb angles showed the strongest correlations in neutral position which is the same for the majority of occipitocervical parameters [20].

The use of dynamic radiograph in diagnosis of occipitocervical pathology was a mainstay for a long time, especially in diagnosis of occipitocervical instability and basilar invagination [21]. MRI on the other hand was developed after dynamic radiograph and is a more expensive modality with limited access compared to dynamic radiograph. However, MRI can provide better details of the soft tissues such as ligament, disc degeneration and pannus of dens in the rheumatoid patient. Multi-positional MRI was has been studied and used since the late 1990s [22, 23]. It came with the benefit of traditional MRI evaluating soft tissue, with the added benefit to allow patients to be scanned in multiple positions. Previous studies revealed that there are changes in soft tissue pathology according to patient position such as neutral, flexion and extension. Xiong et al. reported mobility of the cervical spine in symptomatic patients receiving upright cervical multi-positional MRI. The results showed the translation motion decreased from proximal segment to distal segment and the angular mobility was the greatest at C5/6 and least at C7/T1 [24]. Hayashi et al. demonstrated upper cervical spine motion in order to compensate for lower cervical intervertebral disc degeneration using multi-positional MRI. They found that the occipito-axial angular motion was greater in patients with decreased lower cervical sagittal motion. Thus, occipito-axial motion compensated for motion lost in the lower spine secondary to disc degeneration [25].

All studies about occipitocervical imaging focus on diagnosis of basilar invagination, instability, correlation of cervical disc degeneration and sagittal alignment [5, 7, 16], the relationship of lower cervical alignment and upper cervical compensation [25], correlation between occipitocervical parameters themselves [15] and correlation in lower cervical spine motion between multi-positional MRI and radiograph [20]. Nevertheless, there is no literature on correlation of occipitocervical parameters measured in two imaging modalities.

According to our results, both dynamic radiograph and multi-positional MRI can diagnose occipitocervical instability and basilar invagination in Dens-to-McGregor distance and Redlund-Johnell parameter, Modified Ranawat, clivus canal angle, C02 Cobb angle and C02 distance. We also found positive statistically significant correlation for each parameter for the two imaging modalities demonstrating that they can accurately substitute each other.

Although our study achieved to compare two distinctly different modalities taken not more than 2 weeks interval in each patient, this advantage restricted the number of patients enrolled to the study, and thus, the overall power declined. The last limitation of this study was lack clinical information of the patients such as definite diagnosis or severity of disease; however, we could not compare parameters measurement in both modalities according to type or severity of pathology.

Conclusion

Occipitocervical parameters demonstrated various level of correlation between the multi-positional MRI and dynamic radiograph. Our study suggested that Dens-to-McGregor distance and Redlund-Johnell parameter, Modified Ranawat, clivus canal angle, C02 Cobb angle and C02 distance can be used interchangeably between two image modalities with an acceptable range of error in all cervical positions and that multi-positional MRI can substitute and enhance X-ray outputs.

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Compliance with ethical standards

Conflict of interest None of the authors have any potential conflict of interest. Disclosures outside of submitted work: JCW- Royalties – Biomet, Seaspine, Amedica, DePuy Synthes; Investments/Options – Bone Biologics, Pearldiver, Electrocore, Surgitech; Board of Directors - North American Spine Society, AO Foundation (20,000 honorariums for board position, plus travel for board meetings), Cervical Spine Research Society; Editorial Boards - Spine, The Spine Journal, Clinical Spine Surgery, Global Spine Journal; Fellowship Funding (paid directly to institution): AO Foundation ZB- consultancy: Cerapedics, Xenco Medical (past), AO Spine (past); Research Support: SeaSpine (past, paid to the institution), Next Science (paid directly to institution); North American Spine Society: committee member; Lumbar Spine Society: Co-chair Research committee, AOSpine Knowledge Forum Degenerative: Associate member; AOSNA Research committee- committee member.

References

1. Vastardis H, Carla AE (1996) Evaluation of cervical spine abnormalities on cephalometric radiographs. Am J Orthod Dentofac Orthop 109:581–588
2. Söderman T, Olerud C, Shalabi A, Alavi K, Sundin A (2015) Static and dynamic CT imaging of the cervical spine in patients with rheumatoid arthritis. Skelet Radiol 44(2):241–248
3. Omercikoglu S, Altunbas E, Akoglu H, Onur O, Denizbasi A (2017) Normal values of cervical vertebral measurements according to age and sex in CT. Am J Emerg Med 35(3):383–390. https://doi.org/10.1016/j.ajem.2016.11.019
4. Dvorak J, Panjab MM, Grob D, Novotny JE, Antinnes JA (1993) Clinical validation of functional: flexion/extension radiographs of the cervical spine. Spine 18(1):120–127
5. McGregor M (1948) The significance of certain measurements of the skull in the diagnosis. Br J Radiol 21(244):171–181
6. Redlund-Johnell IPH (1984) Radiographic measurements of the cranio-vertebral region. Designed for evaluation of abnormalities in rheumatoid arthritis. Acta Radiol Diagn (Stockh) 25(1):23–28
7. McRae DL, Barnum AS (1953) Occipitalization of the atlas. Am J Roentgenol Radium Ther Nucl Med 70(1):23–46
8. Thomas H, Paolo A, Nazli B et al (2007) Syndrome of occipitoatlantoaxial hypermobility, cranial settling, and Chiari malformation Type I in patients with hereditary disorders of connective tissue. J Neurosurg Spine 7(6):601–609
9. Nash CL Jr, Gregg EC, Brown RH, Pillai K (1979) Risks of exposure to x-rays in patients undergoing long-term treatment for scoliosis. J Bone Joint Surg Am 61(3):371–374
10. Bone CMHG (2000) The risk of carcinogenesis from radiographs to pediatric orthopaedic patients. J Pediatr Orthop 20(2):251–254
11. Zhong G, Buser Z, Lao L, Yin R, Wang JC (2015) Kinematic relationship between missed ligamentum flavum bulge and degenerative factors in the cervical spine. Spine J 15(10):2216–2221. https://doi.org/10.1016/j.spinee.2015.06.048
12. Kuwazawa Y, Bashir W, Pope MH, Takahashi K, Smith FW (2006) Biomechanical aspects of the cervical cord: Effects of postural changes in healthy volunteers using positional magnetic resonance imaging. J Spinal Disord Tech 19(5):348–352
13. Morishita Y, Hida S, Miyazaki M, Hong SW, Zou J, Wei F et al (2008) The effects of the degenerative changes in the functional spinal unit on the kinematics of the cervical spine. Spine 33(6):178–182
14. Karhu JO, Parkkola RK, Koskinen SK (2005) Evaluation of flexion/extension of the upper cervical spine in patients with rheumatoid arthritis: an MRI study with a dedicated positioning device compared to conventional radiographs. Acta radiol 46(1):55–66
15. Morishita Y, Falakassa J, Naito M, Hymanson HJ, Taghavi C, Wang JC (2009) The kinematic relationships of the upper cervical spine. Spine 34(24):2642–2645
16. Kwong Y, Rao N, Latief K (2011) Craniometric measurements in the assessment of craniovertebral settling: are they still relevant in the age of cross-sectional imaging? Am J Roentgenol 196(4):421–425
17. Reijnierse M, Breedveld FC, Kroon HM, Hansen B, Pope TLBJ (2000) Are magnetic resonance flexion views useful in evaluating the cervical spine of patients with rheumatoid arthritis? Skelet Radiol 29(2):85–89
18. Landis JRKG (1977) The measurement of observer agreement for categorical data. Biometrics 33:159–174
19. Vaus D De (2002) How to interpret a correlation coefficient. In: Analyzing social science data: 50 key problems in data analysis, 1 edn. SAGE Publication Ltd, pp 267–272
20. Paholpak P, Tamai K, Shoell K, Sessumpun K, Buser Z, Wang JC (2018) Can multi-positional magnetic resonance imaging be used to evaluate angular parameters in cervical spine? A comparison of multi-positional MRI to dynamic plain radiograph. Eur Spine J 27(5):1021–1102
21. Sierink JC, Van Lieshout WAM, Beenen LFM, Schep NWL, Vandertop WP, Goslings JC (2013) Systematic review of flexion/extension radiography of the cervical spine in trauma patients. Eur J Radiol 82(6):974–81. https://doi.org/10.1016/j.ejrad.2013.02.009
22. Zeitoun D, El Hajj F, Sariali E, Catonné Y, Pascal-Moussellard H (2015) Evaluation of spinal cord compression and hyperintense intramedullary lesions on T2-weighted sequences in patients with cervical spondylotic myelopathy using flexion–extension MRI protocol. Spine J 15(4):668–674

23. Lord EL, Alobaidan R, Takahashi S, Cohen JR, Wang CJ, Wang BJ et al (2014) Kinetic magnetic resonance imaging of the cervical spine: a review of the literature. Glob Spine J 4:121–128
24. Xiong C, Suzuki A, Daubs MD, Scott T, Phan K, Wang J (2015) The evaluation of cervical spine mobility without significant spondylosis by kMRI. Eur Spine J 24(12):2799–2806
25. Hayashi T, Daubs MD, Suzuki A, Scott TP, Phan K, Aghdasi B et al (2016) The compensatory relationship of upper and subaxial cervical motion in the presence of cervical spondylosis. Clin Spine Surg 29(4):E196–200