Research Article

Establishing a Method for Quantifying Spinal Curvature during Videofluoroscopic Swallow Studies: Applying the Modified Cobb Angle to Healthy Young and Older Adults

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Abstract

The Cobb angle is traditionally used for quantifying the degree of spinal curvature through evaluation of the full spinal cord. When conducting measurements on videofluoroscopy swallowing studies (VFSS), the Cobb angle can measure degree of cervical vertebrae curvature, which may have implications for swallowing. Given that this measure may have utility in dysphagia research, the reliability of this measure taken from C2-C4 and establishing the presence of changes with age were the focus of the current, proof-of-principle study. VFSS from 19 healthy young adults and 39 healthy older adults were

retrospectively analyzed. The C2-C4 Cobb angle was measured between cervical vertebrae two and four on frames of laryngeal vestibule closure (LVC) and post-swallow rest. Results revealed excellent levels of inter- and intra-rater reliability for frame of post-swallow rest (ICCs = 0.788 and 0.793), and fair to good levels of agreement for frame of LVC (ICCs = 0.667 and 0.621). Significant differences in the C2-C4 Cobb angle were found between the healthy young and old data ($p < 0.01$). Healthy younger adults had a mean angle of 5.8±9.0 degrees at LVC and 7.7±4.5 degrees at swallow rest, whereas healthy older adults had a mean angle of 12.5±9.0 degrees at LVC and 12.4±9.7 degrees at rest. Consistent with the existing spine literature, the curvature of cervical vertebrae appears to increase with age. With established reliability, we propose that the C2-C4 Cobb angle may be used to determine the degree of spinal curvature in a variety of patient populations in order to determine impacts on swallowing function.

1. Introduction

Given the rapidly growing population of older adults, it is important to consider how natural and expected changes to the body – specifically to the head and neck – due to aging, might impact swallowing function. Research has previously established that with age we can expect changes to pharyngeal lumen size [1], tongue strength [2] and timing of the swallow [3], amongst other things. Something rarely considered when examining swallowing in older adults is their posture, which is influenced by the shape or curvature of the spine [4]. Interestingly, most previous research suggests that body position has little impact on swallowing [5, 6]. However, one study by Su and colleagues quantified swallowing parameters in both an upright and supine position and determined that positioning had little impact on swallowing a thicker consistency, like pudding, but saw increases in temporal measures when thin liquids were swallowed in the supine position [7]. Anecdotally, clinicians encourage patients to sit upright as close to 90 degrees as possible in order to promote optimal swallowing function. They suggest that any sitting position less than 90 degrees may prevent the efficient passage of the bolus from the oral cavity into the esophagus [8-10]. The focus is on the sitting position and resulting posture, with little consideration of how the natural shape of the spine might influence swallowing function.

Studies analyzing anteriorly protruding cervical osteophytes, which are bony protrusions on the anterior surface of the lower cervical vertebrae, suggest that such changes to the spine impinge bolus passage into the cervical esophagus leading to increased pharyngeal residue and reduced upper esophageal sphincter opening [11-13], and/or altered sensation [14-16], as well as laryngeal penetration [17, 18]. Other than this research, few studies outside of the traumatic spinal cord injury literature have examined the relationship between the changes to the spine and its impact on swallowing physiology and mechanics. Given that swallowing function post-spinal cord injury is dependent on the cause and type of injury [19], we cannot use such studies to make inferences about how non-injury related differences in spinal curvature might affect swallowing. Research

specific to the cervical spine has suggested that kyphosis may result in pharyngeal phase deficits [20] and increased risk of aspiration [21]. Moreover, spinal-specific research has previously established that as one ages the degree of kyphosis (i.e. outward curvature of the spine causing "hunching" of the back [see Figure 1]) is expected to increase along the full spine [22-24]. Other research has postulated that neck posture can influence one's risk of aspiration [25-30]. For example, a few studies have suggested that neck flexion in the form of a chin-down posture improves laryngeal vestibule closure and epiglottic angle, resulting in reduced incidences of airway invasion [25, 31, 32]. Since kyphosis is expected with age and neck flexion may act as a protective mechanism during swallowing, one might assume that age-related changes in the spine might positively influence swallowing physiology.
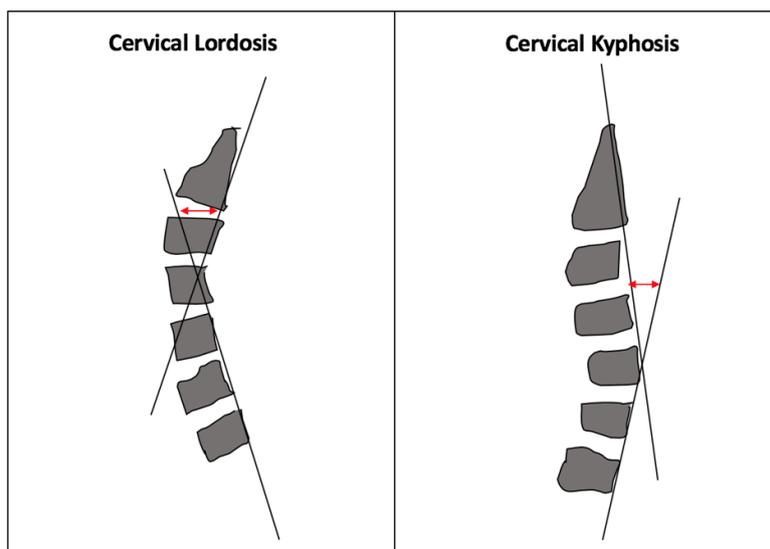

Figure 1 A lordotic spine (left) versus kyphotic cervical spine (right).

The spinal cord literature has provided some evidence of age-related changes to the cervical spine. A recent meta-analysis examined the existence and extent of cervical lordosis in asymptomatic individuals, and evaluated the relationship of this lordosis with age and gender [33]. Upon analyzing 21 studies, the authors found curvature was not significantly different between symptomatic and asymptomatic individuals, and age was not significantly associated with amount of lordotic cervical curvature. Interestingly, other studies have found that the angle of cervical lordosis tends to increase with age [34-37]. The parameter of interest for all of these studies was cervical lordosis – where the spine is curving posteriorly (see the image to the left of Figure 1). However, it is unknown whether kyphosis (anterior curvature or forward head posture) is seen specifically in the cervical vertebrae. These studies also all employed the C2-C7 (cervical vertebra two to cervical vertebra seven) Cobb angle to measure cervical curvature [38].

The Cobb angle has historically been used to quantify the degree of spinal curvature for patients with scoliosis through evaluation of the full spinal cord and has been established as reliable in this context [39]. This method defines angles between 20° and 60° as normal cervical curvature [20]. Typically, to measure the Cobb angle, a right angle is drawn between the top-most and bottom-most curved vertebrae, and measure the angle formed between the intersecting rays from each right angle (Figure 2). The C2-C7 Cobb method measures the curvature of the full

cervical spine using radiographic images [39]. Videofluoroscopy swallowing studies (VFSS) are dynamic x-ray videos that are used to assess swallowing physiology and mechanics, with radiographic images taken depicting the region of the nasal cavity to the cervical esophagus. While a VFSS results in series of radiographic images, more often than not, all cervical vertebrae are not visible. More specifically, it is often difficult to clearly discern C5-C7. Given that C4 (cervical vertebra 4) is generally much more readily visible, we wanted to determine if the Cobb angle could be measured between C2 and C4, rather than between C2 and C7. In essence, the C2-C4 would act as a proxy measure, allowing a clinician to screen for cervical spine changes using VFSS data, rather than subjecting patients to a separate x-ray study of the spine. Interestingly, measures conducted between C2-C4 have become common in the dysphagia literature [40-44], likely due to the fact that they are clearly visible on VFSS, which is the gold standard method for evaluating swallowing. Since we do not currently have an established method for determining degree of cervical curvature on frames taken from VFSS, this was the primary purpose of the current, exploratory, proof-of-principle study. As a first step in this concept development, we aimed to establish if measurements taken from C2 to C4 were reliable. This would help to determine the potential of using the modified method as a proxy measure, instead of the traditional C2-C7 measurement. If the C2-C4 measurements were found to be reliable, we also aimed to determine if differences in cervical spine curvature measured were seen between healthy young and healthy old participants, consistent with previous spinal cord literature. Moreover, C2-C4 is highly correlated with participant height and thus frequently used in dysphagia research for scaling measures [40, 45]. We hypothesized that a) we could reliably measure the Cobb angle between C2 and C4 and b) that we would see a significant increase in the Cobb angle with age.
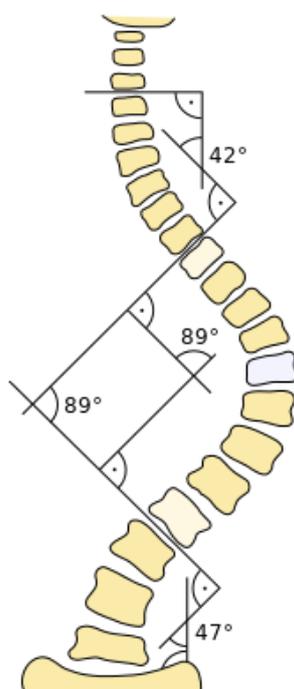

Figure 2 This image depicts the typical method for measuring the Cobb angle. This image by Skoliose-Info-Forum.de is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.

2. Materials and Methods

2.1 Data Collection

The inclusion criteria for the database were that participants were either young adults between 18 and 45 years of age and healthy, or older healthy adults above 65 years of age. The database consisted of videos used for the sole purpose of research. Exclusion criteria for all participant in the database included a history of dysphagia, neurological disease/insult, significant head and neck surgery (other than routine dental surgery, tonsillectomy, or adenoidectomy), major spinal deformities, chemoradiation to the head and neck, and/or possible pregnancy. Ultimately, VFSS were included from 19 healthy young adults (10 males; mean age: 32; range: 22-45) and 39 healthy older adults (18 males; mean age: 77; range: 65-95). VFSS were excluded if image quality and/or positioning of the participant prevented the spine from being viewed clearly (n=6, 1 younger adult and 5 older adults). All studies were conducted using a Kay Pentax Digital Swallow Workstation recording system, with the fluoroscope in lateral view at 30 pulses per second and were captured and recorded at 30 frames per second.

Data for this study were extracted from a retrospective research archive of VFSS. The original studies were approved by the research ethics boards at Toronto Rehabilitation Institute and New York University, and written consent was obtained from each participant prior to study participation.

2.2 Data Processing

Data extraction for this study was restricted to clips of the first, single sip of thin liquid for each participant (continuous cup and straw drinking were excluded). Using standard desktop computers with i7 processors and labs with dim lighting so that the x-ray images were clearly visible, the VFSS were first spliced into bolus-level clips using Corel Video Studio Pro. They were then assigned an alphanumeric code. Raters were a speech-language pathologist and a speech-language pathology graduate student who had 4 years and 1 year, respectively, of previous experience performing frame-by-frame analyses of VFSS, including identifying swallowing physiology, events and kinematics [41]. For the purposes of this study, raters underwent further training on how to measure the Cobb angle. Given the potential for spine angle differences during swallowing and at rest, the raters were asked to identify two frames per participant. First, they identified the frame of maximum laryngeal vestibule closure (LVC), defined as the first frame where there was maximum approximation of the arytenoids to the laryngeal surface of the epiglottis. They also identified the frame of post-swallow rest, defined as the first frame showing the pyriform sinuses at the lowest position, relative to the spine, prior to any hyoid burst or laryngeal elevation for a subsequent subswallow. These two frames were chosen with the intent of capturing the spine angle during the height of the swallow (LVC; i.e. during swallowing) and capturing the spine angle at rest where it would be unlikely for the posture to be influenced by swallowing. Post-swallow rest, rather than pre-swallow bolus hold, was chosen as a frame of rest given that data were extracted retrospectively and not all participants performed bolus holds during their VFSS. Further, the ASPEKT (Analysis of Swallowing Physiology: Events, Kinematics and Timing) method [41] is regularly employed in the lab, and this method requires several measures to be taken at the frame

of LVC and at the frame of post-swallow rest. Given the high reliability of identifying these frames, we felt it best to choose these frames for the current study.

2.3 Videofluoroscopy Rating

Once frames of LVC and post-swallow rest were identified and agreed upon, the degree of cervical spine curvature was measured using the Cobb angle. For the current study, the Cobb angle was measured between C2 and C4 in lateral-view VFSS using the angle tool in ImageJ (https://imagej.nih.gov/nih-image/) on the pre-established frames of LVC and post-swallow rest for thin liquid swallows (Figure 3). These vertebrae were chosen because they tend to be consistently and most easily visible on a VFSS. Further, C7 was not visible in any of the VFSS in our database, likely due to the fact that the shoulder generally obstructs the view of the inferior cervical spine when patients are positioned in the lateral view. C2-C4 appeared far enough apart to obtain a measure of curvature. Raters used the ROI Manager within ImageJ to allow each angle drawn to remain on the screen while subsequent angles were drawn, and measurements were taken. Twenty percent of the measures were taken in duplicate in order to calculate inter- and intra-rater reliability.
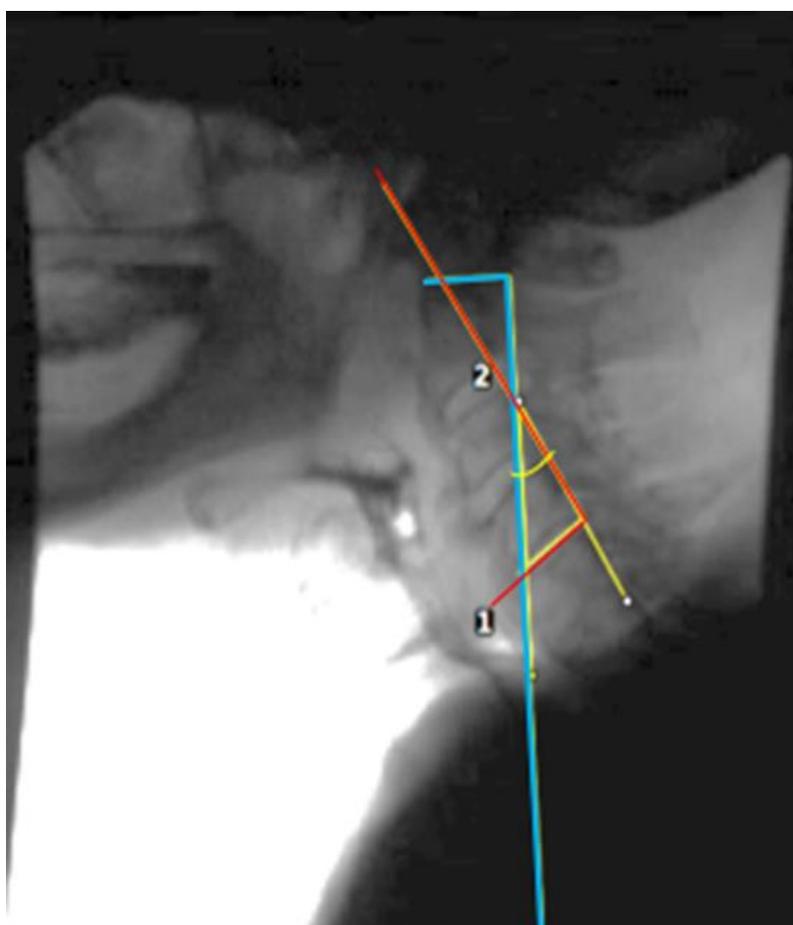

Figure 3 Example of two 90°angles around superior portion of C2 (angle 2, in blue) and the inferior portion of C4 (angle 1, in red) intersect to measure the Cobb angle (in yellow).

2.4 Data Analysis

All statistical analyses were conducted in IBM SPSS version 25. First, all reliability measures were computed using two-way mixed intraclass correlation coefficients (ICCs) for consistency. A priori determined cut-offs for acceptable reliability were established. Intra- and inter-rater reliability assess agreement of the same rater with themselves (intra) or with a second rater (inter). Intra- and inter-rater reliability ICCs of 0.75 and above are considered to have 'excellent' reliability [46]. Next, descriptive statistics were calculated to describe mean cervical curvature for each participant group at both frame of LVC and frame of post-swallow rest. Independent sample t-tests were used to compare degree of curvature at each time point between healthy young and healthy old. Two-tailed p-values *p* < .05 were considered statistically significant. Effect sizes for significant pairwise comparisons were calculated using Cohen's d. Cohen's d can be interpreted as showing a small effect size for values of < 0.5, medium effect size for values of 0.5–0.8, and large effect size for values of > 0.8 [47].

3. Results

Results revealed excellent levels of agreement within and across raters for degree of C2-C4 curvature on the frame of post-swallow rest (ICC = 0.793 (95%CI [-0.032, 0.959]) and 0.788 (95%CI [0.060, 0.952]), respectively). There were fair to good levels of agreement within and across raters for frame of LVC (ICC = 0.621 (95%CI [-0.893, 0.924]) and 0.667 (95%CI [-0.476, 0.925]), respectively).

Descriptive statistics for the parameters of interest (modified Cobb's angle measured at LVC and post-swallow rest) are displayed in Table 1. Significant differences in the C2-C4 Cobb angle were found between healthy young and healthy old at post-swallow rest (t(55) = 2.035, p = 0.003; Cohen's *d* = 0.633 [medium]). Significant differences in the C2-C4 Cobb angle were also found between the healthy young and healthy old data at frame of LVC (t(56) = 3.140, p = 0.001; Cohen's *d* = 0.97 [large]). No significant differences were found between C2-C4 Cobb angle measured from frame of LVC compared to frame of post-swallow rest across collapsed age groups (t(81) = -0.809, p = 0.421).

Table 1 Descriptive statistics for the modified Cobb angle measured across samples at two different timepoints: laryngeal vestibule closure (LVC) and post-swallow rest.

Measure	Healthy young (n = 19)	Healthy old (n = 39)	P-value
C2-C4 angle at frame of LVC (mean ± standard deviation)	5.8 ± 9.0°	12.5 ± 9.0°	0.001*
C2-C4 angle at frame of post-swallow rest (mean ± standard deviation)	7.7 ± 4.5°	12.4 ± 9.7°	0.003*

*Denotes a statistically significant p-value, per the results of t-test.

4. Discussion

The primary objectives of this proof-of-principle study were to establish a reliable method for measuring cervical spine curvature on VFSS and determine if differences existed in cervical spine curvature between healthy young and healthy old samples. Our findings revealed that the C2-C4 Cobb angle may be a reliable method to measure cervical spine curvature, particularly when measured on frame of post-swallow rest. In addition, we found significant differences in curvature between younger and older healthy participants. More specifically, consistent with the existing spinal cord literature, cervical vertebrae two to four appear to increase in curvature with age [22-24, 35-38].

It is interesting to note that reliability is more clearly established on frame of post-swallow rest compared to frame of LVC. The reduced reliability on frame of LVC could be due to the movement inherent within the pharyngeal stage of the swallow, causing artifact within that frame so that the borders of the cervical vertebrae were not completely clear to raters. The overall quality of the videos may have also played a role in making the necessary ratings. Given that no significant differences were found between the C2-C4 Cobb angle at frame of LVC compared to frame of swallow rest, we recommend that future use of the C2-C4 Cobb angle in this context be performed on frame of post-swallow rest over the frame of LVC. It may be warranted to explore other frames of interest in future research.

This non-invasive method of measuring cervical spinal cord curvature has potential use for future dysphagia research. With established reliability, the C2-C4 Cobb angle can be used to determine the degree of spinal curvature in a variety of populations and potentially explore its impact on swallow biomechanics. In order to further establish reliability, it is important that this method is validated by comparing the results to the standard application of the Cobb angle from C2-C7 and by evaluating the efficacy of this measurement in patients with documented cervical spine changes. Once confirmed to be reliable and valid, the modified method might specifically be useful in situations where we expect damage to or deterioration of the cervical spine, without having to request a separate x-ray to take measurements on the full cervical spine using the C2-C7 Cobb method. Moreover, the measurements can be incorporated into statistical analyses to control for variation attributed to spinal curvature during swallowing. They might also be used as a method of monitoring changes in spinal curvature within older adults along the course of a disease trajectory. Some might also choose to use measurements of C2-C4 spine curvature to help explain changes in the swallow that cannot be attributed to timing, coordination or basic kinematics. This proxy measure might eventually be useful for clinicians who are concerned about neck posture and would like to track changes in cervical spine curvature via clinical VFSS performed over time.

When considering that significant differences in C2-C4 curvature were found between the young and older participants, one might question the reason for these changes across the lifespan. Recent research by Brates et al. [40] suggests that changes to spinal morphology result in scaled hyoid movements that are inflated in older individuals because of a reduction in C2 to C4 length, due to cervical disc degeneration present in most older adults [48]. This degeneration results in a loss of intervertebral height. It is possible that this difference in C2 to C4 length may be impacting the Cobb angle, or an increase in kyphosis is contributing to a shorter cervical spine height. Future work will need to consider these age-related changes to the spine and clarify how kyphosis and

disc degeneration are related. In order to monitor these changes over time, we will also need to establish test-retest reliability.

Given that the purpose of the current, exploratory study was to establish proof-of-principle, several limitations require acknowledgement. Firstly, the method itself has some limitations. Since it is measuring spine curvature between a relatively short distance (3 vertebrae), the resulting measurements may not account for disc protrusion, osteophytes, or other factors influencing spine curvature that occur below C4. However, given that the region between C2 and C4 is where many important physiologic swallowing functions take place, we predict that curvature in this area is significant for swallowing physiology and is therefore useful to measure. Another limitation is that the data analyzed for this study was restricted to a retrospective sample of young and older healthy adults, who did not have any documented cervical spine changes. A further limitation is that given that the data were extracted retrospectively from a research archive, it is possible that differences in head posture, patient positioning and/or instructions across participants may have impacted the findings. We were also unable to compare our C2-C4 Cobb angle measurements to measurements taken from C2-C7, given that C7 was not visible on the large majority of VFSS. Future studies should consider validation against x-ray where more of the spine is visible and/or MRI. Moving forward, it will be critical to perform a prospective study, where many of these factors can be controlled. Future studies should also consider minimizing random error by taking a minimum of three measurements and averaging the results.

5. Conclusions

The Cobb angle is a method of measuring spine curvature on x-rays and is a relatively simple measurement to conduct. This proof-of-principle research establishes that the Cobb angle measurements between cervical vertebrae two and four, derived from VFSS using ImageJ on the frame of post-swallow rest, have satisfactory inter-rater and intra-rater reliability. Moreover, we have confirmed changes in cervical spine curvature with age using this modified Cobb angle method, thus suggesting that the measure may be an option for monitoring cervical spine curvature via VFSS. Future work should focus on recruiting a prospective sample that includes patients with documented cervical spine changes that are age-matched with healthy participants. It would also be interesting to determine if the trend of increased C2-C4 spine curvature continues with old, old adults (i.e. those who are 80+ years of age). Given that cervical spine curvature may be influenced by posture and thoracic spine curvature, future work should compare these parameters to measurements taken using a cervical range of motion device, used to evaluate the range of motion of the cervical spine. Validation of this method within a prospective study using the C2-C7 Cobb method will also be an important next step towards using this adapted method in research and clinical practice. Lastly, future studies should determine if and at what point cervical kyphosis influences swallowing physiology. The directionality of the curvature must also be confirmed, as well as the implications of lordotic and kyphotic cervical spines on swallowing function in different populations and in various swallowing postures.

Author Contributions

ANM: conception, experiment design, data analysis, drafted, and revised manuscript; LFR: conception, experiment design, and revised manuscript; SMM: conception, experiment design, data collection, data analysis, and revised manuscript.

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Competing Interests

The authors have declared that no competing interests exist.

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