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A Radiographic Investigation of Anthropometrics, Neck Posture, and Neck Strength in Individuals with Enlarged External Occipital Protuberances

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A Radiographic Investigation of Anthropometrics, Neck Posture, and Neck Strength in Individuals with Enlarged External Occipital Protuberances

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Abstract

Overview: Enlarged external occipital protuberances (EEOPs) are found in 41% of young adults. These EEOPs have the potential to lead to pain throughout life and possibly surgery. Little is known of the pathophysiology or characteristics that could lead to these EEOPs. **Purpose:** The purpose of this study is to use radiographic measurements to investigate how anthropometrics, neck posture and neck strength in flexion and extension differ between those with and without an EEOP. **Methods:** 80 radiographs from three different studies were digitized and the marking of landmarks performed in ImageJ. The cut-off for an EEOP was established as any EOP greater than or equal to 10 mm. Neck strength and anthropometrics have been previously collected while all neck posture variables were measured using models in Microsoft Excel. Outcome measures were (1) body mass, (2) head circumference, (3) neck circumference, (4) neck length, (5) gravitational moment arm, (6) intervertebral joint angles, (7) skull angle, (8) forward head protraction, and (9) isometric neck strength. A two-way ANCOVA was ran with between factors of sex and EEOP occurrence on each variable and a covariate of neck length. A Tukey post hoc test was run on any significant main effects, and simple effects was run on any significant interactions. Significance level was set at $p < .05$. **Results:** There were no significant differences in neck posture, age, body mass, height, or neck strength between the those with and without EEOPs. Neck circumference was significantly different in those with EEOPs, where participants with EEOPs present had larger neck circumferences. **Conclusion:** EEOP occurrence does not seem to be due to differing neck postures in neutral, but a larger neck circumference may indicate larger neck muscle volume which may point to muscle size and strength as possible influences. Future work should look at neck muscle volume and strength between those with and

without EEOPs, focusing on even sample sizes within each age distribution and treatments groups.

Contents

Chapter 1: Introduction

Recent research has reported 41% to 44.9% of young adults have enlarged external occipital protuberances (EEOP)[1,2]. An EEOP is an excessive bony growth off the external occipital protuberance. With these EEOPs come the possibilities of migraines, surgery, surgery complications, and tenderness in the back of the skull[3–8]. If the EEOP were to cause migraines, this can cost an individual on average $4027 a year in medical bills[1,2,99]. With a high prevalence of EEOPs in younger populations and the possibility of medical complications, understanding what differentiates those with and without EEOP is vital to improving the quality of life and reducing the yearly cost of living for these individuals.

A high prevalence of EEOPs in young adults has been previously established [1,2,10]. Furthermore, previous work has studied the pathophysiology of enthesophytes, or an abnormal bony prominences at an attachment site, in other areas of the body[11–15] but little to no work has looked at the pathophysiology of the EEOP. We have been able to rule out inflammatory and genetic causes[16], still leaving mechanical factors as possible explanations. Although the high prevalence of EEOPs is alarming, there is a lack of research looking at common characteristics and posture differences between those with and without EEOPs.

The purpose of this study was to use radiographic measurements to investigate how body mass, height, neck anthropometrics, neck posture and neck strength in flexion and extension differ between those with and without an EEOP and how sex may influence these differences. This was a radiographic retrospective study of 80 radiographs from previous work[17–19]. Radiographs were digitized, and posture measurements recorded using ImageJ. Neck strength and anthropometrics were previously collected. Our hypotheses are as follows:

1. We hypothesize that neck posture in flexion and neutral will differ between those with and without an EEOP. Specifically, those with EEOPs will have more flexed intervertebral and skull angles. Flexed intervertebral angles may cause the nuchal ligament to be more taught, therefore putting more stress on the EOP. To test this hypothesis, we will compare the intervertebral angles, skull angles, neck length and gravitational moment arm of the head between those with and without EEOPs.

2. We hypothesize that those with EEOPs will have greater neck strength in flexion and extension compared to those without. Previous work has shown that bone growth and bony prominences rely on the mechanical pull of muscles, therefore, those with greater neck muscle strength may put more stress on the EOP leading to an excessive growth[20,21]. To test this hypothesis, we will use previously collected isometric neck strength measurements and compared them between those with and without EEOPs.

3. We hypothesize that age, body mass, neck circumference, and head circumference will all be larger in those with an EEOP compared to those without. Similar to neck strength, increased body mass and neck circumference may indicate larger muscle volume, in turn putting more stress on the EOP. A larger head circumference would indicate a heavier head, needing stronger neck extensor muscles to maintain head position, in turn, putting more stress on the EOP. To test this hypothesis, we will compare the anthropometrics of those with EEOPs to those without EEOPs.

Chapter 2: Literature Review

2.1 Anatomy of the EOP

The EOP is located on the external-posterior surface of the occipital bone[22]. Other bony landmarks near the EOP include nuchal lines that run superiorly and inferiorly to the EOP[22]. The EOP can be shaped differently between people and is classified into three categories: Type 1 (smooth), Type 2 (crest), or Type 3 (spine)[4,23] (Figure 1). A Type 1 EOP follows the curvature of the back of the skull with no protrusion from the skull while a Type 2 EOP presents as a crest shape protrusion from the back of the skull. Finally, a Type 3 EOP is an excessive spined shaped protrusion from the back of the skull.

Figure 1: Type 1 (left), Type 2 (middle), and Type 3 (right) EOPs circled in red on a sagittal view radiograph.

Muscles of the EOP

The EOP is an attachment site for the nuchal ligament that extends from the EOP to the spinous process of C7 [24]. The nuchal ligament serves as a site of attachment for the upper trapezius, rhomboid minor, splenius capitis, and serratus posterior muscles[25]. This site of attachment between the nuchal ligament and the EOP is referred to as an enthesis or a sight of ligament or tendon attachment to bone [26]. The enthesis is of importance because it serves to distribute forces from these muscles or joints over a larger surface area of bone[27].

Nerves Of the EOP

There are also nerves that run closely to the EOP (Figure 2). The greater occipital nerve runs between the inferior oblique capitis muscle and semispinalis capitis and continues deep to pierce the aponeurosis of the trapezius inferior to the superior nuchal ridge[3]. This nerve provides sensory innervation the skin of the posterior scalp[3]. The third occipital nerve runs as close as 3 mm from the EOP and has smaller branches that extend inferior to the EOP[28]. This third occipital nerve runs through the trapezius muscle and ends at the skin near the midline of the occipital region[29]. The third occipital nerve innervates the C2-C3 facet joint and partially innervates the semispinalis capitis muscle[28]. It has been proposed that an enlarged EOP may impinge on these nerves, causing occipital neuralgia[3,7].

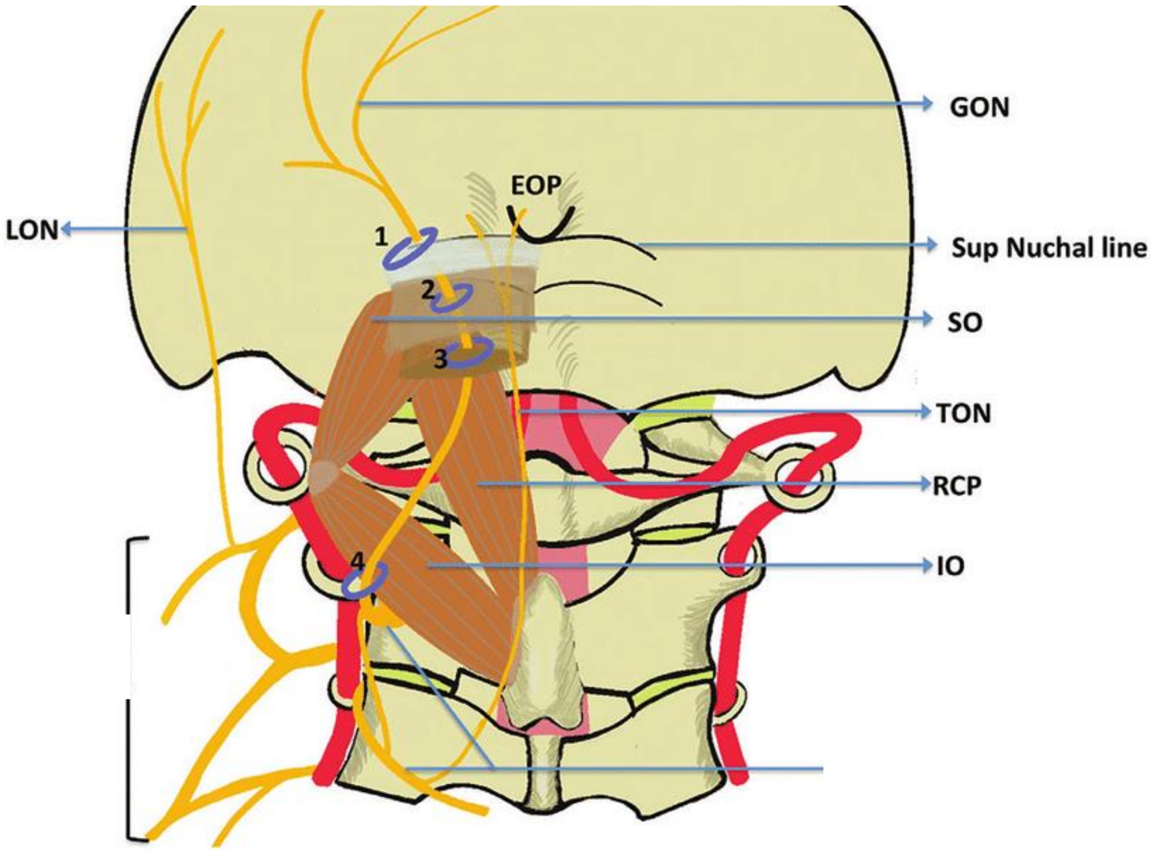

Figure 2: The Greater Occipital Nerve (GON) and the Third Occipital Nerve (TON) run closely to the EOP. Lessor Occipital Nerve (LON) and Inferior Oblique (IO) also surround the EOP. Received From: From Management Options in Occipital Neuralgia: A Review. J Peripher Nerve Surg: 2020; 4:7–14. DOI:10.1055/s-0040-1716451 - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Artistic-representation-of-Posterior-view-of-Occipitocervical-junction-and-Anatomy-of-the_fig1_344455452 [accessed 10 May, 2021]. CC-BY-ND-NC

2.2 Enlarged External Occipital Protuberances

Recent literature has discussed the potential for enlarged external occipital protuberances (EEOPs)[1,2,10]. These EEOPs have been categorized in various ways, including as an enthesophyte[16], an occipital spur[30,31] or simply an EEOP[2,10]. Similar to the different ways to name an EEOP, there has also been different ways to classify if someone presents with an EEOP or not (Table 1). For example, Shahar & Sayers, (2016) classified an EEOP as an EOP that exceeded 10 mm. Yet other studies have simply classified Type 2 and/or 3 EOPs as enlarged[1,31].

Preliminary data from our study has shown that Type 3 EOPs consistently exceed 10 mm while Type 1 and 2 EOPs fall below 10 mm. This allows us to use a cut-off of 10 mm as being considered enlarged.

Table 1
Previous EEOP research

Author	Purpose	Country of Participants	EEOP Classification	EOP Measurement	Results
Jacques et al., 2020	Compare the prevalence and size of EOP enlargement in young adults in 2019 and 2011 along with 2 ancient skulls	France and Egypt	Enlarged EOPs were classified as Type 2 and Type 3 EOPs	EOP volumes were taken with "Freehand Volume of Interest" tool from SyngoVia and Type 1, 2, and 3 were classified by looking at the EOP	In 2011 the EEOP was 2.13 (1.36) cm^3 and in 2019 the EEOP was 2.00 (1.66) cm^3 (not significantly different)
Shahar & Sayers, 2016	To quantify the prevalence of EEOP in young adults and compare with a cohort of mildly symptomatic age-matched individuals	Australia	An EOP was classified as large if it was greater than 10 mm	Genesis OmniVue, Genesis Digital Imaging was used. Measured from the most superior point of the EOP, or base, to the point of the EOP that is most distal from the skull	Average EEOP size in males was 15 (7) mm and in females was 10 (7) mm.
Srivastava et al, 2018	To find the prevalence of occipital spur in human skulls and discuss the anatomic morphological characteristics of occipital spurs	India	Labeled the EEOP as an occipital spur on the EOP.	All measurements were done using a digital Vernier Caliper. The width was measured at the base, the length was from the midpoint of the base to the apex, and the thickness was also measured at the base	Average length (from base to apex) was 13.55 (1.05) mm, Width (Base of spur) was 19.73 (4.85) mm, and Thickness (at the base of the skull) was 1.83 (0.39) mm
Varghese et al, 2017	Description of a medical case of occipital spur	Malaysia	Labeled the EEOP as a Type 3 EOP	Measured from a radiograph. Did not provide what program or steps were used to measure.	One patient with an EEOP that measured 13.4 mm in length and a width of 25.9 mm

2.3 Gender Differences

The frequency of the Type of EOP varies between genders, with women being five times more likely to have a Type 1 (smooth) EOP while men are five times as likely to show a Type 3 (spine) EOP[23]. These differences are so prominent that the EOP can be used as a criterion for determining sex with 85.4% of women having a Type 1 EOP compared to only 17.8% in men[23]. These gender differences are also seen in the prevalence of an EEOP. EEOPs are seen in 67.4% of men and 20.3% in women[2]. These findings are supported by Jacques et al., (2020) that found men had significantly higher EOP volumes compared to women with an average of 2.34 cm^3 vs 1.05 cm^3.

There may be a number of reasons why we see these gender differences. It has been proposed that enthesophytes may occur due to repetitive tensile loading on the enthesis site[32]. Men tend to be more active than females and this increased activity level may contribute to the repetitive loading of the EOP [33–35]. Yet the cause of these gender differences may be more anatomical. Men have been shown to have more muscle mass than women[36] and an increased cross sectional area of muscle allows for more force production[37]. This increased muscle strength may increase the stress on the EOP during daily life and/or activities. Unfortunately, there is a lack of research into possible factors that may influence these gender differences in EEOP occurrence as well as a lack of research into the proposed pathology of EEOPs.

2.6 Proposed Pathology

Although there is a lack of data looking at EEOP occurrence in older adults (greater than 30 years of age), enlarged EOPs have been found to have a high prevalence in younger adults with 41% presenting with EEOPs[2]. Similar rates of EEOPs in young adults were found in a population from 2011 with a 44.2% prevalence[1]. With such a high prevalence of an EEOP in young adults, it has been proposed that the use of cellphones, computers, and tablets with the increased screen time of young adults may play a role in the development of an EEOP[2]. Technological advancements may not tell the whole story though. Jacques et al., (2020) found that EEOPs in young adults have been present since 30 B.C. This suggests that the development of an EEOP may not be solely due to technological advancements but may have more to do with prolonged loading of the EOP in general, similar to what is seen when using a smartphone.

Another proposed explanation of EEOPs is the excessive growth of the EOP may be related to the size of the neck muscles. The development of bony tubercles at entheses rely on the mechanical pull from muscle; a lack of this mechanical pull can decrease the number of osteoclasts, or bone forming cells, at an insertion site[20,21]. We also see a decrease in bone density with a lack of mechanical stress on the bone[38]. If the mechanical stress were to increase with increased muscle size, it would require increased surface area at the entheses and could cause bone growth[11,39]. This theory may also explain why EEOPs are more prevalent in males[2] with men having significantly more skeletal muscle mass compared to women[36] and increased cross sectional area of a muscle fiber increases force production[37]. This increased force production would in turn put more stress on the EOP. This explanation is supported by the theory that enthesophyte formation may be explained by a combination of ossification methods and repetitive tensile loading on the enthesis[32].

Spondyloarthritis and Diffuse Idiopathic Skeletal Hyperostosis (DISH) are both conditions that can lead to enthesophytes. Spondyloarthritis is a Type of arthritis that is caused by a combination of mechanical and inflammatory factors[14]. DISH is a non-inflammatory bone and entheses disease that is characterized by ossification of the enthesis[40,41]. Enthesophytes are a common finding in patients with spondyloarthritis and DISH[13,15,42]. Previous studies have shown that larger enthesophytes occur more commonly in patients with spondyloarthritis compared to healthy controls [13,15,42]. Yet, enthesophyte formation from underlying diseases like spondyloarthritis and DISH are more common in older individuals and enthesophytes that form prior to the age of 60 are generally in healthy individuals without any underlying health conditions[43,44]. Studies have also performed blood tests on those with enlarged EOPs and were able to rule out any genetic predispositions and active inflammation factors[16]. With enthesophytes formation from spondyloarthritis and DISH being more common in older adults and genetic factors being ruled out, the formation of EEOPs may be more reliant on mechanical factors rather than a disorder.

While not explicitly shown in the skull, endochondral ossification comes from another site of enthesophytes formation in the body, the Achilles tendon. Enthesophyte formation in the Achilles tendon can occur without any microtears or inflammatory responses[11]. These enthesophytes form from a process similar to normal enthesis development along with endochondral ossification through the fibrocartilage [11]. It begins with the takeover of blood vessels into the tendon and the holes made by these blood vessels are filled with bone over time[11]. Although this seems like a possibility, these Types of bone spurs are more prevalent in people 60 years or older and take time to develop[44].

2.4 Pain and EOP

Type 3 EOPs can develop into a subcutaneous scalp pseudo tumor in adolescents, which can cause stretching and tenderness of the skin, especially when palpated[8]. A common complaint of patients with EEOPs is pain while laying down in the supine position[31,45]. At times, this pain from the EEOP has required surgery[4,31,45] and can cause complications post-surgery, causing the wounds to breakdown and need medical attention[5]. If the EEOP is subject to trauma, it may even break off and require surgery to remove the bone fragment[6].

The third occipital nerve runs closely to the EOP (within 3 mm) and is therefore susceptible to compression from an enlarged tubercle[7]. When this nerve is compressed, it can lead to occipital neuralgia or migraines[3]. With the occurrence of headaches in the adult population being 47% and 3% experiencing chronic headaches[46], an EEOP could explain some of these issues.

It has been well documented that there is a high prevalence of EEOPs in younger adults as well as the reduced quality of life experienced by those with EEOPs. Yet, little is known about how these EEOPs form and what differentiates those with EEOPs from those without. The current study sought to identify anthropometric and neck posture differences between those with and without EEOPs using radiographic measurements.

Chapter 3: Methods

3.1 Participants

This was a retrospective study of 80 radiographs (40 males, 40 females) from three different studies[17–19] (Table 2). There were 58 radiographs that came from the University of Washington State and 22 radiographs that came from the University of Arkansas. All radiographs were taken by trained radiology techs. All radiographs were pooled to create one data set. Participants of these studies were required to be neck pain and neck injury free at the time of the studies. None of the studies had exclusion criteria based on sex or gender. All prior studies received IRB approval from their respective universities.

Table 2

Summary of studies where radiographs were obtained. Two studies were from Washington State University and one study was from the University of Arkansas

Study	Purpose	Radiographs Received	Posture(s)	Neck Strength	Anthropometrics	Gender (Male/Female)	Neck Circumference	Head Circumference
Vasavada et al., 2015	To assess the biomechanical ergonomics of the head and neck during varying tablet-usage postures	29	Neutral ***Sitting for all conditions***	Yes	Age, body mass, height	17/16	Yes	Yes
Zheng et al., 2012	To assess the saggital plane kinematics of the hyoid bone	30	Neutral Flexion ***Standing for all conditions***	No	Age, body mass, height	16/16	Yes	Yes
Douglas & Gallagher, 2018	To assess how the cervical spine is influenced by reading a tablet in the lap in varying postures	21	Neutral Flexion ***Sitting for all conditions***	No	Age, body mass, height	11/11	No	No

3.2 EEOP Classification

Table 1 demonstrates the need for a standardized classification of an EEOP. Previous work has considered Type 3 EOPs and EOPs exceeding 10 mm as enlarged[1,2,10]. Preliminary data from our lab has demonstrated that those with Type 3 EOPs consistently exceed 10 mm while those with Type 2 and Type 1 EOPs are consistently below 10 mm. With this data as well as previous classifications of EEOPs, we used 10 mm as the cutoff for our two groups: greater than or equal to 10 mm = EEOP present and less than 10 mm = EEOP absent. The EOP length was measured from the base of the EOP to the farthest part of the EOP away from the skull (Figure 3).

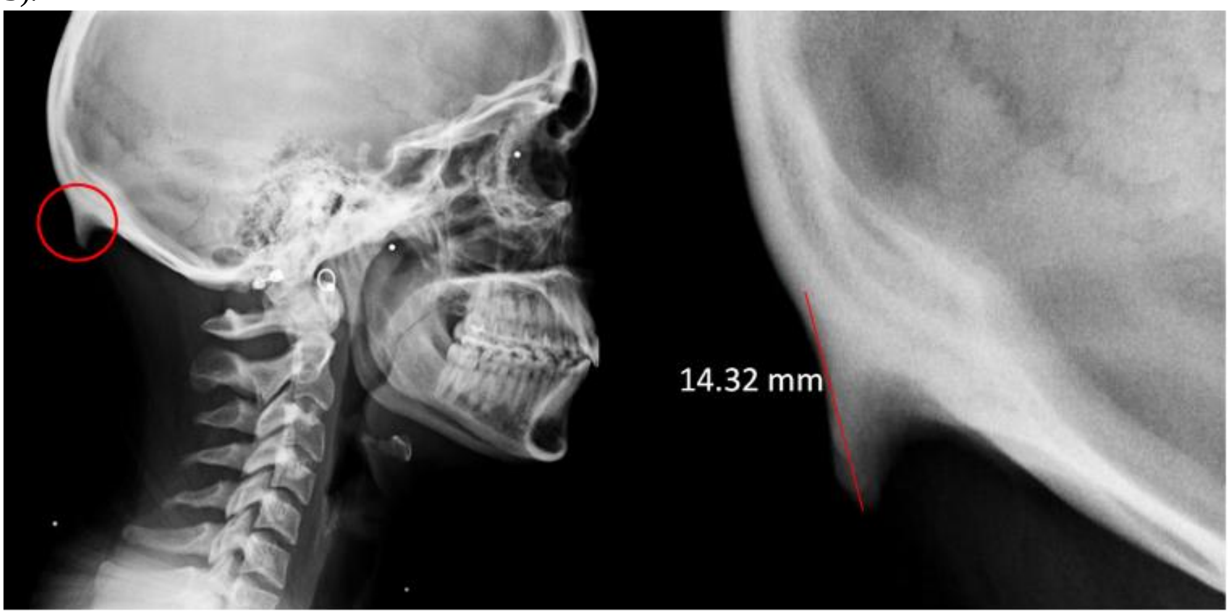

Figure 3: EOPs are measured from the base of the EOP to the farthest tip of the EOP from the skull

3.3 Measurements

Age, height, and body mass were measured previously for all participants. Two of the three studies took measurements of head and neck circumference using a medical tape measure[18,19]. These circumference measurements were taken three times and averaged.

Maximum isometric neck flexion and extension were measured with a hand-held dynamometer for 29 of the radiographs[18]. When measuring neck flexion, participants laid flat on their back on a table with their head and neck extended over the end of the table and arms folded across their chest. The researcher pushed down on the glabella with the dynamometer and the subjected resisted this movement. To measure extension, participants laid flat on their stomach with their arms by their sides and their head and neck extended over the end of the table. The researcher applied pressure with the dynamometer to the opisthocranion while the participant resisted.

The following posture variables were assessed for each radiograph: intervertebral joint angles, skull angle, gravitational moment arm of the head, forward head protraction (FHP) and neck length. Each variable was assessed in neutral for all radiographs and maximum flexion for 51 of the radiographs. 51 of the radiographs were taken with participants sitting while 29 were taken with participants standing. While sitting in a neutral posture, the cervical spine has more lordotic curve compared to standing in a neutral posture, demonstrating the influence of posture on cervical spine alignment[47]. A between group t-test with between factors of posture (sitting vs standing), was run on any significant findings to ensure the two groups were not significantly different on these variables.

Vertebral and skull position were defined by digitizing the corners of each cervical vertebral body from C1-C7 and the following anatomical landmarks on the skull: canthus, tip of the mastoid process, external auditory meatus, and the EOP. The coordinate systems for C1-C7 were in line with the recommendations from the International Society of Biomechanics (ISB)[48]. The positioning of the vertebrae was defined as the geometric center of the digitized corners of each vertebra. The C1 vertebra was defined as the mid-point between the posterior and anterior tubercles. The skull position was defined by the point on the tip of the mastoid.

The radiographs were uploaded into ImageJ for the marking of landmarks. The landmarking was done by one researcher (Caleb Burruss) to assure reliability. This researcher has previous experience with landmarking in ImageJ as well as training from the principal investigator on reading radiographs. Intraclass Correlation Coefficients (ICCs) and their 95% confidence intervals were calculated using SPSS (SPSS Inc, Chicago, IL) based on the mean of two measurements ($k = 2$) by one rater, absolute agreement, two-way mixed effects model[49] (Table 3). These values determine the precision that the rater has for landmarking each radiograph.

Table 3
ICC Values, presented are the ICC values and their 95% confidence intervals

Variables	ICC Value	95% CI	Level of Reliability*
Neck Length	.992	0.969-0.998	Excellent
Gravitational Moment Arm	1.000	1.000-1.000	Excellent
Skull Angle	.985	.943-.996	Excellent
C1-C2 Angle	.996	.976-.999	Excellent
C2-C3 Angle	.986	.937-.997	Excellent
C3-C4 Angle	0.960	.844-.990	Good to Excellent
C4-C5 Angle	0.970	.887-.993	Good to Excellent
C5-C6 Angle	0.934	.753-.983	Good to Excellent
C6-C7 Angle	.952	.807-.988	Good to Excellent

*Poor reliability <0.5; moderate reliability = 0.5-0.75; good reliability = 0.75-0.9; excellent reliability > 0.9[49].

The marker data was exported from ImageJ and uploaded into Microsoft Excel to run through models. To calculate intervertebral angles, a vector was created for each vertebra running through the center of the vertebrae posteriorly to anteriorly and at an angle to the horizontal. These vectors were run through the ATAN2 function in Microsoft Excel to get the arctangent of the vector and converted to degrees, giving the individual angle for each vertebra in reference to the horizontal. Each intervertebral angle was taken in reference to the superior vertebrae. For example, the C1-C2 intervertebral angle was calculated as the C2 angle subtracted from the C1 angle (Figure 4). The skull angle was calculated as the angle formed between the canthus, tip of mastoid process, and the horizontal (Figure 4). Moment arms were calculated by subtracting the x-coordinates of the two landmarks, giving us the perpendicular distance between the two points (Figure 4). Neck length was measured as the summation of vertebrae heights and intervertebral spaces between C1 to C7 (Figure 4). FHP was calculated as the horizontal distance between the superior posterior point of C2 vertebral body and the inferior posterior point of the C7 vertebral body[10].

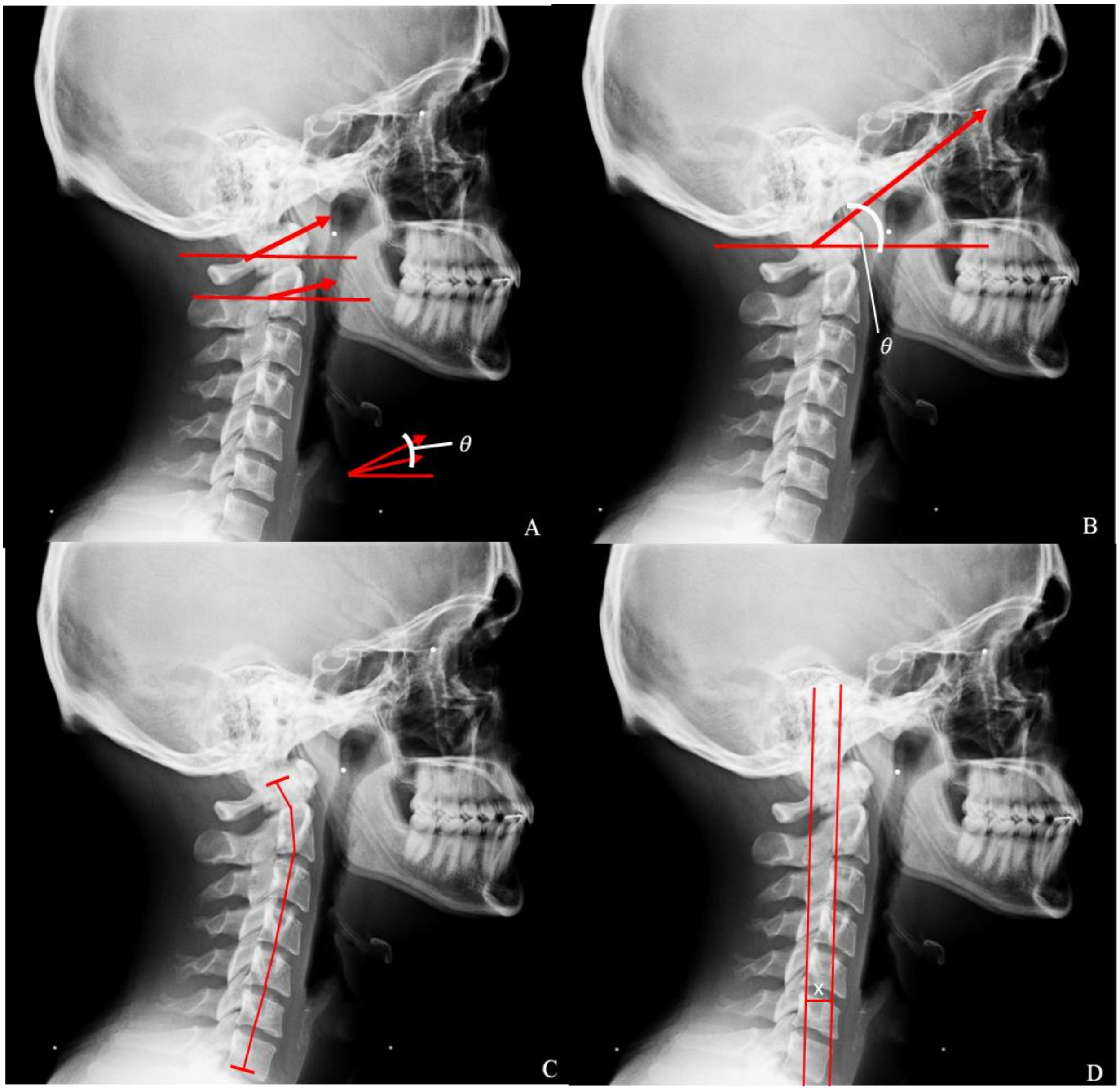

Figure 4: (A) Intervertebral Joint Angle, (B) Skull Angle, (C) Neck Length, and (D) Gravitational Moment Arm

3.4 Statistical Analysis

A 2x2 ANCOVA design with parametric analysis was used to investigate the following question: how do body mass, neck anthropometrics, neck posture and isometric neck strength differ between those with and without an EEOP and do these differences depend on sex? The independent variables for this study are: EEOP occurrence (present or absent) and sex (male or female) with a covariate of neck length. Neck length is being used as a covariate because previous work has demonstrated anthropometrics can influence neck posture[50]. Outcome measures were (1) body mass, (2) head circumference, (3) neck circumference, (4) neck length, (5) gravitational moment arm of the head, (6) intervertebral joint angles, (7) skull angle, (8) FHP and (9) isometric neck strength (flexion and extension). A Shapiro-Wilk test was used to assess normality of the data. For outcome measures that are normally distributed, a Levene's test for homogeneity of variance (HOV) was used. For outcome measures that violate our normality assumption, a Brown-Forsythe test of HOV was run. A Tukey's post hoc test was run on any significant effects at $p<.05$. All statistics were run in either SAS (v9.4, SAS Institute Inc. Cary, NC) and SPSS (v26, IBM Corp. Armonk, NY). Finally, p-values falling between 0.05 and 0.2 were also reported as these would be worth designing future studies to better estimate potential effects of these variables[51].

4. Results

Of the eighty participants used in this study, 18 participants presented with an EEOP group and 62 did not. For males, 35% (14/40) had an EEOP while only 10% (4/40) of females had an EEOP. The average EOP lengths were 14.10 $\pm$ 3.33 mm for those with an EEOP and 2.98 $\pm$ 3.22 mm for those without an EEOP. Based on visual classification, 51% of participants had a Type 1 EOP, 26% had a Type 2 EOP, and 23% had a Type 3 EOP. The range for Type 2 EOPs was 1.79 mm to 10.76 mm. The Type 2 EOP measuring 10.76 mm was the only Type 2 EOP to exceed 10 mm. With this 10.76 mm EOP taken out, the max for Type 2 EOPs falls to 9.73. Similarly, there was one Type 3 EOP that did not exceed 10 mm at 6.96 mm. These outliers were left in the data to be consistent with the visual classifications. The between groups t-test found no significant differences between sitting and standing for any of the significant findings of this study.

4.1 Assumptions

There were no violations of normality for the between groups t-tests nor were there any violations in HOV between groups.

When testing normality for the interaction of group and sex, body mass for EEOP males, C4-C5 angle for EEOP females and age for all groups were non-normal. When assessing normality by just group, flexion strength, extension strength, age, neck circumference and body mass were non-normal for the non-EEOP group. Age, head circumference, and body mass were not normally distributed for the EEOP group. Even with these violations, we chose to run a parametric test due to the lack of non-parametric tests alternatives of a two-way ANCOVA. This increases the likelihood of a Type 1 error with our data set but ANOVAs and ANCOVAs tend to be robust to non-normality. There were no violations of HOV between groups.

Head circumference violated the Homogeneity of Regression Slopes assumption of an ANCOVA. Females with an EEOP (n=2) had a regression slope of 1.00 which was a difference greater than .4 from the other groups on this variable. Due to this violation and small sample size, there is an increased risk of Type 1 error for this variable.

4.2 Neck Posture

When controlling for neck length, there were no significant differences between EOP groups for skull angle, intervertebral angles, forward head protraction, or gravitational moment arms in either neutral or flexion between the two groups (Table 4 & 5). Although not significant, the C5-C6 intervertebral angle was more extended in the EEOP group ($p=0.13$, $\eta^2=0.0297$) (Table 4).

Table 4

Neck posture variables (mean + standard deviation) for ***neutral*** *with their main effects and interactions. Positive values for angle indicate extension and negative values indicated flexion.*

	Enlarged EOP		Group Effect		Sex Effect		Interaction Effect	
Variable	**Present (n=18)**	**Absent (n=62)**	**p-value**	η^2	**p-value**	η^2	**p-value**	η^2
Gravitational Moment Arm (mm)	16.5 + 14.3	18.1 + 11.2	0.71	0.0018	0.16	0.0258	0.51	0.0059
Forward Head Protraction (mm)	20.6 + 10.6	21.6 + 9.0	0.78	0.0010	0.19	0.0216	0.83	0.0006
Skull Angle	32.1 + 5.8	30.6 + 7.1	0.25	0.0012	0.13	0.0301	0.78	0.0010
C1-C2	22.0 + 8.2	24.1 + 6.7	0.22	0.0197	0.15	0.0271	0.54	0.0051
C2-C3	10.3 + 4.7	10.3 + 5.0	0.46	0.0073	0.005*	0.1027	0.29	0.0148
C3-C4	2.2 + 2.8	2.3 + 3.8	0.58	0.0040	0.26	0.0172	0.51	0.0059
C4-C5	1.1 + 4.2	-1.3 + 4.7	0.21	0.0211	0.68	0.0022	0.92	0.0001
C5-C6	1.3 + 4.4	-1.1 + 4.1	0.13	0.0297	0.63	0.0031	0.52	0.0056
C6-C7	3.3 + 4.0	2.8 + 3.9	0.66	0.0026	0.07	0.0442	0.24	0.0187

*η^2= Partial Eta Squared Effect Size, small effect size = 0.04, medium effect size = 0.06, large effect size = 0.1. * indicates significance at $p<.05$.*

Table 5

*Neck posture variables (mean ± standard deviation) for **flexion** with their main effects and interactions. Positive values for angle indicate extension and negative values indicated flexion.*

	Enlarged EOP		Group Effect		Sex Effect		Interaction Effect	
Variable	**Present (n=18)**	**Absent (n=62)**	**p-value**	η^2	**p-value**	η^2	**p-value**	η^2
Gravitational Moment Arm (mm)	83.7 ± 24.3	86.4 ± 19.0	0.17	0.0405	0.91	0.0003	0.62	0.0052
Skull Angle	-11.4 ± 15.0	-14.6 ± 8.2	0.25	0.0282	0.74	0.0024	0.97	0.0000
C1-C2	17.9 ± 8.8	15.3 ± 6.6	0.29	0.0240	0.44	0.0133	0.85	0.0008
C2-C3	4.2 ± 5.5	5.2 ± 4.1	0.19	0.0366	0.98	0.0000	0.06	0.0738
C3-C4	-4.3 ± 3.8	-2.4 ± 15.2	0.72	0.0029	0.89	0.0004	0.55	0.0079
C4-C5	-6.5 ± 3.0	-9.8 ± 15.6	0.55	0.0077	0.81	0.0012	0.63	0.0051
C5-C6	-7.7 ±4.4	-8.9 ± 4.0	0.30	0.0235	0.76	0.0020	0.79	0.0016
C6-C7	-3.6 ± 4.8	-5.9 ± 5.1	0.16	0.0419	0.31	0.0226	0.64	0.0049

*η^2 = Partial Eta Squared Effect Size, small effect size = 0.04, medium effect size = 0.06, large effect size = 0.1. * indicates significance at $p<.05$.*

4.3 Anthropometrics

Age, height, and body mass are presented across groups in Table 6. Height was significantly different between males and females ($F(1,75) = 7.39$, $p=.0082$) with males on average being taller than females.

Neck and head circumference were available for fifty-nine participants. There was a main effect of group on neck circumference after controlling for neck length ($F(1,54)= 5.43$, $p= .0236$). The EEOP group had an average neck circumference that was 3.9 cm larger than the those without an EEOP (Table 6). About nine percent of the variance in neck circumferences, after removing the variance associated with other effects, is explained by group (Table 6). This is a medium to large effect size. There was a main effect of group on head circumference ($F(1,54)= 18.48$, $p<.001$). The EEOP group had an average head circumference that was .4 cm smaller than those without an EEOP. About 14.8% of the variance in head circumference is explained by group differences; this is a large effect size (Table 6). It is important to note that with only 11 people in the EEOP group, we have a small sample size that may result in an increased risk a Type 1 error.

There was a main effect of sex for both neck and head circumferences ($F(1,54) = 7.47$, $p=.009$; $F(1,54) = 38.81$, $p<.001$) (Table 6). Males had an average neck circumference that was 6.1 cm larger than females. Similarly, males had a head circumference that was 3.4 cm larger than females. About 5.5% of the variance in neck circumference can be explained by differences in sex; this is a small to medium effect size. About 32.1% of the variance in head circumference can be explained by differences in sex; this is a large effect size (Table 6).

The interaction of group and sex was significant for head circumference (Table 6). Females with EEOPs had significantly different head circumferences than the other three groups ($p<.0001$); however, males with EEOPs were only significantly different from females without EEOPs ($p=.0477$). Head circumference for females with an EEOP was smaller than the three other groups while males with EEOPs had a larger head circumference compared to females without EEOPs. Males without EEOPs had significantly different head circumferences than females without EEOPs ($p=.0078$). Males without EEOPs had an average head circumference of 58.9 cm while females without EEOPs had an average of 56.3 cm. About 23.6% of the variance in head circumference can be explained by the interaction of group and sex. This is a large effect; however, females with a EEOP violated the homogeneity of regression slopes assumption and had a small sample size (n=2) so there is a high risk of a type 1 error.

Although not significant, the EEOP group weighed more ($p=0.06$, $\eta^2=0.05$) and were taller than those without an EEOP ($p=0.16$, $\eta^2=0.03$) (Table 6). These variables also had interactions that were not considered significant of group and sex ($p=0.12$, $\eta^2=0.0314$; $p=0.17$, $\eta^2=0.0245$) (Table 6). Females with EEOPs weighed more and were taller than females without EEOPs ($p=0.0872$). Males with EEOPs weighed more than males without EEOPs ($p=0.0487$).

Table 6
Anthropometric data (mean ± standard deviations) for both groups (EEOP present and absent).

	Enlarged EOP		Main Effect of Group		Main Effect of Sex		Interaction of Group and Sex	
Variable	**Present** (n=18)	**Absent** (n=62)	**p-value**	**Effect Size**	**p-value**	**Effect Size**	**p-value**	**Effect Size**
Age (Years)	23.3 ± 5.6	26.3 ± 6.9	0.30	0.0139	0.81	0.0007	0.56	0.0044
Body Mass(kg)	81.3 ± 17.4	71.4 ± 14.6	0.06	0.0372	0.40	0.0069	0.12	0.0140
Height (cm)	177.8 ± 9.3	169.7 ± 9.8	0.16	0.0080	0.008*	0.0289	0.17	0.0035
Neck Circumference (cm)	38.8 ± 3.6	34.9 ± 4.0	0.02*	0.0399	0.009*	0.0549	0.11	0.0193
Head Circumference (cm)	57.0 ± 5.6	57.4 ± 2.0	<.001*	0.1483	<.001*	0.3209	p<.001*	0.1334
Flexion Strength (lbs)	28.1 ± 4.5	24.7 ± 11.6	0.70	0.0030	0.11	0.0350	0.35	0.0179
Extension Strength (lbs)	53.7 ± 11.7	46.1 ± 13.5	0.49	0.0082	0.02*	0.1162	0.94	0.0001

η^2 = Partial Eta Squared Effect Size, small effect size = 0.04, medium effect size = 0.06, large effect size = 0.1. indicates significance at $p<.05$.*

4.4 Neck Strength

Flexion and extension neck strength was available for 29 participants (Table 6). There were no significant main effects or interactions of EEOP presence and sex for flexion neck strength when controlling for neck length. There was a significant main effect of sex for extension neck strength (p= .02); however, there was no interaction with the presence of an EEOP. Males had an average extension strength that was 20 lbs. greater than females.

5. Discussion

The purpose of this study was to compare neck posture, anthropometrics, and neck strength between those with and without EEOPs. Our first hypothesis that neck posture in neutral and flexion will differ between groups was not supported. We found that posture did not differ between those with and without EEOPs in either a neutral or maximum flexion position. Our second hypothesis that those with EEOPs will have greater neck strength was also not supported. Neck strength was not significantly different between the two groups. Finally, our third hypothesis of body mass, neck circumference, and head circumference being larger for those with EEOPs was partially supported. Although age, height, and body mass were not significantly different between the two groups, the EEOP group had larger neck circumferences than the those without EEOPs and females with EEOPs had smaller head circumferences than all other groups. Overall, our findings do not support the idea that neck posture is different if an individual presents with an EEOP; however, muscle size may be related to their presence.

On average, those with EEOPs had a larger neck circumference than those without EEOPs. Previous work has shown that neck circumference is a reliable predicter of total neck muscle volume[52]. A larger neck muscle volume has the potential to produce greater force on the skull due to an increase in cross sectional area of muscle[37]. This increased force would also be felt at the EOP, possibly requiring greater surface area, leading to an enlargement of the EOP[11,39]. It is important to note that we did not find any differences in neck flexion or extension strength between groups. We only had this data for 29 out of our 80 participants, impacting the overall power for the analysis of this variable. A larger sample size for these variables may be beneficial for future studies. Body mass was close to being significantly different between our two groups (p=.0558 and .06 effect size) with those presenting with an EEOP being heavier than those absent of an EEOP, with an average mass of 81.3 kg vs 71.4 kg. Future work should investigate the differences in muscle volume between those presenting with an EEOP and those absent of an EEOP.

Twenty-six percent (17/65) of 18–30-year-olds presented with an EEOP compared to 7% (1/15) for those over the age of 30. Previous research has found a prevalence of 41% to 44.9% in young adults[1,2]. Jacques et al., (2020) considered both a Type 2 and Type 3 EOP to be enlarged. If Jacques et al., (2020) only considered Type 3 enlarged their prevalence drops to 13.7% of young adults. Previous work has used an EEOP threshold of greater than 10 mm as enlarged, and our study found all Type 1 EOPs and all but one Type 2 EOP fell below 10 mm[2]. Therefore, we chose 10 mm as a cut-off for enlarged which were all Type 3 EOPs. Shahar & Sayers, (2016) considered EOPs exceeding 10 mm as enlarged and found a prevalence of 41% in young adults, a much higher prevalence than our 26%; however, they did not correct for the differing torso widths of participants to the radiograph machine. By not correcting for differing participants widths from the radiograph machine, they will have larger magnifications, leading to larger measurements for participants. They stated there was minimal error due to this; however, this may have resulted in some participants into the EEOP group due to this small amount of error.

Consistent with previous literature, more males (35%) presented with an EEOP than females (10%) in our study[1,2]. Shahar & Sayers (2016) reported 67.4% of males had an EEOP and 20.3% of females had an EEOP. Similarly, Jacques et al. (2020) found 42-44% of females and 55-57% of males had EEOPs. Jacques et al. (2020) found a much higher percentage of EEOPs in females, but this is due to them including Type 2 EEOPs as enlarged. If Jacques et al. (2020) included only Type 3, their prevalence falls to 6.6-6.9% in females and 18.7-20.9% in males and is similar to our findings. These findings are consistent with anthropology literature that found Type 3 EEOPs are more common in males while Types 1 and Types 2 are more common in females[23].

There was a lack of evidence to support the idea that kinematics in neutral or flexed neck posture differ between those who present an EEOP and those who do not. This is in partial contradiction with previous literature. Forward head protraction was found to be a significant predicter of EEOP occurrence with every 10 mm increase in FHP resulting in a 1.03 times likelihood of having an EEOP[10]. We found no significant difference in FHP between our EOP groups. Shahar & Sayers, (2018) had an overall average FHP of 26 mm while our overall average FHP was 21.4 mm. Shahar & Sayers, (2018) had a sample size of 1200 radiographs with an even distribution of age groups ranging from 18-86 years of age. Our study was much smaller with only 80 radiographs and a narrower age range of 18-43 with only 15 participants above the age of 30. Shahar & Sayers (2018) also found that FHP was greater in those older than 60 compared to younger adults, yet they also stated EEOPs were more common in younger adults (18-30 years of age). These two findings are in conflict with their results that larger FHPs lead to a higher chance of an EEOP. This may indicate that FHP is not as strong of a predictor for EEOP occurrence as previously stated.

The C5-C6 intervertebral angle fell between the 0.5 to 0.2 range of p-values (Table 5). The EEOP group had a more extended C5-C6 intervertebral angle. The C5-C6 angle lies in the base of the lordotic curve of the cervical spine. A more extended C5-C6 could result in a more exaggerated lordotic curve. This exaggerated curve may be due to excessive pull/stress on the EEOP from neck musculature. If the nuchal ligament were taught due to pull from neck musculature, it would in turn put excessive stress on the EOP, possibly leading to an EEOP. This pull from the neck musculature may be due to higher neck muscle activity in neutral postures.

We also found an interaction of group and sex for head circumference. Females with EEOPs were significantly different than all other groups, males with EEOPs were different than females without EEOPs, and finally, males without EEOPs were different from females without EEOPs. There are no previous works looking at head circumference differences in those with EEOPs. A larger head circumference may indicate a heavier head which would put more strain on the neck musculature to maintain a neutral posture. This, in turn, would put more stress on the EOP possibly leading to an EEOP over time. Although, we found that females with EEOPs had significantly smaller head circumferences indicating less work on the neck musculature, due to the extremely small sample size of this group for this variable (n=2), the power of this analysis is very small. Future work will need to have larger and equal groups of both sexes (male and female) and both groups (present and absent) to increase the power of the analysis and solidify any differences.

6. Future Work

Although not investigated in this study, there may be an influence of activity level or occupation on EEOP formation. Boney spurs or enthesophytes in other parts of the body can occur due to repetitive stress on the bone[53–55]. For example, olecranon spurs are commonly seen in those who perform heavy manual labor or experience repetitive elbow extension[54,55]. When looking at heel spurs, it was found that these spurs seem to form not from the traction from soft tissue but rather from vertical loading of the bone, similar to the stress seen during standing or walking[53]. Unfortunately, there is a gap in research looking at occupation or activity level in those with EEOPs. With active inflammation factors and genetic predispositions being ruled out, the formation of an EEOP may follow a similar pattern to enthesophytes and bone spurs in other parts of the body. Occupations that require prolonged and repetitive neck flexion and/or require the prolonged use of heavy headwear may follow similar patterns as olecranon spurs. This would put stress on the EOP that could lead to the development of an EEOP. Future work should collect variables on occupation, activity levels, and smartphone usage between those with and without EEOPs to look at the possibility of prolonged loading as a contributor.

7. Limitations & Delimitations

This was a cross sectional study therefore only capturing one point in time and leaving external factors that could have contributed to the EEOP occurrence over time such as occupation. Future work would benefit from performing a longitudinal study that follows participants from a young age into early adulthood to better understand the development of the EEOP. This may not be a feasible option so other scenarios should be considered as well, such as performing a retrospective study on a previously collected longitudinal study. Another limitation of this study would be that this was a convenience sample. This being a convenience sample hurts the generalizability of our data set. Due to this convenience sampling, our sample size was not as large as it needed to be, and we could not collect more radiographs. We also saw uneven groups. With only 15 participants greater than 30 and 1 participant greater than 30 years old with an EEOP, our analysis has lower power with these groups. Future work should ensure even grouping within all age groups and treatments. Another limitation was that neck strength, as well as head and neck circumferences were not collected for all participants. This may have inhibited how representative the data is for those variables with a smaller sample size.

A delimitation of this study is that all measurements were taken by one researcher. This ensures all measurements were consistent. Table 3 shows that all ICC values were high, ranging from good to excellent, establishing that all measurements were consistent and accurate.

8. Conclusion

Individuals with EEOPs had larger neck circumference than those without EEOPs; however, there were no significant differences in neck strength between the two groups, contradicting the idea that this increase neck circumference may be due to increased neck muscle volume and strength. Neck posture in neutral and flexion also did not differ between those with and without EEOPs. Future work should investigate the influence of neck muscle volume and strength between those with and without EEOPs and the potential influence of occupation and activity level on EEOP occurrence. In addition, future work should look at possible lordotic curve differences due to the C5-C6 intervertebral angle being close to significant in this study.

9. Bibliography

1. Jacques T, Jaouen A, Kuchcinski G, Badr S, Demondion X, Cotten A. Enlarged External Occipital Protuberance in young French individuals' head CT: stability in prevalence, size and type between 2011 and 2019. *Sci Rep*. 2020;10(1):6518. doi:10.1038/s41598-020-63554-y

2. Shahar D, Sayers MGL. A morphological adaptation? The prevalence of enlarged external occipital protuberance in young adults. *J Anat*. 2016;229(2):286-291. doi:10.1111/joa.12466

3. Dougherty C. Occipital Neuralgia. *Curr Pain Headache Rep*. 2014;18(5):411. doi:10.1007/s11916-014-0411-x

4. Marshall RC, Abela C, Eccles S. Painful exostosis of the external occipital protuberance. *J Plast Reconstr Aesthet Surg*. 2015;68(11):e174-e176. doi:10.1016/j.bjps.2015.06.013

5. Ricks CB, Agarwal N, Jankowitz BT. Wound dehiscence from a prominent external occipital protuberance: An indication for prophylactic drilling? *Interdiscip Neurosurg*. 2017;10:49-51. doi:10.1016/j.inat.2017.06.005

6. Sattur M, Korson C, Henderson F, Kalhorn S. Presentation and management of traumatic occipital spur fracture. *Am J Emerg Med*. 2019;37(5):1005.e1-1005.e2. doi:10.1016/j.ajem.2019.01.043

7. Singh R. Bony Tubercle at External Occipital Protuberance and Prominent Ridges: *J Craniofac Surg*. 2012;23(6):1873-1874. doi:10.1097/SCS.0b013e31826c7d48

8. Gómez Zubiaur A, Alfageme F, López-Negrete E, Roustan G. Type 3 External Occipital Protuberance (Spine Type): Ultrasonographic Diagnosis of an Uncommon Cause of Subcutaneous Scalp Pseudotumor in Adolescents. *Actas Dermo-Sifiliográficas Engl Ed*. 2019;110(9):774-775. doi:10.1016/j.adengl.2019.06.001

9. Tsai S-T, Tseng C-H, Lin M-C, et al. Acupuncture reduced the medical expenditure in migraine patients: Real-world data of a 10-year national cohort study. *Medicine (Baltimore)*. 2020;99(32):e21345. doi:10.1097/MD.0000000000021345

10. Shahar D, Sayers MGL. Prominent exostosis projecting from the occipital squama more substantial and prevalent in young adult than older age groups. *Sci Rep*. 2018;8(1):3354. doi:10.1038/s41598-018-21625-1

11. Benjamin M, Rufai A, Ralphs JR. The mechanism of formation of bony spurs (enthesophytes) in the achilles tendon. *Arthritis Rheum*. 2000;43(3):576-583. doi:10.1002/1529-0131(200003)43:3<576::AID-ANR14>3.0.CO;2-A

12. Hardcastle SA, Dieppe P, Gregson CL, et al. Osteophytes, Enthesophytes, and High Bone Mass: A Bone-Forming Triad With Potential Relevance in Osteoarthritis: Osteophytes,

Enthesophytes, and High Bone Mass in OA. *Arthritis Rheumatol*. 2014;66(9):2429-2439. doi:10.1002/art.38729

13. Jacobs JC. Spondyloarthritis and Enthesopathy: Current Concepts in Rheumatology. *Arch Intern Med*. 1983;143(1):103. doi:10.1001/archinte.1983.00350010109019

14. Jacques P, Lambrecht S, Verheugen E, et al. Proof of concept: enthesitis and new bone formation in spondyloarthritis are driven by mechanical strain and stromal cells. *Ann Rheum Dis*. 2014;73(2):437-445. doi:10.1136/annrheumdis-2013-203643

15. McGonagle D, Wakefield RJ, Tan AL, et al. Distinct topography of erosion and new bone formation in achilles tendon enthesitis: Implications for understanding the link between inflammation and bone formation in spondylarthritis. *Arthritis Rheum*. 2008;58(9):2694-2699. doi:10.1002/art.23755

16. Shahar D, Evans J, Sayers MGL. Large enthesophytes in teenage skulls: Mechanical, inflammatory and genetic considerations. *Clin Biomech*. 2018;53:60-64. doi:10.1016/j.clinbiomech.2018.02.004

17. Douglas EC, Gallagher KM. A radiographic investigation of cervical spine kinematics when reading a tablet in a reclined trunk position. *Appl Ergon*. 2018;70:104-109. doi:10.1016/j.apergo.2018.02.020

18. Vasavada AN, Nevins DD, Monda SM, Hughes E, Lin DC. Gravitational demand on the neck musculature during tablet computer use. *Ergonomics*. 2015;58(6):990-1004. doi:10.1080/00140139.2015.1005166

19. Zheng L, Jahn J, Vasavada AN. Sagittal plane kinematics of the adult hyoid bone. *J Biomech*. 2012;45(3):531-536. doi:10.1016/j.jbiomech.2011.11.040

20. Rudnicki MA, Schnegelsberg PNJ, Stead RH, Braun T, Arnold H-H, Jaenisch R. MyoD or Myf-5 is required for the formation of skeletal muscle. *Cell*. 1993;75(7):1351-1359. doi:10.1016/0092-8674(93)90621-V

21. Thomopoulos S, Genin GM, Galatz LM. The development and morphogenesis of the tendon-to-bone insertion - what development can teach us about healing -. *J Musculoskelet Neuronal Interact*. 2010;10(1):35-45.

22. Logan BM, Reynolds PA, Rice S. *McMinn's Color Atlas of Head and Neck Anatomy*. 5th ed. Elsevier; 2017.

23. Gülekon IN, Turgut HB. The external occipital protuberance: can it be used as a criterion in the determination of sex? *J Forensic Sci*. 2003;48(3):513-516.

24. Kadri PAS, Al-Mefty O. Anatomy of the Nuchal Ligament and Its Surgical Applications. *Oper Neurosurg*. 2007;61(suppl_5):ONS301-ONS304. doi:10.1227/01.neu.0000303985.65117.ea

25. Mercer SR, Bogduk N. Clinical anatomy of ligamentum nuchae. *Clin Anat*. 2003;16(6):484-493. doi:10.1002/ca.10121

26. Slobodin G, Rozenbaum M, Boulman N, Rosner I. Varied Presentations of Enthesopathy. *Semin Arthritis Rheum*. 2007;37(2):119-126. doi:10.1016/j.semarthrit.2007.01.004

27. Claudepierre P, Voisin M-C. The entheses: histology, pathology, and pathophysiology. *Joint Bone Spine*. 2005;72(1):32-37. doi:10.1016/j.jbspin.2004.02.010

28. Tubbs RS, Mortazavi MM, Loukas M, et al. Anatomical study of the third occipital nerve and its potential role in occipital headache/neck pain following midline dissections of the craniocervical junction: Laboratory investigation. *J Neurosurg Spine*. 2011;15(1):71-75. doi:10.3171/2011.3.SPINE10854

29. Lee M, Lineberry K, Reed D, Guyuron B. The role of the third occipital nerve in surgical treatment of occipital migraine headaches. *J Plast Reconstr Aesthet Surg*. 2013;66(10):1335-1339. doi:10.1016/j.bjps.2013.05.023

30. Srivastava M, Asghar A, Srivastava NN, Gupta N, Jain A, Verma J. An Anatomic Morphological Study of Occipital Spurs in Human Skulls. *J Craniofac Surg*. 2018;29(1):217-219. doi:10.1097/SCS.0000000000004205

31. Varghese E, Samson RS, Kumbargere SN, Pothen M. Occipital spur: understanding a normal yet symptomatic variant from orthodontic diagnostic lateral cephalogram. *BMJ Case Rep*. Published online May 22, 2017:bcr-2017-220506. doi:10.1136/bcr-2017-220506

32. Benjamin M, Toumi H, Suzuki D, Hayashi K, McGonagle D. Evidence for a distinctive pattern of bone formation in enthesophytes. *Ann Rheum Dis*. 2009;68(6):1003-1010. doi:10.1136/ard.2008.091074

33. Azevedo MR, Araújo CLP, Reichert FF, Siqueira FV, da Silva MC, Hallal PC. Gender differences in leisure-time physical activity. *Int J Public Health*. 2007;52(1):8-15. doi:10.1007/s00038-006-5062-1

34. van Uffelen JGZ, Khan A, Burton NW. Gender differences in physical activity motivators and context preferences: a population-based study in people in their sixties. *BMC Public Health*. 2017;17(1):624. doi:10.1186/s12889-017-4540-0

35. Kelley GA. Gender differences in the physical activity levels of young African-American adults. *J Natl Med Assoc*. 1995;87(8):545-548.

36. Janssen I, Heymsfield SB, Wang Z, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. *J Appl Physiol*. 2000;89(1):81-88. doi:10.1152/jappl.2000.89.1.81

37. Gilliver SF, Degens H, Rittweger J, Sargeant AJ, Jones DA. Variation in the determinants of power of chemically skinned human muscle fibres: Determinants of muscle power. *Exp Physiol*. 2009;94(10):1070-1078. doi:10.1113/expphysiol.2009.048314

38. Thomopoulos S, Kim H-M, Rothermich SY, Biederstadt C, Das R, Galatz LM. Decreased muscle loading delays maturation of the tendon enthesis during postnatal development. *J Orthop Res*. 2007;25(9):1154-1163. doi:10.1002/jor.20418

39. Galtés I, Rodríguez-Baeza A, Malgosa A. Mechanical morphogenesis: A concept applied to the surface of the radius. *Anat Rec A Discov Mol Cell Evol Biol*. 2006;288A(7):794-805. doi:10.1002/ar.a.20337

40. Resnick D, Niwayama G. Radiographic and Pathologic Features of Spinal Involvement in Diffuse Idiopathic Skeletal Hyperostosis (DISH). *Radiology*. 1976;119(3):559-568. doi:10.1148/119.3.559

41. Vaishya R, Vijay V, Nwagbara IC, Agarwal AK. Diffuse idiopathic skeletal hyperostosis (DISH) – A common but less known cause of back pain. *J Clin Orthop Trauma*. 2017;8(2):191-196. doi:10.1016/j.jcot.2016.11.006

42. Rogers J, Shepstone L, Dieppe P. Bone formers: osteophyte and enthesophyte formation are positively associated. *Ann Rheum Dis*. 1997;56(2):85-90. doi:10.1136/ard.56.2.85

43. Hiyama A, Katoh H, Sakai D, Sato M, Tanaka M, Watanabe M. Prevalence of diffuse idiopathic skeletal hyperostosis (DISH) assessed with whole-spine computed tomography in 1479 subjects. *BMC Musculoskelet Disord*. 2018;19(1):178. doi:10.1186/s12891-018-2108-5

44. Shaibani A, Workman R, Rothschild BM. The significance of enthesopathy as a skeletal phenomenon. *Clin Exp Rheumatol*. 1993;11(4):399-403.

45. Satyarthee G. External occipital protuberance projecting as downward curved horn presenting with intractable occipital pain: Report of a first case. *J Pediatr Neurosci*. 2019;14(3):173. doi:10.4103/jpn.JPN_94_18

46. Stovner L, Hagen K, Jensen R, et al. The Global Burden of Headache: A Documentation of Headache Prevalence and Disability Worldwide. *Cephalalgia*. 2007;27(3):193-210. doi:10.1111/j.1468-2982.2007.01288.x

47. Hey HWD, Lau ET-C, Wong GC, Tan K-A, Liu GK-P, Wong H-K. Cervical Alignment Variations in Different Postures and Predictors of Normal Cervical Kyphosis: A New Understanding. *Spine*. 2017;42(21):1614-1621. doi:10.1097/BRS.0000000000002160

48. Wu G, Siegler S, Allard P, et al. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine. *J Biomech*. 2002;35(4):543-548. doi:10.1016/S0021-9290(01)00222-6

49. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med*. 2016;15(2):155-163. doi:10.1016/j.jcm.2016.02.012

50. Yoakum CB, Romero AN, Latham C, Douglas EC, Gallagher KM, Terhune CE. Sex and Height Influence Neck Posture When Using Electronic Handheld Devices. *Clin Anat.* 2019;32(8):1061-1071. doi:10.1002/ca.23440

51. Wainer H, Robinson DH. Shaping Up the Practice of Null Hypothesis Significance Testing. *Educ Res*. 2003;32(7):22-30. doi:10.3102/0013189X032007022

52. Zheng L, Siegmund G, Ozyigit G, Vasavada A. Sex-specific prediction of neck muscle volumes. *J Biomech*. 2013;46(5):899-904. doi:10.1016/j.jbiomech.2012.12.018

53. Li J, Muehleman C. Anatomic relationship of heel spur to surrounding soft tissues: Greater variability than previously reported. *Clin Anat.* 2007;20(8):950-955. doi:10.1002/ca.20548

54. Reilly D, Kamineni S. Olecranon bursitis. *J Shoulder Elbow Surg*. 2016;25(1):158-167. doi:10.1016/j.jse.2015.08.032

55. Cimmino CV. The Olecranon Spur and Its Fracture. *Radiology*. 1969;92(6):1305-1305. doi:10.1148/92.6.1305