**Review**

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# A review of the anatomy of soft tissues associated with sexually dimorphic landmarks on the cranium

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## Abstract

**Objectives:** This review systematically assesses literature relating to five muscles and one ligament connected to sexually dimorphic cranial landmarks – the nuchal crest and mastoid process – used for sex estimation in anthropology: the upper trapezius, semispinalis capitis, sternocleidomastoid, splenius capitis, and longissimus capitis muscles and the nuchal ligament. Although these soft tissues are not commonly grouped together in anatomical literature, they are anthropologically relevant in relation to cranial sex estimation. This review demonstrates how anatomical analyses can inform anthropological research and illustrates the benefit of multidisciplinary studies.

**Methods:** A systematic literature review was conducted following PRISMA (preferred reporting items for systematic reviews and meta-analyses) guidelines and included journal articles and texts that discussed attachment sites, muscle architecture, function, and sexual dimorphism of the soft tissues in of interest.

**Results:** A total of 804 publications were assessed with a final number of 64 relevant texts, including 53 primary scientific articles and 11 textbooks. Upper trapezius and sternocleidomastoid were the most widely studied, while longissimus capitis and the nuchal ligament were the least. Additionally, there was limited consistent data on muscle architecture, attachment site morphology (entheses), sexual dimorphism, and population variation in these studies.

**Conclusion:** This paper highlights the need for more detailed architectural and enthesis data from diverse sex and population groups, and interdisciplinary research that will improve understanding of sexual dimorphism in humans. This can be applicable in clinical anatomy when assessing injury rates between males and females, and in anthropology, when estimating sex from the skeleton.

**Keywords:** anthropology; mastoid process; muscle architecture; nuchal crest; sexual dimorphism

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## Introduction

In biological anthropology, biological sex is often estimated from the skeleton using the pelvis;[1–3] however, in its absence, robusticity of certain skeletal landmarks on the cranium may be used to estimate sex in forensic and archaeological situations.[1,4] Humans show sexual dimorphism (morphological differences between males and females) in these areas, with males typically demonstrating greater robusticity compared with females. Two of these cranial landmarks – the nuchal crest and mastoid process – are sites of muscle attachment. Although anthropological analyses consider each of these landmarks as a single, generalized muscle or ligament attachment site, these skeletal features actually represent the location of several soft tissue attachments.[5] In the anthropological literature, it is assumed that the robusticity of these skeletal landmarks is associated with the robusticity of the muscles attached at these sites.[1] However, this hypothesis has not been specifically tested and assumes anatomical knowledge of these attachment sites, which are not well understood in the anthropological literature.[1,4] To better identify why these cranial skeletal landmarks are sexually dimorphic, it is essential to study the nuances of the attached soft tissue anatomy, including any presence of sex differences in these areas. This is important because observation of sexual dimorphism in the associated soft tissues may help improve sex estimation methods using these landmarks, when working with unidentified human skeletal remains.

Collectively, five muscles and one ligament span the cervical spine and have attachments associated with the nuchal crest and mastoid process. These include the upper trapezius and semispinalis capitis muscles and the nuchal ligament – associated with the nuchal crest – and sternocleidomastoid, splenius capitis, and longissimus capitis – associated with the mastoid process.

The overall objective of this review was to systematically evaluate research on the morphology of the relevant soft tissues to better understand musculoskeletal relationships and how this may relate to anthropological research in sex estimation. To achieve this, the literature covering muscle and ligament morphology, including attachment sites, size (physiological cross-sectional area [PCSA], cross sectional area [CSA], and mass or volume), and pennation angle was examined. Muscle and ligament function were also considered, alongside any findings that indicated evidence of sexual dimorphism.

## Materials and Methods

A systematic search of the primary literature was conducted in December 2020 and updated June and November 2021, following the PRISMA (preferred reporting items for systematic reviews and meta-analyses) guidelines and using the keywords summarized in **Figure 1**.[6] Although neurovascular supply has been included in similar reviews of soft tissue,[7] this study focused on muscle and ligament morphology and function, which is most relevant to its overall aim. Studies that did not appear in the database search, but were found during general research (forwards search) or through screening the reference lists (backwards search), were also included (**Figure 2**). During this general search, five books and/or book chapters with information relevant to this study were also found and included. An additional six text books (three modern, three historical) that provided relevant information on this topic were also selected for a total of 11 books. Exclusion criteria are outlined in **Figure 2**. All literature was screened by the first author.

## Results

A total of 65 publications, consisting of 54 primary scientific articles and 11 books or book chapters were included. A review of each muscle, grouped by the two skeletal landmarks of interest (nuchal crest and mastoid process), is presented below.

### Nuchal Crest

The soft tissues associated with the nuchal crest are the upper trapezius and semispinalis capitis muscles, and the nuchal ligament. Trapezius is the most superficial, with semispinalis capitis lying deep to the trapezius and splenius muscles.[8] From its proximal to distal extent, the nuchal ligament runs superficial to deep, extending along the midline of the posterior neck. It is an attachment site for the upper trapezius, among other muscles.[9–11]

Nine studies (five dissection, four imaging) contained information relating to upper trapezius, and nine (four dissection, six imaging) were also reviewed for semispinalis capitis. Although the nuchal ligament was described in a number of resources, only one provided quantitative data.

**Upper trapezius:** The trapezius is a large, flat, triangle shaped muscle in the cervical, thoracic, and shoulder regions[8,12,13] and is described as the most superficial muscle of the posterior neck.[14–16] The area of interest in this study is the upper trapezius,[10] also termed the clavotrapezius[17] or the pars descendens or descending part.[18,19] The upper trapezius is smaller than the middle trapezius, being one-fifth of its mass.[20]

***Attachment sites:*** The upper trapezius muscle attaches proximally at the superior nuchal line and the ligamentum nuchae, wrapping around the neck to attach distally at the lateral third of the clavicle.[8,10,13,16,17,21,22] Proximal attach-

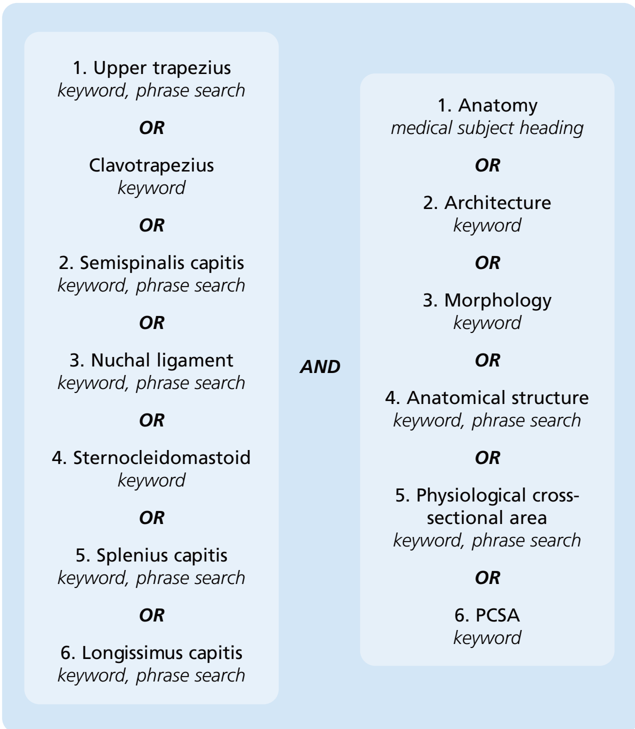


**Figure 1.** Search terms and keywords.

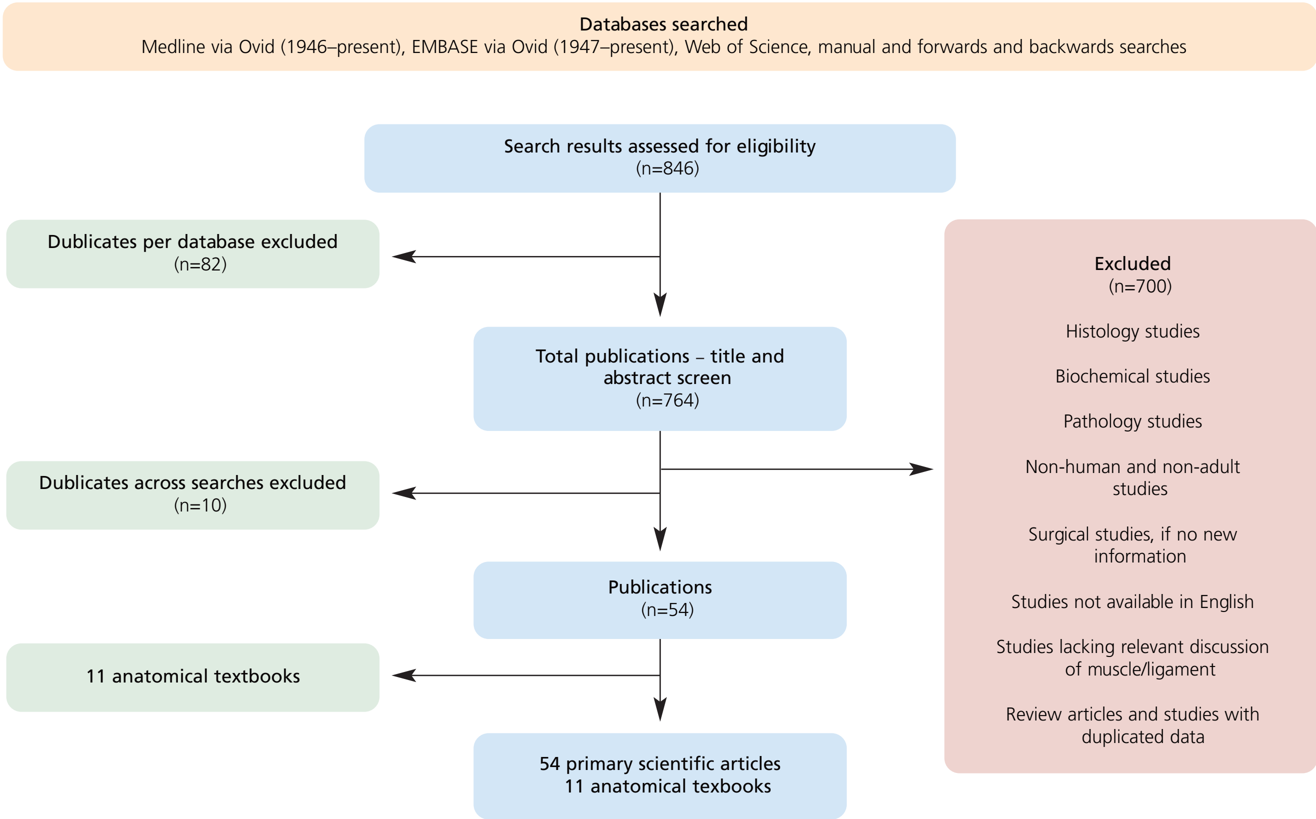


**Figure 2.** PRISMA flow chart of the review process.

ment sites may vary although they are generally within the upper cervical/occipital area of the neck and head region: occiput and C1–C5,[18] C2–C3,[19] posterior border of the nuchal ligament,[23] occipital and nuchal ligament as far as the level of C7,[11] medial third of the superior nuchal line, external occipital protuberance, and nuchal ligament,[24] and occiput and nuchal ligament.[12,20] Additionally, the midline muscle fibers of upper trapezius attach to the nuchal ligament and pass over the midline connecting with the contralateral muscle fibers.[25] The distal attachment is described as the clavicle, specifically the superior posterior surface of its lateral third.[12,18–20,26–30] Variation may occur, with extension to the medial clavicle and occasional overlapping with the sternocleidomastoid attachment.[12,13] None of the literature reviewed discussed entheseal (muscle attachment) measurements or morphology, for either the proximal or distal attachments of the upper trapezius.

***Muscle architecture:*** Architectural data from dissection, magnetic resonance imaging (MRI), and ultrasound studies for upper trapezius are presented in **Table 1**. Mean fascicle length was fairly consistent at around 8 cm, although one study, which reported data from only one individual, showed a larger value of 12 cm.[18] Pennation angle ranged from 0–30° for all studies, although some did not provide detailed methods for how these data were collected.[19] Two other studies described the measurement as the angle at which the muscle fibers lay in relation to the line of action for the muscle.[17,18] Interestingly, these two studies report different pennation angles (0° compared to 0–30°), but as the proximal attachments of upper trapezius span the length of the neck, it is possible that there is some variation across this part of the muscle. Muscle mass was provided in all studies, except Johnson et al.,[10] which reported volume. All measurements fell within a range of approximately 18.7–37.6 g, with volume reported as 30 ml. Although different units of measurement, mass and volume are comparable, as absolute values do not vary greatly when converting between the two using standard muscle density measures.[31] The largest value of 37.6 g is likely because trapezius was split into two segments,[18] rather than the standard three.[10]

The PCSA values obtained from dissection show a range of 2.0–3.8 $cm^2$ and CSA values from imaging ranged between 3.1–36.0 $cm^2$. In two studies, PCSA was larger (>3.5 $cm^2$) than others, as the muscle was divided into two segments, rather than three.[18,32] Additionally, in an MRI

**Table 1**
Muscle architecture data for upper trapezius.

| | Study | Sample/sex/age | Fascicle[1] Length (cm) | Fascicle[1] Pennation angle (°) | Muscle[1] Volume (ml) or mass (g) | Muscle[1] PCSA (cm²) | Muscle[1] CSA (cm²) |
|---|---|---|---|---|---|---|---|
| Dissection studies | Bayoglu et al. (2017) | n=1<br>Male<br>79 years | 8.9 | 0 | 25.7 (g) | 2.9 | - |
| | Borst et al. (2011)[2] | n=1<br>Male<br>86 years | 12 | 0 | 37.6 (g) | 3.5 | - |
| | Johnson et al. (1994)[3] | n=8<br>Unknown<br>>65 years | 8–11 | - | 30 (ml) | 3.3 | - |
| | Kamibayashi and Richmond (1998) | n=9[4]<br>7 M / 3 F<br>66–92 years | 8.1 (1.6) | 0–30 | 18.7 (4.5) (g) | 2.0 (0.6) | - |
| | Van Ee et al. (2000) | n=6<br>4 M / 2 F<br>70–83 years | - | 0–5 | - | 3.8[2] | - |
| Imaging studies - MRI | Dawson et al. (2013) | n=10<br>Male<br>26–54 years | - | - | - | - | 3.2 (1.0) |
| | De Loose et al. (2009) | n=25<br>Male<br>20–40 years | - | - | - | - | 4.3 (1.4)[5] |
| | Li et al. (2014) | n=16<br>11 M / 5 F<br>23–33 years | - | - | - | - | 36.0[6] |
| Imaging studies - Ultrasound | Valera-Calero et al. (2020) | n=15<br>Male<br>22.5±4.5 years | - | - | - | - | 13.1 (3.8) |
| | | n=10<br>Female<br>25.5±6 years | - | - | - | - | 7.6 (1.8) |

**CSA:** cross-sectional area; **F:** female, **M:** male; **MRI:** magnetic resonance imaging; **PSCA:** physiological cross-sectional area. [1]Mean values presented where relevant (standard deviation) given where available. [2]Trapezius considered as two segments instead of the standard three. [3]Upper trapezius split into three segments; these data represent a range or total mean for each measurement (standard deviation not recalculated). [4]Ten cadavers were included (seven males, three females) with nine used for the analysis of trapezius; however, the representation of each sex is not clear. [5]Data given for right side only. Fighter pilot neck pain study. Data show control group with no neck pain. [6]Study gave maximum CSA of the trapezius at C6–C7.

study, Li et al.[33] reported a much larger CSA (36.0 cm$^2$), likely due to the study reporting the maximum CSA of the muscle rather than values from a specified anatomical location, such as C4.[34]

***Function:*** Trapezius is a major extensor muscle of the head and neck,[8,35] providing stability to the scapula through the clavicle.[26,27] Specifically, upper trapezius produces lateral flexion and extension of the head.[13] It also contributes to shoulder elevation and upward scapula rotation (in conjunction with lower trapezius), as well as scapula retraction.[15,16,21,22,24,30]

***Sexual dimorphism:*** One study addressed sex differences, reporting that males had a significantly larger upper trapezius CSA than females.[36] The authors also noted that larger weight, height, and body mass index were significantly correlated with larger CSA, an association that corresponded with male sex. They suggest that overall sexual dimorphism was apparent in their sample for physical size characteristics as well as muscle CSA.[36]

**Semispinalis capitis:** Semispinalis capitis, also called semispinalis complexus in historical texts,[12,21,30] is a long and thick muscle, located in the third layer of the neck,[14,15,37,38] deep to the trapezius and splenius muscles.[8,12,16] Semispinalis capitis is consistently described as a digastric muscle which is divided into two sections by internal aponeuroses,[37] or alternatively described as being interspersed with internal tendons that connect the muscle bellies.[12,17,19]

**Table 2**
Muscle architecture data for semispinalis capitis.

| | Study | Sample/sex/age | Fascicle[1] Length (cm) | Fascicle[1] Pennation angle (°) | Muscle[1] Volume (cm³) or mass (g) | Muscle[1] PCSA (cm²) | Muscle[1] CSA (cm²) |
|---|---|---|---|---|---|---|---|
| Dissection studies | Bayoglu et al. (2017) | n=1<br>Male<br>79 years | 8.4 | 0 | 20.3 (g) | 3.1 | - |
| | Borst et al. (2011) | n=1<br>Male<br>86 years | 10.3 | 0 | 45.3 (g) | 4.3 | - |
| | Kamibayashi and Richmond (1998) | n=9[2]<br>7 M / 3 F<br>66–92 years | 6.2 (1.1) | 0–20 | 38.5 (9.4) (g) | 5.4 (1.3) | - |
| | Van Ee et al. (2000) | n=6<br>4 M / 2 F<br>70–83 years | - | >3 | - | 5.5 | - |
| Imaging studies - MRI | Elliot et al. (2014)[3] | n=34<br>Female<br>26.9±5.6 years | - | - | - | - | 1.5 (1.4-1.6) |
| | Li et al. (2014) | n=16<br>11 M / 5 F<br>23–33 years | - | - | - | - | 4.5[4] |
| | Reddy et al. (2021) | n=13<br>Male<br>30.5±1.7 years | - | - | M: 60.6 (3.2) (cm³) | M: 5.5 (0.2)[5] | M: 9.9 (0.3)[6] |
| | | n=17<br>Female<br>30.8±1.7 years | - | - | F: 38.2 (1.5) (cm³) | F: 3.7 (0.1)[5] | F: 6.7 (0.2)[6] |
| | Uthaikhup et al. (2017)[7] | n=14<br>Female<br>64.2±4 years | - | - | - | - | 1.9 (0.3) |
| Imaging studies - Ultrasound | Rankin et al. (2005) | n=46<br>Male<br>20–72 years | - | - | - | - | M: 1.8 (0.4) |
| | | n=53<br>Female<br>18–70 years | - | - | - | - | F: 1.3 (0.4) |
| | Rezasoltani et al. (1998)[8] | n=46<br>18 M / 28 F<br>19–34 years | - | - | - | - | M: 2.0 (0.4)<br>F: 1.6 (0.4) |

**CSA:** cross-sectional area; **F:** female, **M:** male; **MRI:** magnetic resonance imaging; **PSCA:** physiological cross-sectional area. [1]Mean values presented where relevant (standard deviation) given where available. [2]Ten cadavers were included (seven males, three females) with nine used for the analysis of semispinalis capitis; however, the representation of each sex is not clear. [3]Study looks at whiplash-associated disorders measuring CSA at both C2–C3 and C5–C6. Data here given for healthy control group measured at the level of C5–C6. [4]Study gave maximum CSA of the semispinalis capitis at C1–C2, which may account for the large number. [5]Study estimated PCSA by dividing reconstructed muscle length by muscle volume and reporting RCSA (reconstruction-based cross-sectional area) as the equivalent of PCSA. [6]Study reported ACSA (anatomical cross-sectional area), which was the maximum CSA of each muscle and may account for the large numbers. [7]Cervicogenic headache study of older female sample. Data show control group with no neck pain. [8]Study compares right and left side for males and females in sitting and prone positions. Data here given for right side in prone position.

***Attachment sites:*** Semispinalis capitis attaches distally at the transverse processes of the lower cervical and upper thoracic vertebrae and proximally at the mid-occipital region.[12,13,16,20,21,30] The proximal attachment is described consistently in most studies with some variation: at the mid-occipital level inferior to the superior nuchal line,[20] between the superior and inferior nuchal lines,[37] or at the linea nuchae.[18] There is some variability in the exact vertebrae included as the distal attachment sites: C3–T4,[18] C4–T6,[19] and C3–T6,[37] although this is likely related to standard anatomical variation. Despite details about the proximal and distal attachments of this muscle, none of the included studies discussed entheseal morphology.

***Muscle architecture:*** Table 2 summarizes the data relating to muscle architecture. The mean fascicle length of semispinalis capitis ranged from 6.2–10.3 cm. As described above, the individual from Borst et al.[18] had larger values, yet it is unclear why this individual is an outlier. Pennation angle ranged from 0–20°, which reflects the morphology of this muscle attaching distally to a number of transverse processes in the cervical and thoracic regions of the spine. With respect to muscle size, mass was reported in three studies, ranging between 20.3–45.3 g. In two of these, data were collected from one individual[18,19] and fell nearly within the reported values from the third study (mean: 38.5, range: 21.3–55.8 g,), which included 10 specimens.[17] Volume was reported in one imaging study,[39] with a mean value of 60.6 $cm^3$ for males and 38.2 $cm^3$ for females. PCSA ranged between 3.1–5.5 $cm^2$ and CSA was 1.3–9.9 $cm^2$, although the larger values for CSA were based on maximum CSAs.[33,39] Similar to upper trapezius a limited number of studies provided architectural data for semispinalis capitis. Additionally, there were differences in which architectural parameters were examined. For example, an ultrasound study reported the mean lateral dimension (3.73 cm for males and 3.27 for females) and muscle thickness (0.53 cm for males and 0.48 cm for females).[14] Further, a computed tomography (CT) study[15] provided measurements for thickness and depth, describing semispinalis capitis as a thin layer of muscle with a mean thickness of 1 cm for males and 0.8 cm for females. The depth measurements were taken from both the inner and outer muscle border to the skin giving mean depth measurements of 3.3 cm (inner) and 2.4 cm (outer) for males and 2.9 cm (inner) and 2.1 cm (outer) for females.[15]

***Function:*** Acting bilaterally, semispinalis capitis is a major extensor of the head and neck while also stabilizing the head,[13,16,21,22,35,40,41] although Rankin et al.[14] state that there are varying opinions on whether or not the muscle is active at rest. Acting unilaterally, it extends the head ipsilaterally.[21] Despite multiple studies mentioning the presence of interspersed tendons within semispinalis capitis,[17,19,37] their function is not discussed in the literature.

***Sexual dimorphism:*** Significant differences were found between males and females in three studies.[14,15,39] These studies found sex differences when analysing various muscle architecture parameters, including overall size and strength, muscle CSA, lateral dimension, and thickness of the semispinalis capitis. In general, they found that muscles were larger in males than females.

**Nuchal ligament:** The nuchal ligament, or ligamentum nuchae, described as a triangular fibrous septum positioned along the midsagittal plane of the neck, serves as an attachment site for surrounding posterior cervical muscles.[9–12,21–23] These include the upper trapezius where, as previously described, the right and left aponeuroses interdigitate across the nuchal ligament.[16,23,25,42,43] Johnson et al.,[42] in a detailed dissection study describe that the posterior portion of the ligament is formed by the bilateral aponeuroses of trapezius, splenius capitis, rhomboid minor, and serratus posterior superior, with the anterior portion composed of thin connective tissue. They also state that the ligament is fragile and difficult to dissect, as it cannot be clearly differentiated from the surrounding muscles and tendons.

***Attachment sites:*** The ligamentum nuchae attaches to the external occipital protuberance[30] and the posterior spinal dura mater at C1 and C2.[9] With respect to variation, three publications state that the ligament attaches to the C2–C6 spinous processes,[11,42,44] while one reports that it does not.[9] Most studies agree that, generally, the nuchal ligament attaches proximally at the occiput, specifically the external occipital protuberance, and distally at C7.[12,13,21,23,25,42,43,45,46] Some studies provide additional descriptions that suggest that the anterior portion of the ligament attaches at the foramen magnum[23,46] or the posterior tubercle of the atlas.[42]

Both dissection and imaging studies report a connection between the nuchal ligament and cervical dura mater in the occipital region;[9,45,47] however, this connection was not observed by Nash et al.[48] in plastinated cadaveric sections. Additionally, Mitchell et al.[45] found that the proximal attachment site can extend bilaterally along the occiput as far as the temporal bone, suggesting a complex morphology, possibly similar to the “fan-like” portions described in Allia and Gorniak.[25]

***Ligament architecture:*** The architecture of the nuchal ligament is described differently in various literature having two to four parts. Allia and Gorniak[25] define four parts: a cord-like portion, running from the occiput to the C7 spinous process in the midline; a septum that connects this cord anteriorly to the spinous processes; a large “fan-like” portion attaching to the occiput; an additional small “fan-like” portion, inferior to the large one, also attaching to the occiput. Fielding et al.[23] similarly describe it as triangular shaped, attaching anteriorly to the cervical spinous processes, and composed of two portions: lamellar (anterior) and funicular (posterior), similar to the descriptions of Kadri and Al-Mefty[43] and Takeshita et al.[46] Kadri and Al-Mefty[43] further describe the lamellar portion as superficial at the level of C6 and C7, but deep at the level of C1. The lamellar and funicular portions are described in Standring[13] as the median septal and dorsal raphe portions, respectively.

One study identified part of the nuchal ligament as a separate entity, which they referred to as the “to be named ligament".[49] They defined it as a band of fibrous tissue arising from the nuchal ligament and extending anteriorly at C1 and C2. However, the description of this fibrous band is consistent with definitions of the lamellar portion in four other studies and is likely referring to this segment of the ligament.[23,25,46,48]

No data were found that discuss the standard length, width, thickness, mass, volume, or CSA of the nuchal ligament. A dissection study of 30 individuals is the only publication that provides some measurements, which are related to the width (several mm to 1.5 cm) and length (0.03–1.0 cm) of the occipital attachment.[9] These data are more appropriately associated with the enthesis rather than the architecture of the ligament itself.

***Function:*** The nuchal ligament comprises strong, elastic connective tissue[12,25,43] that contributes to stabilizing the head and neck during movement, particularly rotation and flexion.[45,46] The elastic fibers provide flexibility, allowing the ligament to stretch and return to its normal length.[16] Johnson et al.[42] suggest the architecture of the nuchal ligament indicates that it directs forces from the associated muscles to the lower cervical spine to prevent unnecessary loading on the upper neck.

***Sexual dimorphism:*** No sex differences of the nuchal ligament were discussed in any of the publications reviewed.

## Mastoid Process

Three muscles that attach to the mastoid process have been included in this review: sternocleidomastoid, splenius capitis, and longissimus capitis. These muscles lie from superficial (sternocleidomastoid[8]) to deep (longissimus capitis[8,14]) in the neck.[14,15,37] Fifteen publications (six dissection, nine imaging) provide architectural data for sternocleidomastoid, alongside an additional 13 publications specifically related to observations of anatomical variation. For splenius capitis, multiple studies discussed this muscle, with architectural data available in four dissection and five imaging studies. Less research has focused on longissimus capitis, with architectural data reported in five (four dissection, one imaging) studies.

**Sternocleidomastoid:** Sternocleidomastoid is a long, flat, oblique, superficial muscle enclosed in deep fascia.[8,13,21] It has a thick centre and broad ends[12,13,21] and can generally be divided into four segments, variable in size,[50] based on attachment sites: sternomastoid, sternooccipital, cleidooccipital, and cleidomastoid.[17,38,50] Kamibayashi and Richmond[17] describe the first three of these segments as superficial and parallel to one another, while the fourth lies deeper at a different orientation. The sternocleidomastoid separates the neck into the anterior and posterior triangles, and is covered by platysma[12,21,22,24] and the superficial layer of deep cervical fascia.[51] Anatomical variation is common in this muscle[12,21,52,53] and is described below.

***Attachment sites:*** Sternocleidomastoid attaches distally to the sternum (manubrium) and clavicle, and proximally to the mastoid process and superior nuchal line.[8,13,16–19,22,24,29,30,38,50,51,54] It separates inferiorly at its distal attachment and has a thick proximal attachment.[51] Houseman et al.[8] and Rea[24] give more detail to this description with distal attachments at the anterior surface of the manubrium and superior medial third of the clavicle and proximal attachments at the outer mastoid process and lateral superior nuchal line. The clavicular attachment is detailed in Phadnis and Bain[29] as arising from the medial curve of the posterior surface, opposite to the pectoralis major clavicular head and lateral to the sternohyoid clavicular attachment. Taken together, these studies largely agree that the sternocleidomastoid attaches distally to the medial half of the clavicle and anterior manubrium and proximally to the mastoid process and lateral superior nuchal line.

Some publications provide enthesis information for sternocleidomastoid. The manubrium attachment is round and tendinous and the clavicular attachment as flat, wide, and variable in size,[13,16] while the proximal attachment is described as thick.[51] Lee et al.[54] report data for the manubrial attachment with an enthesis area of 8.3 (range: 6.8–9.9) cm$^2$. No data are available for the clavicular or cranial entheses.

***Muscle architecture:*** Muscle architecture data are presented in **Table 3**. Fascicle length ranged between 11–14.1 cm, with the males from the study by Kennedy et al.[50] exhibiting the highest mean values. The range for pennation angle from these studies was 0–20° and is consistent with the variable angles seen across the four different sections of this muscle. Of the five studies that provided values for mass/volume, data from three were obtained from dissection, one from both dissection and imaging (MRI), and one from imaging (MRI). Mass obtained from cadaveric specimens had a small range (38.8–40.4 g), showing consistency across these studies.[17–19] Volume from dissection, however, was smaller at 24.8 cm$^3$ for males and 15.2 cm$^3$ for females.[50] Compared with dissection, the volume obtained via imaging was larger,[39,50] although the volume for females from Kennedy et al.[50] fell within range of the reported masses from the above dissection studies.

The PCSA ranged between 1.3–4.9 cm$^2$ across all dissection studies, with the reported mean PCSA from an

**Table 3**
Muscle architecture data for sternocleidomastoid.

| Study | | Sample/sex/age | Fascicle[1] Length (cm) | Fascicle[1] Pennation angle (°) | Muscle[1] Volume (cm$^3$) or mass (g) | Muscle[1] PCSA (cm$^2$) | Muscle[1] CSA (cm$^2$) |
|---|---|---|---|---|---|---|---|
| Dissection studies | Bayoglu et al. (2017) | n=1<br>Male<br>79 years | 11 | 0 | 38.8 (g) | 3.8 | - |
| | Borst et al. (2011)[2] | n=1<br>Male<br>86 years | 13.9 | 0 | 39.2 (g) | 2.9 | - |
| | Kamibayashi and Richmond (1998) | n=9[2]<br>7 M / 3 F<br>66–92 years | 11.8 (0.9) | 0-20 | 40.4 (9.0) (g) | 3.7 (0.9) | - |
| | Van Ee et al. (2000) | n=6<br>4 M / 2 F<br>70–83 years | - | >3 | - | 4.9 | - |
| Dissection and imaging (MRI) study | *Dissection*<br>Kennedy et al. (2017) | n=6<br>3 M / 3 F<br>63–93 years | M: 14.1 (0.8)<br>F: 12.3 (1.6) | - | 24.8 (3.9) (cm$^3$)<br>15.2 (4.8) (cm$^3$) | 1.8 (0.3)<br>1.3 (0.3) | - |
| | *Imaging* | | - | - | M: 72 (8.0) (cm$^3$)<br>F: 39.4 (12) (cm$^3$) | - | - |
| Imaging studies – MRI | Dawson et al. (2013) | n=10<br>10 M<br>26–54 years | - | - | - | - | 5.3 (0.8) |
| | De Loose et al. (2009)[3] | n=25<br>25 M<br>20–40 years | - | - | - | - | 6.3 (1.1) |
| | Elliot et al. (2014)[4] | n=34<br>Female<br>26.9 (5.6) years | - | - | - | - | 2.3 (2.2–2.4) |
| | Li et al. (2014) | n=16<br>11 M / 5 F<br>23–33 years | - | - | - | - | 5.0 |
| | Reddy et al. (2021) | n=13<br>Male<br>30.5 (1.7) years | - | - | M: 107.9 (6.4) (cm$^3$) | 5.6 (0.3)[5] | 9.9 (0.6)[6] |
| | | n=17<br>Female<br>30.8 (1.7) years | - | - | F: 72.7 (3.5) (cm$^3$) | 4.1 (0.2)[5] | 7.1 (0.4)[6] |
| | Uthaikhup et al. (2017)[7] | n=14<br>Female<br>64.2 (4) years | - | - | - | - | 10.1 (0.7) |
| Imaging studies - Ultrasound | Alsalaheen et al. (2019) | n=34<br>20 M / 14 F<br>18–30 years | - | - | - | M: 4.1 (0.8)<br>F: 2.8 (0.5) | - |
| | Botticchio et al. (2021) | n=17<br>12 M / 5 F<br>22.2 (1.9) years | - | - | - | - | 3.9 (0.6) |
| | Kim et al. (2021) | n=18<br>11 M / 7 F<br>79.2 (10.7) years | - | - | - | - | 1.4 (0.6)[8] |

**CSA:** cross-sectional area; **F:** female, **M:** male; **MRI:** magnetic resonance imaging; **PSCA:** physiological cross-sectional area. [1]Mean values presented where relevant (standard deviation) given where available. [2]Ten cadavers were included (seven males, three females) with nine used for the analysis of sternocleidomastoid; however, the representation of each sex is not clear. [3]Data given for right side only. Fighter pilot neck pain study. Data here show control group with no neck pain. [3]Study looks at whiplash associated disorders measuring CSA at both C2–C3 and C5–C6. Data here given for healthy control group measured at the level of C5–C6. [5]Study estimated PCSA by dividing reconstructed muscle length by muscle volume and reporting reconstruction-based cross-sectional area (RCSA) as equivalent of PCSA. [6]Study reported anatomical cross-sectional area (ACSA), which was the maximum CSA of each muscle and may account for the large numbers. [7]Cervicogenic headache study of older female sample. Data show control group with no neck pain. [8]Ultrasound measurements taken on cadaveric material at upper, middle, and lower sections of the muscle. The CSA reported here is for the middle measurement.

ultrasound study[55] also falling within this range. Estimated PCSA from another imaging (MRI) study[39] showed larger values for males (5.6 $cm^2$), with only females falling in the range of the other studies (4.1 $cm^2$). As seen above, the Kennedy et al.[50] study had the lowest values, but it is unclear why, as the age ranges are similar for all publications. Additionally, a large range is evident for CSA obtained via imaging (1.4 $cm^2$ to 10.1 $cm^2$), which is higher than the dissection data, although with some overlap.

***Function:*** Sternocleidomastoid, when contracting bilaterally is primarily a cervical flexor,[41] producing flexion of the lower cervical spine, and concomitant extension of the upper cervical levels.[12,13,16,21,22] It contributes to other movements such as contralateral rotation and lateral bending,[20,21,51] with unilateral activation resulting in ipsilateral lateral flexion coupled with contralateral rotation.[24] Both sides also work together to elevate the clavicle and sternum during inspiration,[13,16] and the sternal head supports the sternoclavicular joint anteriorly.[30]

***Anatomical variation:*** Anatomical variation has been regularly observed with case reports published on single cases,[56–66] although a few studies have looked at variation in multiple subjects.[52,53] Most of the case studies report bilateral supernumerary heads of the sternocleidomastoid,[58,61–64,66] while some observed additional heads on either the left[56,57,59,60] or right[65] side.

In these studies, populations represented included American-European,[58] Brazilian,[56] European,[64] Greek,[62] Indian,[52,57,65] Korean,[60,61,63] Spanish[53] and Turkish.[59,66] Additionally, males are over-represented in case studies on single individuals,[56–62,65,66] with only two studies discussing females.[63,64] This may suggest that females are not commonly studied, or that males exhibit variation in this muscle more regularly than females. Two cadaveric studies[52,53] that examined multiple individuals from both sexes reported variation only in males, in five[52] and three[53] of 18 cadavers, in each study.

***Sexual dimorphism:*** Kennedy et al.[50] reported significantly larger sternocleidomastoid volume in males compared with females, from both dissection and MRI data. Similarly, Alsalaheen et al.[55] found significant differences in a number of architectural parameters, including PCSA, with larger values in males. Additionally, Reddy et al.[39] reported that males had significantly larger and stronger neck muscles than females, including sternocleidomastoid.

**Splenius capitis:** Splenius capitis is in the second layer of the posterior neck[14,15,37] deep to trapezius and sternocleidomastoid,[8,13,16] although the fibers do not cross the midline like the trapezius.[25] Splenius capitis and cervicis form a layer over semispinalis capitis, and in cross-section splenius capitis can be seen as a distinct layer between trapezius and semispinalis capitis.[38] It should be noted that some authors consider splenius capitis and cervicis as a single muscle due to their continuity[17,67] and Vasavada et al.[20] reported that splenius cervicis is contiguous distally from splenius capitis and may, therefore, not be distinguishable at times. All other studies analyzed these two muscles separately.

***Attachment sites:*** Splenius capitis attaches proximally to the mastoid process, lateral third of the superior nuchal line, and occiput and distally to the inferior half of the ligamentum nuchae and adjacent spinous processes.[8,11–13,16–18,21,22,25,30,38,67] Some variation exists mainly with respect to the distal attachment. However, most studies agree that splenius capitis attaches distally at the nuchal ligament (C3 to C7) and spinous processes, from C7 to T4.[8,11,17–20,25,38] No data were provided for either proximal or distal attachment site morphology for this muscle, such as the size of the tendinous enthesis.

***Muscle architecture:*** Muscle architecture data are shown in **Table 4**. Mean fascicle length ranges between 8–10.5 cm, with the individual from Borst et al.[18] again exhibiting the largest values. However, the range for fascicle length reported by Kamibayashi and Richmond[17] does encompass the entirety of the reported values (7–10.7 cm). Pennation angle was consistent throughout studies with a range of 0–5°.

For mass, three dissection studies provided data, two of which included one individual, and one of which dissected splenius capitis and splenius cervicis together.[17–19] The combination of these muscles is reflected in the larger value for mass (42.9 g) from Kamibayashi and Richmond[17] compared with the other studies (14.6–27.1 g). Additionally, three dissection studies provided PCSA for splenius capitis with a range of 2.0–3.1 $cm^2$,[18,19,32] with the outlier value of 4.3 $cm^2$ for both splenius capitis and cervicis.[17] Values for CSA from imaging (1.5–3.8 $cm^2$) were consistent with PCSA obtained from dissection, although the large value from Li et al.[33] may be related to them reporting a maximum CSA.

In addition to the data presented in **Table 4**, Mayoux-Benhamou et al.[15] provided CT data for thickness and depth. They describe splenius capitis as a very thin muscle, with a mean thickness of 0.7 cm in males and 0.5 cm in females. The mean depth from the inner muscle border to skin was 1.9 cm for males and 1.7 cm for females, while the outer muscle border to skin depth was reported as a 1.3 cm for males and 1.2 cm for females.

**Table 4**
Muscle architecture data for splenius capitis.

| | Study | Sample/sex/age | Fascicle[1] Length (cm) | Fascicle[1] Pennation angle (°) | Muscle[1] Mass (g) | Muscle[1] PCSA ($cm^2$) | Muscle[1] CSA ($cm^2$) |
|---|---|---|---|---|---|---|---|
| Dissection studies | Bayoglu et al. (2017) | n=1<br>Male<br>79 years | 8.0 | 0 | 14.6 | 2.0 | - |
| | Borst et al. (2011) | n=1<br>Male<br>86 years | 10.5 | 0 | 27.1 | 2.5 | - |
| | Kamibayashi and Richmond (1998) | n=9[2]<br>7 M / 3 F<br>66–92 years | 8.6 (1.1) | 0–5 | 42.9 (13.8)[3] | 4.3 (1.0)[3] | - |
| | Van Ee et al. (2000) | n=6<br>4 M / 2 F<br>70–83 years | - | >3 | - | 3.1 | - |
| Imaging studies - MRI | Dawson et al. (2013) | n=10<br>Male<br>26–54 years | - | - | - | - | 2.5 (0.3) |
| | De Loose et al. (2009)[4] | n=25<br>Male<br>20–40 years | - | - | - | - | 2.9 (0.7) |
| | Elliot et al. (2014)[5] | n=34<br>Female<br>26.9±5.6 years | - | - | - | - | 1.9 (1.8–2) |
| | Li et al. (2014) | n=16<br>11 M / 5 F<br>23–33 years | - | - | - | - | 3.8[6] |
| | Uthaikhup et al. (2017)[7] | n=14<br>Female<br>64.2±4 years | - | - | - | - | 1.5 (2.1) |

**CSA:** cross-sectional area; **F:** female, **M:** male; **MRI:** magnetic resonance imaging; **PSCA:** physiological cross-sectional area. [1]Mean values presented where relevant (standard deviation) given where available. [2]Ten cadavers were included (seven males, three females) with nine used for the analysis of splenius capitis; however, the representation of each sex is not clear. [3]This study considered splenius capitis and cervicis together, hence the larger mass and PCSA values. [4]Data given for right side only. Fighter pilot neck pain study. Data here show control group with no neck pain. [5]Study examines whiplash associated disorders measuring CSA at both C2–C3 and C5–C6. Data here given for healthy control group measured at the level of C5–C6. [6]Study provided maximum CSA of splenius capitis at C2–C3 and C6–C7, which may account for the large number. [7]Cervicogenic headache study of older female sample. Data are for the control group with no neck pain.

***Function:*** Splenius capitis acts as a cervical extensor when activated bilaterally[12,13,21,22,41,67] and produces ipsilateral axial rotation and lateral flexion of the head.[12,13,16,20–22,67] Additionally, it reinforces the nuchal ligament and provides stability to the upright head and neck.[12,25]

***Sexual dimorphism:*** A CT study by Mayoux-Benhamou et al.[15] found that mean muscle thickness and depth were significantly larger ($p<0.05$) in males than females. Keidan et al.[67] found significant sex differences in splenius capitis and cervicis attachment sites in 35 cadavers (19 females, 16 males), with muscles covering more of the posterior neck in males than females.

**Longissimus capitis:** The longissimus capitis, also called trachelo-mastoideus in historical texts,[12,13,21,30] is a long, thin muscle located in the third layer of the neck.[8,13,14,16] Longissimus is made up of three muscles – capitis, cervicis, thoracis – which extend from the mastoid process of the cranium to the lumbar vertebrae and form part of the erector spinae group.[13,20] Longissimus capitis is a continuation of longissimus cervicis.[17] Kamibayashi and Richmond[17] also describe it as a fleshy muscle that is difficult to dissect, due to its close adherence to the bone in several places. This is further complicated by the presence of intermediate tendons.[12,19]

***Attachment sites:*** Longissimus capitis attaches proximally to the posterior aspect of the mastoid process[12,13,16,19,20,30] with a flat tendinous attachment.[21] Distally, it attaches at the transverse processes of the lower cervical and upper thoracic vertebrae.[8,13,16–21,38] The distal

**Table 5**
Muscle architecture data for longissimus capitis.

| | Study | Sample/sex/age | Fascicle[1] Length (cm) | Fascicle[1] Pennation angle (°) | Muscle[1] Mass (g) | Muscle[1] PCSA ($cm^2$) | Muscle[1] CSA ($cm^2$) |
|---|---|---|---|---|---|---|---|
| Dissection studies | Bayoglu et al. (2017) | n=1<br>Male<br>79 years | 7.2 | 0 | 3.9 | 0.6 | - |
| | Borst et al. (2011) | n=1<br>Male<br>86 years | 6.5 | 0 | 5.5 | 0.8 | - |
| | Kamibayashi and Richmond (1998) | n=9[2]<br>7 M / 3 F<br>66–92 years | 13–18 (muscle-tendon length) | - | 16–24 | - | - |
| | Van Ee et al. (2000) | n=6<br>4 M / 2 F<br>70–83 years | - | >3 | - | 1.0 | - |
| Imaging study - MRI | Li et al. (2014) | n= 16<br>11 M / 5 F<br>23–33 years | - | - | - | - | 1.2 |

**CSA:** cross-sectional area; **F:** female, **M:** male; **MRI:** magnetic resonance imaging; **PSCA:** physiological cross-sectional area. [1]Mean values presented where relevant (standard deviation) given where available. [2]Data are estimated from two individuals, PCSA value not provided.

attachments may vary, although are consistently in the same region: C2–C6,[17] C3–T5,[19] C4T2,[18] C4–T4,[38] and T1–T4.[8] Enthesis morphological data for longissimus attachment sites were not provided.

***Muscle architecture:*** There were fewer studies on the longissimus capitis than on the other muscles covered in this review, which resulted in limited architectural data (Table 5). Two studies provided mean fascicle length (6.5 and 7.2 cm), and despite having data from only two individuals, both lengths are similar.[18,19] These studies also reported muscle mass with similar consistency between individuals (3.9 and 5.5 g). A third study provided estimations of length and mass from two individuals in their study, which appears to include the entirety of the muscle and tendon.[17] Pennation angle is consistent at less than 3°. PCSA ranged between 0.6–1.0 $cm^2$, with a slightly larger reported CSA value of 1.2 $cm^2$. No studies reviewed observed variation between males and females for the longissimus capitis muscle.

***Function:*** The longissimus capitis stabilizes the vertebral column and cranium.[8] It contributes to extension of the head and neck[67] and unilaterally, produces ipsilateral axial rotation of the head[20] and lateral flexion of the cervical vertebrae.[21,67]

## Discussion

The soft tissues associated with the nuchal crest and mastoid process contribute to the musculature of the head and neck, with their proximal attachments directly associated with the skeletal landmarks and their distal attachments covering broad areas of the cervical vertebrae, clavicle, and sternum/manubrium. Collectively, the associated muscles range from small to large, with the smallest dissection PCSA reported for longissimus capitis (0.6 $cm^2$)[19] and the largest for sternocleidomastoid (4.9 $cm^2$).[32] Imaging CSA values showed a large range from 1.2 $cm^2$ for longissimus capitis[33] to 36 $cm^2$ for upper trapezius,[33] although this large measurement was based on a single maximum CSA measurement at the level of C6 and C7. These soft tissues also contribute to the stability and movement of the head, neck, and shoulders. Specifically, upper trapezius, semispinalis capitis, splenius capitis, and longissimus capitis act as extensors of the neck when contracting bilaterally,[8,12,13,16,21,22,35,40,41,67] while sternocleidomastoid acts as a flexor[12,13,16,21,22,41] and the nuchal ligament provides stabilization.[45,46] They also contribute to cervical rotation and lateral flexion. The reviewed literature that discussed function focused mostly on the muscles' concentric actions, with limited discussion of eccentric muscle contraction. The emphasis on concentric functions in the existing literature suggests that research in this area should aim to explore more distinct muscular functions.

Although descriptions of the cervical muscles and nuchal ligament are numerous, there are limited architectural data presented in dissection and imaging studies.

Additionally, very few provide complete or uniform data. Some dissection studies reviewed here do report on several architectural parameters,[17–19] although two only included one individual.[18,19] Conversely, imaging studies often provide CSA measurements, with limited information on other architectural parameters.

The most widely studied muscles were upper trapezius and sternocleidomastoid. Five dissection studies provided architectural data for these muscles with four overlapping publications[17–19,32] and one study each, which explored trapezius[10] and sternocleidomastoid[50] individually. The architectural data for all other muscles were derived from the same four dissection studies that examined multiple muscles in the head, neck, and shoulders.[17–19,32] This illustrates that further studies are required to provide architectural data for these groups and segments of muscles. The imaging studies were more variable in representation of muscles, and one encompassed all the muscles in this review.[33] However, the measurements were often not as comparable due to the reporting of a maximum CSA value. Sternocleidomastoid was the most widely analyzed muscle with data from seven imaging studies,[33,34,41,50,55,68,69] although the study by Kennedy et al.[50] focused mostly on dissection, providing volume data from MRI. Longissimus capitis had the least amount of data, with architectural measurements limited to one imaging study,[33] which reflects the few studies that discussed this small muscle. Also, as described above, no architectural data was provided for the nuchal ligament, with the exception of the size of its enthesis on the cranium.[9]

With the exception of two studies that provided enthesis morphology of the nuchal ligament and sternocleidomastoid,[9,54] no other data were available for the size or shape of tendinous attachments or ligament entheses. Additionally, the existing literature does not provide detailed information for attachment sites, such as the location of attachment on the mastoid process. Further exploration in this area would assist in informing research into sexual dimorphism in the skeleton as it relates to muscular and skeletal robusticity. It may also improve our understanding of how soft tissues interact with the skeleton in other contexts. For example, some research in bioarcheology examines entheses to study activity markers on the bone,[70,71] and data from anatomical studies could inform future research in this area.

Another area with limited discussion was the variation between dissection and imaging studies. One study compared data from both,[50] while another completed an imaging study on a cadaveric population.[72] As seen in the ranges of measurements, imaging values were higher than those obtained from dissection, specifically for sternocleidomastoid.[50] This is to be expected given the older age of cadaveric specimens, compared with living individuals, and possible tissue shrinkage related to preservation processes.[50,72] Additionally, there may be a higher incidence of error in imaging studies, particularly when assessing single slice CSA measurements.[38,68] Finally, few publications addressed sex or population differences. Although sexual dimorphism was observed in four muscles – upper trapezius, semispinalis capitis, sternocleidomastoid, and splenius capitis – this was discussed in only six of the 19 studies[14,15,36,50,55,67] that provided architectural data. Of the other 13 studies, two included one individual,[18,19] four studied one sex,[34,41,68,69] one did not provide a breakdown of sex,[10] and six provided data for both sexes, but did not assess sexual dimorphism.[17,32,33,37,72,73] With the knowledge that sex differences do exist in humans, it seems relevant that potential variation in anatomical parameters between sexes should be consistently addressed. The field of anatomy would benefit by including both males and females in research to understand the role that sexual dimorphism plays not only for anthropological research, but also in terms of clinical and functional applications. Similarly, understanding of population variation in these muscles is limited. Although the studies reviewed were from diverse regions of the world – which was especially apparent in case reports of anatomical variation in sternocleidomastoid – only one discussed the possibility that population differences may influence their findings.[72]

Despite the amount of information available on the soft tissues associated with the nuchal crest and mastoid process, there are still some gaps in the literature that need to be addressed. Based on this review, it is clear that further research is warranted to provide comprehensive and uniform data on posterior cervical muscle architecture and entheses morphology, incorporating diverse populations and age groups. Moreover, although sexual dimorphism and population differences has been considered in some studies, these areas of require exploration in future studies.

## Conflict of Interest

The authors declare that there are no conflicts of interest.

## Author Contributions

JSDLP: study design, systematic search and screening of literature, drafting the manuscript, edits; HRB: supervising work, commenting on drafts and the final version of the manuscript; SEH: supervising work, commenting on drafts and the final version of the manuscript; SJW:

senior author, supervising work, commenting on drafts and final version of the manuscript.

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