I. OBJECTIVE: Atopic badges

1. Identify the growth trend and type of cervical vertebral body heights and depths during the first two decades of life.
2. Identify if there are sex differences in cervical vertebral growth.

II. INTRODUCTION:

The neck has a complex growth pattern. Scammon noted its growth to follow both the general/somatic and neural growth types. As seen in Figure 1:

- Both growth types are accelerated during early childhood; however, by age 6 years neural growth attains most of the adult size, while somatic growth attains only 1/3 of the adult size.
- During puberty, neural growth is slow and steady while somatic growth is accelerated.

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Cervical Vertebrae Maturation Index (CVMI) is an important method to qualitatively assess the morphological changes in the cervical vertebrae body to determine skeletal maturation and when surgical intervention/treatment should occur in modern populations, as well as assess age-at-death in past populations.

The six CVMI stages of morphological changes of C2-C6 during puberty are depicted in Figure 2.

- C2-C6 during puberty are depicted in Figure 2.
- CVMI has been found to have poor reproducibility given the qualitative nature of this method.
- Sexual dimorphism is present in shape and size of cervical vertebral bodies is present during growth as well as in adulthood, however CVMI does not account for it.

III. MATERIALS:

- Subject: 115 medical CT studies (70 males, 45 females) from modern typically developing individuals between the ages of 6 months to 20 years.
- Image and data acquisition: Retrospective medical imaging studies were acquired and data collected as specified in Miller et al. (2019). Vorperian et al. (2009) and 2011).

IV. METHODS:

- Landmark-based measurements were calculated from 23 landmarks placed in the midsagittal plane of each cervical vertebra. See first panel, Figure 4.
- Using the 23 landmarks the 3D Euclidean distance was calculated between the ages of 6 months to 20 years.
- The height and depth measurements were plotted as a function of age for each sex and significant differences were assessed using the composite growth model by Wang et al. (2013).

V. RESULTS:

<table>
<thead>
<tr>
<th>Anterior Height</th>
<th>Sex</th>
<th>Somatic (mm)</th>
<th>Neural (mm)</th>
<th>Growth Type</th>
<th>Sex</th>
<th>Somatic (mm)</th>
<th>Neural (mm)</th>
<th>Growth Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2A Male</td>
<td>7</td>
<td>93 Somatic</td>
<td>73 Neural</td>
<td>Male</td>
<td>16</td>
<td>84 Somatic</td>
<td>64 Neural</td>
<td>Male</td>
</tr>
<tr>
<td>C3A Male</td>
<td>97</td>
<td>3 Somatic</td>
<td>37 Neural</td>
<td>Male</td>
<td>94</td>
<td>9 Somatic</td>
<td>93 Neural</td>
<td>Male</td>
</tr>
<tr>
<td>C3A Female</td>
<td>57</td>
<td>6 Somatic</td>
<td>61 Neural</td>
<td>Female</td>
<td>10</td>
<td>5 Somatic</td>
<td>55 Neural</td>
<td>Female</td>
</tr>
<tr>
<td>C4A Male</td>
<td>97</td>
<td>3 Somatic</td>
<td>37 Neural</td>
<td>Male</td>
<td>94</td>
<td>9 Somatic</td>
<td>93 Neural</td>
<td>Male</td>
</tr>
<tr>
<td>C4A Female</td>
<td>97</td>
<td>3 Somatic</td>
<td>37 Neural</td>
<td>Female</td>
<td>10</td>
<td>5 Somatic</td>
<td>55 Neural</td>
<td>Female</td>
</tr>
<tr>
<td>C5A Male</td>
<td>99</td>
<td>3 Somatic</td>
<td>37 Neural</td>
<td>Male</td>
<td>25</td>
<td>75 Somatic</td>
<td>75 Neural</td>
<td>Male</td>
</tr>
<tr>
<td>C5A Female</td>
<td>99</td>
<td>3 Somatic</td>
<td>37 Neural</td>
<td>Female</td>
<td>25</td>
<td>75 Somatic</td>
<td>75 Neural</td>
<td>Female</td>
</tr>
<tr>
<td>C6A Male</td>
<td>0</td>
<td>0 Somatic</td>
<td>0 Somatic</td>
<td>Male</td>
<td>48</td>
<td>52 Somatic</td>
<td>52 Neural</td>
<td>Male</td>
</tr>
<tr>
<td>C6A Female</td>
<td>0</td>
<td>0 Somatic</td>
<td>0 Somatic</td>
<td>Female</td>
<td>48</td>
<td>52 Somatic</td>
<td>52 Neural</td>
<td>Female</td>
</tr>
<tr>
<td>C7A Male</td>
<td>98</td>
<td>2 Somatic</td>
<td>2 Somatic</td>
<td>Male</td>
<td>20</td>
<td>80 Somatic</td>
<td>80 Neural</td>
<td>Male</td>
</tr>
<tr>
<td>C7A Female</td>
<td>98</td>
<td>2 Somatic</td>
<td>2 Somatic</td>
<td>Female</td>
<td>20</td>
<td>80 Somatic</td>
<td>80 Neural</td>
<td>Female</td>
</tr>
</tbody>
</table>

VI. DISCUSSION:

This study quantified sex-specific growth of the cervical vertebral bodies in height and depth during the first two decades of life. Findings reveal that:

- General growth is related to the plane of growth. Specifically, growth in the vertical plane follows a somatic growth type while growth in the horizontal plane follows a neural growth type.
- The accelerated growth in height during puberty based on previous studies revealed an increase in height of an average of 6 mm. This study found similar results for the anterior cervical vertebra body heights (female=6.5mm, male=6.2mm). However, the posterior height increased by an average of 5 mm (female=4.9 mm, male=5.5).
- Depth growth trends for all cervical vertebrae had neural growth where the majority of the growth is achieved (about 75%) by early childhood.
- The height and depth findings in this study quantify the six stages of CVMI changes in shape.
- Heights have accelerated growth during the period associated with CVMI, whereas depths have attained most of the adult size before the CVMI stages. Therefore, shape changes of CVMI are likely to occur in height rather than depth.
- The slow and steady growth in depth suggest the changes in the inferior border of cervical vertebrae bodies during CVMI stages 3-6 occur more due to concavity than growth in depth.

Sexual dimorphism is present in height and depth growth trends even though both males and females follow a somatic growth type in height and neural growth type in depth.

- As seen in Figure 5, the intersection of the height and depth growth trends reflect equivalent lengths and imply a square shape.
- This intersection occurs at around 13 – 15 years in females, supporting Altan et al. (2011) and Lamparski CVMI stage association with chronological age, while occurring in males around 16 – 18 years.
- The difference in age between the sexes when height and depth intersect, suggests females progress through the CVMI stages earlier than males.
- As seen in Figure 6, larger depths in males at all ages support previous research findings of sex differences in shape.
- The poor reproducibility and reliability of CVMI is likely due to sexual dimorphism evidenced by timing differences in growth/maturation between males and females as seen in Figure 5, and sex differences in height and depth as seen in Figure 6.

VII. CONCLUSION:

Cervical vertebrae body (C3-C7) growth in height and depth differ following growth types, somatic and neural respectively. C2 growth in height and depth are both neutral.

Sex differences are present as evidenced by differences in age of maturation with females maturing sooner than males; also, the cervical vertebrae growth is greater in males than females at all ages.

Based on the strong evidence of sexual dimorphism, reassessment of the CVMI stages accounting for sex differences is needed to improve determination of skeletal maturation and better serve for clinical guidance.

REFERENCES: