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Arcuate foramen prevalence in South African subjects: A cadaveric study based on 120 atlas vertebrae

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ABSTRACT

Background: This study was a prospective cadaver-derived skeletal study looking at the skeletal remains of a modern human population. The complete arcuate foramen (AF) is an anatomical variant of the atlas vertebra with a complete osseous bridge over the groove for the vertebral artery (VA). Awareness of the anatomic variations of the atlas related to the course of the VA, such as the AF, is important because the course and variations of VAs are critical to spine surgeons. We aimed to detect the prevalence of AF in sub-Saharan African subjects.
Materials and methods: We analyzed the prevalence of AF in 120 atlas vertebrae from the Raymond A Dart Collection of the University of the Witwatersrand, Johannesburg, South Africa.
Results: Twelve (13.3 %) atlases of the 90 that were from sub-Saharan African ancestry subjects presented at least one AF: the presence of AF frequency was 6.7 % in the Sotho sample, 23.3 % in the Xhosa sample and 10.0 % in the Zulu sample. However, no significant difference was found in their distribution regarding the presence of AF ratios ($p = 0.221$). The AF frequency was 3.3 % in the South African Caucasian subjects. No significant differences were found in their distribution regarding the presence of AF ratios between the Caucasian and the Sotho ($p = 1.000$), Zulu ($p = 0.612$) and Xhosa ($p = 0.052$) samples.
Conclusions: Our research shows a tendency for a higher AF presence in Xhosa subjects. It has increased the knowledge of the AF prevalence in sub-Saharan Africa, drastically increasing the population.

1. Introduction

The complete arcuate foramen (AF) is an anatomical variant of C1 (atlas vertebra) that consists of a complete osseous bridge over the groove for the vertebral artery (VA) from the posterior region of the superior articular facet to the superior lateral border of the posterior arch [1] that encircles the suboccipital nerve, the vertebral venous plexus, and VA [2,3]. (Figs. 1 and 2)

The AF has been called different names in the literature, such as Kimmerle anomaly canal retroarticular, atlas bridging, *canalis arteriae vertebralis*, *foramen arcuale*, *foramen atlantoideum*, foramen retroarticular, foramen sagittale, Kimmerle anomaly, Kimmerle deformity, Kimmerle variant, pons posticus, posterior atlantoid foramen, posterior glenoid process, posterior glenoid speculum, posterior ponticulus, retroarticular ring, and retro-condylar bony foramen ponticulus posticus and foramen arcuale [3–10].

AF has been observed as an incidental finding in subjects presenting migraine, cervicogenic headache, acute headache, neck pain, arm pain, shoulder pain, vertigo, nausea, retro-orbital pain, vertebrobasilar insufficiency, and VA dissection [2,6,10–14]. Additionally, awareness of the presence of anatomic variations of C1 related to the course of the VA, such as the AF, is important because the course and the variations of VAs are critical to spine surgeons [1]. Thus, a prevalence study such as this can educate surgeons on which patients to investigate further for

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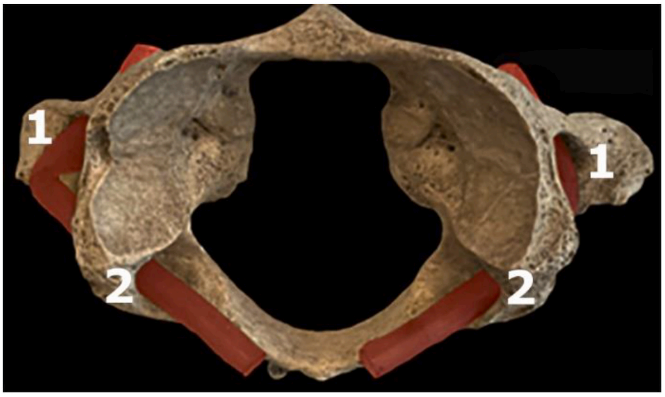

Fig. 1. Superior view of an atlas with a bilateral complete arcuate foramen that presents in red how the vertebral artery runs through the transverse foramen (1) and passages through the arcuate foramen (2). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 2. Superolateral view of an atlas with a bilateral complete arcuate foramen (asterisks).

abnormal anatomy.

In addition, the official reports of the United Nations about the population in sub-Saharan Africa [15] have revealed that "since the 1980s, sub-Saharan Africa has been the region with the fastest growing population, and between 2022 and 2050, the population of sub-Saharan Africa is expected to almost double, surpassing 2 billion inhabitants by the late 2040s, and is also projected to become the most populous of the eight geographic regions in the late 2060s, surpassing both Eastern and South-Eastern Asia and Central and Southern Asia in size". Knowledge of the AF prevalence in a sub-Saharan population will be crucial to prevent and minimize possible surgical complications during C1 lateral mass screw placement [8].

Following this, we focused on increasing the knowledge of AF prevalence in subjects from sub-Saharan Africa.

2. Materials and Methods

We conducted a dry vertebrae cadaveric study to analyze the complete AF (unilateral or bilateral) prevalence in 120 atlas vertebrae from the Raymond A. Dart Collection of Modern Human Skeletons (Dart Collection) housed at the School of Anatomical Sciences, Faculty of Health Sciences of the University of the Witwatersrand, Johannesburg, South Africa. The study was carried out following the tenets of the Declaration of Helsinki. It was approved by the Ethics Committee of the University of the Witwatersrand, Johannesburg, South Africa (IRB number: W-CJ-140604-1) and the University of Valencia, Spain (IRB number: HI393415855483).

The skeletons were chosen from the list of Sotho, Zulu, and Xhosa (representative of Bantu-speaking groups of Southern Africa [16]) and Caucasian skeletons of the Dart Collection with the unique inclusion criteria of being obtained from adult subjects. As a result, the skeletal sample analyzed comprised 90 well-preserved adult atlases obtained from Zulu ($n = 30$), Xhosa ($n = 30$) and Sotho ($n = 30$) individual skeletons with a mean age of death of 43.5 ± 13.9 years old (range 25–80 years old) and another 30 adult atlases obtained from Caucasian individual skeletons with a mean age at death of 52.0 ± 13.7 years old (range 32–86 years old). Exclusion criteria for the sample studied were any atlas that exhibited post-mortem damage (especially in the area related to observed AFs) or missing vertebral components, identified pathologies that covered any aspect of the atlas, or incompletely closed arcuate foramina either unilaterally or bilaterally.

The atlas of each individual of each population affinity group was viewed from its lateral aspects to note the presence of any complete AF and whether this presence was bilateral or unilateral and side-specific. Frequencies were calculated for each population affinity group and grouped for the total Sub-Saharan African sample. The Caucasian group was left separate.

Observation of AF prevalence was done by the corresponding author, who is an anatomist with three decades of experience in teaching, learning and research in modern human anatomy and its associated anomalies or variations. Any observed complete AF was verified by means of interobserver verification by the senior curator (also an anatomist) of the Dart Collection. If there were any disputes related to the identification of the complete AF, this atlas was then shown to a third anatomist of the School of Anatomical Sciences at Wits to confirm its presence and completeness.

Data were analyzed with SPSS v.27 (SPSS Inc., Chicago, IL, USA) software. Variable distributions were examined with the Shapiro−Wilks test. Variables with a normal distribution are presented as the mean ± standard deviation. Frequencies with percentages expressed categorical variables. Categorical variables were compared with the Fisher-Freeman-Halton exact test. A p-value <0.05 was considered statistically significant.

3. Results

We found that 12 atlases of the 90 individuals analyzed (13.3 %) presented with at least one AF. Only one atlas of the Caucasian sample (3.3 %) showed a unilateral right AF (male, 40 years old). However, no significant difference was found between the sub-Saharan African ancestry sample and the Caucasian sample in their distribution regarding the presence of AF ratios ($p = 0.181$).

Regarding the sub-Saharan African ancestry sample, the AF frequency was 6.7 % (2/30) in the Sotho, 23.3 % (7/30) in the Xhosa and 10.0 % (3/30) in the Zulu sample. However, no significant difference was found in their distribution regarding the presence of AF ratios ($p = 0.221$). No significant differences were found in their distribution regarding the presence of AF ratios between the Caucasian and the Sotho ($p = 1.000$), Zulu ($p = 0.612$) and Xhosa ($p = 0.052$) samples.

Five (5.6 %) of those 90 sub-Saharan African ancestry atlases presented AF in both posterior atlas hemiarches (bilateral AF). The bilateral AF rates were 3.3 % (1/30) in the Sotho sample, 10.0 % (3/30) in the Xhosa sample and 3.3 % (1/30) in the Zulu sample. No significant difference was found in their distribution among Sotho, Xhosa and Zulu subjects regarding bilateral AF ratios ($p = 0.608$).

Another 7 (7.8 %) of the 90 atlases presented AF in only one posterior hemiarch (unilateral AF). The unilateral AF rates were 3.3 % (1/30) in the Sotho sample, 13.3 % (4/30) in the Xhosa sample and 6.7 % (2/30) in the Zulu sample. Again, no significant difference was found in their distribution among Sotho, Xhosa and Zulu subjects regarding unilateral AF ratios ($p = 0.496$).

The possible coexistence of an AF and a posterior atlas arch defect in the same atlas [1,17,18] was not found in the 120 atlases analyzed because only 1 (0.8 %) atlas from a Sotho female with an age at death of 30 years old presented a posterior atlas arch defect. That atlas did not present an AF. Additionally, no other congenital fusion anomalies associated with the subaxial spine were found in the 120 atlases analyzed.

4. Discussion

As for AF, anomalies in the craniovertebral region (i.e., occiput-C1-C2 portions of the spinal column) are considered incidental findings on radiographic examinations [3]. Nevertheless, radiographic studies are usually performed after trauma or after an indication of clinical symptoms.

In this context, we analyzed the complete AF because any incomplete ones would have possibly resulted from the post-mortem handling of skeletons by researchers. This could potentially create incorrect numbers in the sample, and thus, it was decided that it would be best to look only at complete AFs. In addition, we also focused on the complete AF because the compression of the VA present in the complete AF may lead to neurological symptoms much more often than the incomplete AF [12]. The results found can also be of clinical importance as AF presence hypothetically may lead to a higher risk of presenting clinical symptoms such as migraine, cervicogenic headache, acute headache, neck pain, arm pain, shoulder pain, vertigo, nausea, retro-orbital pain, vertebrobasilar insufficiency, and VA dissection [2,6,10–14] following neck trauma, or possibly will be a risk to develop a Bow hunter's syndrome [19–21] due to a possible higher risk of VA compression. As the South African population is increasing drastically, there will be millions of South African subjects with AF in the near future. Thus, we recommend that the next Medical Doctors generations based in Southern Africa keep related clinical symptoms with AF in mind.

As indicated earlier, the clinical symptoms that may be associated with the potential presence of a unilateral or bilateral AF (complete or partial) would range from an associated pain (cervicogenic headache or cervical pain) to the effects of vascular tethering and potential compression because of a restricted space as the vessel transverse the suboccipital triangular area [2,6,11]. Neural compression similarly would affect clinical symptoms that could present as pectoral pain and even potential effects on muscle functionality and tone. The risk of injury during cranial and cervical movement is also potentially increased in the presence of an AF. Surgical procedures that involve the placement of lateral mass screws at C1 become difficult as there is, again, the risk of neurovascular compression and compromise [22]. These all emphasize the need for prudent and early detection of an AF presence in a patient coming for evaluation and surgical treatment, as some authors "strongly support preoperative screening for detecting the presence of AF" [23].

Nevertheless, AF prevalence studies carried out in a clinical/medical context could be biased, as they represent only a clinical/medical/illness population (with a possibly higher AF prevalence) and may not represent the generalized population. In this context, anatomical collections of dry bones represent a perfect target for detecting AF prevalence in the general population. These are the reasons for using cadaveric bones from the Raymond A. Dart Collection of Modern Human Skeletons of the School of Anatomical Sciences of the Medical School of the University of the Witwatersrand.

Focusing on the AF prevalence, Mitchell [5] and Karau et al. [14] found AF prevalence rates of 13.3 % and 14.7 % in their sub-Saharan African samples, similar to the results we obtained in our sub-Saharan African sample (13.2 %). Moreover, the above percentages of sub-Saharan African samples (13.3 %, 14.7 % and 13.2 %) are higher than the 12.7 % and 9.7 % found by Elliott & Tanweer [7] and Pekala et al. [9] in their meta-analyses carried out analyzing worldwide studies.

The higher results found in sub-Saharan African ancestry subjects can be of surgical importance because, as remarked [19], "*the AF may give the false impression that the posterior arch of the atlas is of adequate size to tolerate a C1 lateral mass screws and may lead to inadvertent VA injury*". Thus, human skeletal remains represent the ideal target for detecting the prevalence of anatomical variations that may lead to surgical complications if unknown or unrecognized by clinicians during preoperative assessments.

Regarding the sub-Saharan African sample analyzed, we found that Xhosa subjects presented AF more frequently than Sotho and Zulu subjects. However, the differences among the three samples analyzed were not statistically significant, and no significant differences between the sub-Saharan African sample and the Caucasian sample were found. A similar tendency was also found for the bilateral and unilateral AF prevalence because the prevalence of bilateral AF was 3.3 %, 10.0 % and 3.3 % in the Sotho, Xhosa and Zulu samples analyzed, respectively. In comparison, the prevalence of unilateral AF was 3.3 %, 13.3 % and 6.7 % in the Sotho, Xhosa and Zulu samples analyzed, respectively. In this context, the results by Mitchell [5] in her sub-Saharan African sample revealed that the prevalence of bilateral AF was 6.2 %, and the prevalence of unilateral AF was 7.1 %. In addition, it has been said that complete AF is most prevalent in North Americans, followed by Europeans, Africans, South Americans and Asians [10].

Nevertheless, we have analyzed a museum collection that identifies subjects such as Sotho, Zulu, and Xhosa. This is a limitation because that identification is more historically cultural and becoming less "genetic"/modern as population intermarry and mobility across regions expands. In this context, and according to Karapetian [24], "no one can obviate that the differences in the distribution of the AF among groups of different ancestry might also be a result of random processes such as genetic drift because it is unlikely that geographical fluctuations in frequencies of discrete morphological variants of the cervical spine in modern humans are related to adaptation to certain environmental conditions". As there is an archaic component related to that classification of subjects in Sotho, Zulu, and Xhosa, it is necessary to recognize that it is a major limitation of using a museum collection. However, the detection of AF using dry vertebrae (as we have made using a skeletal collection) seems to be the best choice in comparison with the radiographic method due to the lower sensitivity of the radiographic method [10].

Additionally, we analyzed the possible coexistence of an AF and a posterior atlas arch defect in the same atlas vertebra as reported in the literature [1,17,18]. Nevertheless, we did not find that association in our sample, probably due to the size number analyzed. The limitation of this study would be mainly associated with the lack of specific and detailed information on the clinical presentation of an AF presence. The skeletal collection used for this study has the demographic details of the individuals in the collection, but there is a dearth of clinical information. The skeletons of the collection were all historically from individuals classified as being "unclaimed"; thus, no clinical information can be found as none was captured for the deceased individuals. In a sample with a larger sample size, an association between AF and posterior atlas arch defects could be possible.

This study has shown the prevalence of anomalous AF in a specific population group. Within the context of an equal or similar prevalence based on other studies, the awareness of its presence by clinicians becomes imperative in clinical evaluations. The use of modalities for detecting or negating the AF presence must be employed to minimize associated patient risk. The data we present may be linked to the fact that access to imaging technologies in health care is one of the challenges faced, especially by the sub-Saharan population [25–27]. While the diagnostic imaging modalities of CT and MRI may be available at some public health facilities in more urban centers or major cities, these are inaccessible to patients in remote or rural areas. Sub-Saharan nations often need more financial resources, making allocating sufficient funds to develop healthcare infrastructure difficult. The high expenses in purchasing, operating, and maintaining these advanced and complex machines further compound the issue. The need for more expertise in operating the scanners further compounds the challenge. Thus, there is a high demand, as reflected by the high patient-to-scanner ratio at health facilities. Consequently, many patients in Sub-Saharan countries cannot undergo CT or MRI studies or evaluations, which are important for accurate diagnosis and effective treatment planning.

5. Conclusions

In conclusion, we have found that sub-Saharan African ancestry subjects tend to have a higher possibility of present AF than the Caucasian ones and that inside the sub-Saharan African ancestry subjects, Xhosa subjects are those that present a higher tendency to have an AF. In addition, the AF prevalence in sub-Saharan African subjects does not present gender differences, left v right AF prevalence differences, or unilateral v bilateral AF prevalence differences.

Ethics statement

The study was approved by the University of the Witwatersrand institutional review boards, Johannesburg (IRB number: W-CJ-140604-1) and the University of Valencia (IRB number: HI393415855483).

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Funding statement

No financial support was received for the study, and all authors declare no conflict of interest-associated biases

CRediT authorship contribution statement

Juan A. Sanchis-Gimeno: Protocol/project development, Data collection or management, Formal analysis, Manuscript writing/editing. **Ilker Ercan:** Data management, Formal analysis, Manuscript writing/editing. **Susanna Llido:** Data management, Formal analysis, Manuscript writing/editing. **Özlem Toluk:** Data management, Formal analysis, Manuscript writing/editing. **Nilgün T. Çini:** Data management, Formal analysis, Manuscript writing/editing. **Senem T. Ozdemir:** Data management, Formal analysis, Manuscript writing/editing. **Shahed Nalla:** Protocol/project development, Data collection or management, Formal analysis, Manuscript writing/editing.

Declaration of competing interest

We declare to have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare that they have no conflict of interest.

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