Author's response to reviews

Title: Variation in the circle of Willis in a Sri Lankan Population

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# Title Page

## TITLE
Types of the cerebral arterial circle (circle of Willis) in a Sri Lankan Population

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Ratuwithana for data entry.
Types of the cerebral arterial circle (circle of Willis) in a Sri Lankan Population

ABSTRACT

Background: The variations of the circle of Willis (CW) are clinically important as patients with efficient collateral circulations have a lower risk of transient ischemic attack and stroke than those with ineffective collaterals. The aim of the present cadaveric study was to investigate the anatomical variations of the CW and to compare the frequency of occurrence of the different variations with previous autopsy studies as variations in the anatomy of the CW as a whole have not been studied in the Indian subcontinent.

Methods: The external diameter of all the arteries forming the CW in 225 normal Sri Lankan adult cadaver brains was measured using a calibrated grid to determine the occurrence of prevalence in the variation in CW. Pearson-Brown ranked correlation (\(\rho\)) Chisquared tests and a correspondence analysis were performed to study the anatomical variations in the CW across the 6 studies of diverse ethnic populations.

Results: We report 15 types of variations of CW out of 22 types previously described and one additional type: hypoplastic precommunicating part of the anterior cerebral arteries (A1) and contralateral posterior communicating arteries (PcoA) 5(2.2%). A global chisquared test was used to compare across all 6 studies and pairwise chisquared tests were used to test for differences between each pair of studies; all comparisons were statistically significant (\(p=0.0000\)) indicating differences among the studies. A subsequent correspondence analysis revealed a marked difference between the
configurations in the variations of the CW in previous 5 studies and the present study. An especially notable difference was observed in the following 4 configurations: 1) hypoplastic precommunicating part of the posterior cerebral arteries (P1), and contralateral A1, 2) hypoplastic PcoA and contralateral P1, 3) hypoplastic PcoA, anterior communicating artery (AcoA) and contralateral P1, 4) bilateral hypoplastic P1s and AcoA in Caucasian dominant study conducted by in Riggs and Rupp versus the rest of the studies.

Conclusion: The present study reveals that there are marked variations in the CW among intra and inter ethnic groups (Caucasian, African and Asian: Iran and Sri Lanka dominant populations), and warrants further studies keeping the methods of measurements, data assessment, and the definitions of hypoplasia the same.

Key words: Circle of Willis, Cerebral arteries, Variation, Anatomical study, Asia
Background

Based on anatomical [1-4] and radiological studies, [5-8] it has been shown that more than 50% of healthy control subjects have anatomical variations in the circle of Willis (CW). Comparisons based on radiological studies [5-8] in living patients and anatomical autopsy studies [1-4] are not possible as in-vivo data from angiography record luminal diameters of vessels distended by normal arterial blood pressure, whereas the cadaveric studies report on external diameters of collapsed vessels with zero luminal pressures. The variations of the CW are clinically important as the CW plays an important role in cerebral haemodynamics as a collateral anastomotic channel network and patients with efficient effective collateral circulations have a lower risk of transient ischemic attack and stroke than those with ineffective collaterals. [9, 10] Autopsy studies have shown that more Fetal configuration [where the blood supply to the occipital lobe is mainly via the internal carotid arteries due to a hypoplastic precommunicating (P1) segment of the posterior cerebral artery (PCA)] were found in autopsy brains with infarcts than in brains without.[11,12] Studies have shown that there also exists a correlation between cerebral aneurysms and certain variations of the CW.[13-15]
Several studies [2, 16-19] have reported a range of variations in the anatomy of the CW as a whole, but it is not clear whether the frequency of occurrence of the different variations of the CW are similar in the studies done in the Indian subcontinent as compared to studies done in other ethnic or racial populations. The range of variations in the anatomy of the CW has not been previously studied in Sri Lanka and the aim of this cadaveric study was to investigate the anatomical variations of the CW in subjects who have died of causes unrelated to the brain and to compare the frequency of occurrence of the different variations with previous autopsy studies.
Methods

225 postmortem brains (184 male and 41 female) were obtained following ethical approval from the Ethics Committee of the Faculty of Medicine, Colombo from medicolegal autopsies in individuals aged between 18 and 73 years who have died of causes unrelated to the brain. The brains were removed from the cranial cavity and fixed in 10% formaldehyde for a minimum period of two weeks. The arteries comprising the CW together with the basilar artery and its minute branches arising from the main vessels were then carefully removed from the base of the brain. Blood was carefully washed out from the CW with isotonic saline and line diagrams in all 225 brains and in some photographic records obtained. Blood was carefully washed out from the CW with isotonic saline. Line diagrams of all 225 circles were obtained, including photographic records in some cases.

Segments were taken from the following corresponding regions: right and left internal carotid arteries (ICA) close to their distal ends, precommunicating and postcommunicating part of the anterior cerebral arteries (A1), (A2) and the posterior cerebral arteries (P1), (P2) close to their origin, right and left posterior communicating arteries (PcoA) at their middle point and anterior communicating artery (AcoA) (with its variations if present) at its middle point. Transverse sections were then cut from each of
the segments obtained as stated above in a plane that was perpendicular to the vessel on a microtome (Shandon M1R, UK) at 40 µm, from each artery, a random “section” was then obtained from the water bath, three measurements of the external diameter were performed on randomly selected each section by the first Author under a stereomicroscope equipped with a micrometer-calibrator (Leica, WILD M3B, Stereomicroscope). The calculated average was then recorded as the value for each artery. Arteries where the external diameter was less than 1 mm, were documented as < 1 mm. The equipment was standardised according to the manufacturer’s specifications.

In the present study, the CW was defined as “typical CW” (Figure 1) only if:

1. All the component vessels (i.e. ICA, A1, AcoA, PcoA and P1 arteries) were present.
2. Origin of the arteries forming the CW was from its normal source with no excess vessels.
3. The external diameter of a component artery was not less than one millimeter.

Figure 1 (Type 1) – “Typical CW”

External diameter less than 1 mm. in any artery was considered to be “hypoplastic” (string-like appearance) (Figure 2), in order to be consistent with many previous anatomical studies.[12,17,19, 20] A vessel was recorded as “absent” only when it was not visualized following examination under the dissecting microscope.
There are many anatomical variations of the CW, their classification into a few clearly arranged groups is hardly possible, we classified variations of CW using 28 Types as defined by Ozaki et al., 1977, [3] Lazorthes et al., 1979, [18] and Eftekhar et al., 1985[19]. To the best of our knowledge only six studies [2,3,16-19] and the present study have investigated variations of CW as a whole and have classified all vessels with diameter under 1 mm as hypoplastic, but the selection of cases, nomenclature and the methodology adapted to measure the external diameter of the vessels were not identical.

In order to study the relationship of the anatomical variations of the CW between the studies in Caucasian dominant (USA [2,17] and France [18]), African (Morocco) [16] and Asian (Iran, [19] and present study from Sri Lanka) we performed a global chisquared test to compare across all 6 studies, and then a series of pairwise chisquared tests to test for differences between each pair of studies. Thereafter we performed a correspondence analysis [23], which is an effective way to display and compare configuration profiles with two-way categorical data. This analysis allows us to see which studies are most similar to one another and, for those studies that differ, which configurations are primarily responsible for the difference.
The Spearman-Brown-ranked correlation was used to study the relationship of the anatomical variations of the CW between the studies in Caucasian dominant (USA [2,17] and France [18]), African (Morocco) [16] and Asian (Japan, [3] Iran, [19] and present study from Sri Lanka) populations countries.

Results

We report 15 types of variations of CW out of 22 types previously described by Ozaki et al., 1977, [3] Lazorthes et al., 1979, [18] and Eftekhar et al., 1985.[19] and one additional type: hypoplastic A1 and contralateral PcoA 5(2.2%), categorized under “others” in Table I. Variations in the CW in the present study are shown in table I. The most common variations are as follows:

Type 1-“Typical CW”: 32(14.2%); Type 3 – Hypoplastic AcoA: 32(14.2%); Type 4 - Unilateral hypoplastic PcoA: 26(11.5%); Type 5 - Unilateral hypoplastic PcoA and AcoA: 15(6.6%); Type 6 - Bilateral hypoplastic PcoAs, 52(23.1%); Type 7 - Bilateral hypoplastic PcoAs and hypoplastic AcoA: 37(16.4%).

A global chisquared test was used to compare across all 6 studies and pairwise chisquared tests were used to test for differences between each pair of studies; all comparisons were statistically significant (p=0.0000) indicating differences among the studies. Thereafter, a correspondence analysis was used to study the degree of similarities among the studies;
the resulting plot of the data in Table 1 is shown in Figure 3, the 6 studies are represented by filled circles and the 23 configurations are represented by unfilled circles.
**Discussion**

Correspondence analysis (Fig I) between the configurations in the variations of the CW in previous studies [2,16 -19] and the present study of diverse ethnic origins indicate, that studies reported from Sri Lanka (present study), Iran [19] and France [18] all have somewhat similar profiles, USA [2] is clearly distinct from the rest driven by marked differences in configuration numbers 11, 17, 19 and 22. These 4 configurations, 11, 17, 19, and 22 involve 2 or more hypoplastic arteries of the CW, in fact, 22.2% of USA2 [17] falls into these 4 configurations as compared to USA 1 [2] ; 4.8%, Morocco [16]; 2.9% France [18]; 2%, Iran [19] 1% and 0.8% in the present study. This is in contrast to Eftekhar et al., 2006 who studied CW of 102 male, deceased Iranian subjects and evaluated the distribution of configurations in the variations of the CW in different populations [2,16 -19]; they did not find any racial variation.

Table I reveals that there is a marked variation in CW among ethnic and racial populations. There exist several postulates as to the underlying reasons for the anatomical variation of the CW among which are, selection of cases: brains obtained from those who have died of causes unrelated to the brain in [16,19] and the present study, brains obtained from pathological or infarcted brains in [2] and in unselected cases in [17]. Gender: male and female cases were studied in [16] and the present study, male only in [19]. Other studies [2,17,18] had not mentioned the sex distribution of their cases.
The definition of hypoplasia was consistent in these studies [2, 16-19] but the diameter of component vessels of the CW has not been performed in all the studies [2,18]. Prevalence of the “typical” configuration in the present study is 14.2% in 225 brains examined as compared to studies reported in India: 26.8% in Maharashtra, India [21] 53.2% in South India, [22] and 45.20% in Chandigarh-Northwest India, [4] in 175, 357 and 1000 apparently normal brains examined respectively. The definition of hypoplasia was consistent in these studies [4, 21, 22] but the diameter of component vessels of the CW has not been performed in all the samples, and has not investigated the variations of CW as a whole. It is believed that Sri Lankans have a common origin from India, further studies are needed to ascertain reasons for the wide range in the prevalence of “typical” configuration between studies in India and Sri Lanka.

Correlation Coefficient between the configurations in the variations of the CW in previous studies [2,16,18,19] and the present study–of diverse ethnic origins–were significant for the Caucasian dominant (USA [2] and France [18]), African (Morocco) [16] (p < 0.05) and Asian (Iran [19] and present study from Sri Lanka) (p < 0.05) populations, excluding—Japan [3]—which was not significantly correlated with either study (p > 0.05).

, amplitude of neck movements,[18] hemodynamic factors,[23,24] postnatal development,[25]—and genetic factors. [26] have been considered. However, the methods and definition of hypoplasia differ among anatomical studies in the literature, which
may hamper the comparison of these studies. Establishing an international standard method for nomenclature on the variation and for quantitative measurement of the diameters of all the component vessels of the CW and quantitatively define hypoplasia would make it possible for comparison of data with studies in diverse populations.

Studies have also shown that there are variations in the incidence of cerebrovascular diseases in different ethnic or racial groups. Hospital-based prospective studies conducted at the National Hospital of Sri Lanka, in 1974 and in 1989 revealed that the incidence of stroke in young adults (aged 15–45 years) was 10.4% [27] and 33.6% [28] respectively. Hospital-based studies from India in 2001 stated that young-stroke (aged 15–45 years) accounted for (15%–30%) of all strokes.[29] The average age of patients in the developing countries with stroke is 15 years younger than in developed countries.[30] The reasons for these differences are not well-understood and the etiology of the majority of strokes in young adults in Sri Lanka is unexplained.[27,28,31,32] In a post mortem study in the below 40 year age group, 92% of patients with cerebral infarction has been due to occlusive arterial disease of large vessels due to nonatherosclerotic vasculopathy.[33] It has been reported that in Asians the incidence of intracranial atherosclerosis in the anterior circulation stroke is much higher compared to Caucasians.[27] Prevalence of posterior circulation stroke among Asians[28] also has been reported to be much higher as compared to the West.[29-31] Further studies are needed to ascertain the role of variations in the configurations of the of the CW in the
pathogenesis of cerebrovascular diseases in different ethnic or racial groups in the Indian subcontinent.
Conclusion

The present study reveals that there are marked variations in the circle of Willis among Caucasian dominant, African and Iran populations (p < 0.5), this is of clinical importance and warrants further studies to ascertain the influence of genetic, racial, regional, environmental and haemodynamic factors or a combination of any of the above.

The present study reveals that there are marked variations in the CW among intra and inter ethnic groups (Caucasian, African and Asian: Iran and Sri Lanka dominant populations, this is of clinical importance and warrants further studies to ascertain the influence of genetic, racial, regional, environmental and haemodynamic factors or a combination of any of the above keeping the methods of measurements, data assessment, and the definitions of hypoplasia the same.
List of abbreviations

AcoA  Anterior communicating artery
ACA  Anterior cerebral artery
A1  pre communicating part of ACA
A2  post communicating part of ACA
CW  circle of Willis
ICA  Internal carotid artery
PCA  Posterior cerebral artery
P1  pre communicating part (P1) of PCA
P2  post communicating part (P2) of PCA
PcoA  Posterior communicating artery

Competing interests

The author(s) declare that they have no competing interests.

Authors' contributions

KRDS carried out the data extraction, performed the analysis and drafted the manuscript.

RS helped out with the data extraction WSLG and RWJ supervised the study and participated in its coordination. DA did the statistical analysis. All authors read and approved the final manuscript.
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References


22. Reddy DR, Prabhakar V, Rao BD: **Anatomical study of circle of Willis.** *Neurology (India)* 1972, **20**: 8-12.

Table 1: comparison of the variations of the CW

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<td></td>
<td>Country</td>
<td>USA (1)</td>
<td>Iran</td>
<td>USA (2)</td>
<td>France</td>
<td>Morocco</td>
<td>Sri Lanka</td>
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<tr>
<td></td>
<td></td>
<td>Total brains</td>
<td>994</td>
<td>100</td>
<td>414</td>
<td>200</td>
<td>102</td>
<td>225</td>
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<td>1</td>
<td>Typical</td>
<td></td>
<td>192(19.3)</td>
<td>18(18)</td>
<td>20(4.8)</td>
<td>29(14.5)</td>
<td>29(28.4)</td>
<td>32(14.2%)</td>
</tr>
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<td>2</td>
<td>all segments hypoplastic</td>
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<td>54(5.4)</td>
<td>0(0)</td>
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<td>10(5)</td>
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<td>91(9.1)</td>
<td>11(11)</td>
<td>6(1.4)</td>
<td>9(4.5)</td>
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<td>88(8.8)</td>
<td>14(14)</td>
<td>24(5.8)</td>
<td>28(14)</td>
<td>20(19.6)</td>
<td>26(11.5%)</td>
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<td>41(4.1)</td>
<td>6(6)</td>
<td>12(2.8)</td>
<td>10(5)</td>
<td>4(3.9)</td>
<td>15(6.6%)</td>
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<td></td>
<td>126(12.6)</td>
<td>24(24)</td>
<td>131(31.6)</td>
<td>44(22)</td>
<td>28(27.4)</td>
<td>52(23.1%)</td>
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<td>67(6.7)</td>
<td>10(10)</td>
<td>58(14.0)</td>
<td>34(17)</td>
<td>4(3.9)</td>
<td>37(16.4%)</td>
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<tr>
<td>8</td>
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<td></td>
<td>38(3.8)</td>
<td>2(2)</td>
<td>0(0)</td>
<td>3(1.5)</td>
<td>0(0)</td>
<td>6 (2.6%)</td>
</tr>
<tr>
<td>9</td>
<td>Unilateral hypoplastic P1</td>
<td></td>
<td>47(4.7)</td>
<td>3(3)</td>
<td>4(0.9)</td>
<td>5(2.5)</td>
<td>1(0.9)</td>
<td>2(0.88%)</td>
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<td>33(3.3)</td>
<td>1(1)</td>
<td>16(3.8)</td>
<td>6(3)</td>
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<td>1(0.44%)</td>
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<td>2(0.2)</td>
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<td>10(2.4)</td>
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<td>20(2.0)</td>
<td>1(1)</td>
<td>1(0.2)</td>
<td>3(1.5)</td>
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<td>13</td>
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<td>5(0.5)</td>
<td>0(0)</td>
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<tr>
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<td>35(3.5)</td>
<td>4(4)</td>
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<td>4(2)</td>
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<td>6(2.6%)</td>
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<td>16(1.6)</td>
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<td>2(0.4)</td>
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<td>17</td>
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<td>26(2.6)</td>
<td>0(0)</td>
<td>46(11.11)</td>
<td>3(1.5)</td>
<td>2(1.9)</td>
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<td>A1 and bilateral hypoplastic PcoAs</td>
<td>58(5.8)</td>
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<td>6(3)</td>
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<td>4(1.7%)</td>
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<tr>
<td>19</td>
<td>hypoplastic PcoA, AcoA and contralateral P1</td>
<td>17(1.7)</td>
<td>1(1)</td>
<td>28(6.7)</td>
<td>1(0.5)</td>
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<td>hypoplastic P1, contralateral PcoA and ipsilateral A1</td>
<td>10(1.0)</td>
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<td>21</td>
<td>Bilateral hypoplastic P1s and AcoA</td>
<td>13(1.3)</td>
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<td>1(0.44%)</td>
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<td>22</td>
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<td>3(0.3)</td>
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<td>8(1.9)</td>
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<td>1(1)</td>
<td>8(1.9)</td>
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<td>1(0.9)</td>
<td>5(2.2%)</td>
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% is in ( )
Figure 3: Correspondence analysis plot of the data in Table 1. The plot is a 2-dimensional representation of the 23-dimensional Countries data (the 6 filled circles) together with a 2-dimensional representation of the 6-dimensional Configuration Types data (the 23 unfilled circles). One notable observation is that USA2 separates from the rest of the Countries; since the separation is in the same direction as the deviation of Configuration Types numbered (in order from right to left) 11, 22, 17 and 19 from the center of the plot, these are the Configuration Types most associated with this separation; the proportions contributing to the separation can be read off from Table 1.