Morphometry of the Middle Cerebral Arteries: A Radio-Anatomical Study Based on Computed Tomography Angiography Findings

INTRODUCTION

Middle cerebral artery (MCA), which is the thickest branch of internal carotid artery (ICA), is also an important artery associated with 20-43 % of all intracranial haemorrhages. While an occlusion in MCA is known to be the most common cause of ischemic stroke, the blockage of M1 segment of MCA may cause severe damage to the brain, and even death (Shi et al., 2010). It is reported that 86.2 % of MCA’s aneurysms occur in M1 segment of the artery (Brzegowy et al., 2018).

Although MCA infarction isn’t a rare condition, it is seen only in 0.9 % of acute stroke disease (Akiyama et al., 2001). However, studies have reported that when the irrigation area of MCA is considered, 30-66 % probability of death is reported (Hacke et al., 1996; Gürol & St Louis, 2008). In the case of a malignant MCA, this rate can go up to 80 % (Vahedi et al., 2007).

MCA, which has the largest irrigation area of the three main arteries known to feed the brain, is also the continuation of ICA in terms of calibration and course. The fact that it supplies blood to a large part of the brain, including a part of the frontal lobe and the lateral surface of the temporal and parietal lobes, causes serious clinical pictures in aneurysm...
using CTA images.

segment of MCA in patients with T2DM and hypertension by
aims to compare the morphometric characteristics of M1
morphology of T2DM and hypertensive patients. This study
conducted, no studies were found evaluating the MCA
et al
vascular wall and consequently predispose to stroke (Dolan
important pathologies which increase the tension of the
neuropathy. Nutrition of the brain is also affected by recurrent
nephropathy, angiopathy, retinopathy and peripheral
metabolic associated with chronic complications such as
cerebrovascular disorders in the chronic period of type 2 dia-
Iadecola, 2013). It is reported that there are frequent diabetic
by changing cerebral blood flow (Chobanian, 1992; Faraco &
These changes trigger or accelerate atherosclerosis formation
factor for stroke, has been reported to cause cerebrovascular
imaging. 80-100 ml low osmolarity non-ionic contrast ma-
section was placed on the reference image from the ‘region
scanning area was set from vertex to mentum. A single
mA for tube voltage, 64¥0.6 mm for collimation, 500 ms
contrast material is 100 ml. For CTA scanning, parameters
thickness of the device is 0,6 mm, and the amount of
CTA. The device was 256
double source spiral CTA. The device was 256
Germany double source spiral CTA. The device was 256
Simens Healthcare, Forchheim,
section multislice CT. Its dose is 120 kv 35 mA. Section
thickness of the device is 0,6 mm, and the amount of
contrast material is 100 ml. For CTA scanning, parameters
were adjusted as 120 kv for tube voltage for Simens, 200
mA for tube voltage, 64¥0.6 mm for collimation, 500 ms
for gantry turnaround time, 0.6 mm for section thickness.

The patient was laid on the table in supine position
with the head in the front and the arms on the sides. The
scanning area was set from vertex to mentum. A single
section was placed on the reference image from the ‘region
of interest’ design to aorta by using the ‘Bolus tracking’
method and the threshold was adjusted as 100 HU to start
imaging. 80-100 ml low osmolarity non-ionic contrast ma-
terial was injected to the median cubital vein with an
automatic pump with an injection rate of 4-5 ml/sec and
following the contrast material, 40 ml physiological saline
solution was injected for homogeneous distribution.

MCA has 4 main segments:

M1 (sphenoidal) segment: It is parallel to sphenoid canal,
it has a posterior course.
M2 (insular) segment: It progresses in insula.
M3 (opercular) segment: It progresses over frontal, parietal
and temporal opercula.
M4 (cortical) segment: It progresses in lateral fissure and spreads to the cortex in the lateral side of frontal, parietal and temporal lobes. MCA has central (perforating) and cortical branches throughout the course mentioned above (Brzegowy et al., 2018).

The following parameters were measured bilaterally by performing vascular analysis and using 3D images so that vascular residue does not affect measurement:

1. Length of M1 measured bilaterally from the internal carotid artery division to the M1 bifurcation,
2. Diameter of M1 in the middle section of the artery. Figure 1 shows measurement parameters.

In the literature, it is stated that the normal limit of the length value of the M1 segment of the MCA is 15-17 mm, while the normal limit of the diameter measurement is 2.4-4.6 mm (Özsoy et al., 2007).

**Ethical consideration.** Malatya Clinical Researches Ethical Board (2020/1377).

**Data Analysis.** The data were transferred to the screen for radiological analysis. All radiological measurements determined were performed and recorded by a single specialist radiologist. The images taken were started to be evaluated from axial sections. They were then analysed in each of the three planes (axial, sagittal, coronal) by using maximum intensity projection images.

**Statistical Analysis.** The compliance of data to normal distribution was examined with Kolmogorov Smirnov test and it was found that the data were not normally distributed. For data which were not normally distributed, median and minimum (min) and maximum (max) values were given. Mann Whitney U test was applied to the data to compare the parameters of male and female patients in the same group. Kruskall Wallis H test was applied to the data to compare the parameters of the patients between the groups. Post Hoc Mann Whitney U test and paired comparisons were conducted to find out from which groups the difference between the groups originated from. Post Hoc test was given as Model Viewer table. p<0.05 values were considered as statistically significant. IBM SPSS Statistics 22.0 for Windows program was used in statistical analyses.

**RESULTS**

85 women (42.5 %) and 115 men (57.5 %) were included in the study; mean age of women was found as 57.25±1.1, while mean age of men was found as 59.39±0.7.

In our study, the normal limit of MCA M1 segment length measurement was 23 % on the right and 22 % on the left; The normal limit of the diameter measurement was determined as 79 % on the right and 80 % on the left (Table I).

Fig. 1. M1 Segment of MCA (A: Starting point of M1 segment, B: midpoint of M1 C: End of M1 segment).
In CTA assessments, M1 segment diameter of right MCA was found to be larger in men when compared with women in Group 4 (p<0.05) (Table II).

According to the results of Kruskal Wallis test used for the M1 segment diameter and segment length measurements of MCA between groups in female and male patients, statistically significant difference was found in bilateral MCA M1 segment diameter measurement in the comparison of female and male patients between the groups (p<0.05), while no statistically significant difference was found in segment length (p>0.05) (Table III).

In parameters which were found to be statistically significant in terms of the result of Kruskal Wallis test, Mann-Whitney U test was conducted as post hoc test to find out which group the difference resulted from. According to the analysis results, difference was found between group 1 and group 2 and group 4 in right MCA M1 segment diameter measurements of male patients, while difference was found between group 3 and group 2 and group 4 in left MCA M1 segment diameter measurements. In female patients, difference was found between group 3, group 2, group 1 and group 4 in right MCA M1 segment diameter measurements and between group 3 and group 2 and group 4 in left MCA M1 segment diameter measurements (p<0.05) (Fig. 2).

Table I. Occurrence of the value ranges of the diameter and segment lengths of the M1 segment of the MCA

<table>
<thead>
<tr>
<th>Parameters (mm)</th>
<th>Right M1 Segment</th>
<th>Left M1 Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>LENGTH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;15</td>
<td>%31</td>
<td>%29</td>
</tr>
<tr>
<td>15-17</td>
<td>%23</td>
<td>%22</td>
</tr>
<tr>
<td>&gt;17</td>
<td>%47</td>
<td>%49</td>
</tr>
<tr>
<td>D. AMAT ERS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;2.4</td>
<td>%21</td>
<td>%20</td>
</tr>
<tr>
<td>2.4-4.6</td>
<td>%79</td>
<td>%80</td>
</tr>
<tr>
<td>&gt;4.6</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table II. Comparison of M1 segment diameter and segment length measurements of MCA between groups in female and male patients according to groups.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Parameters (mm)</th>
<th>Female</th>
<th>Male</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median (min - max)</td>
<td>Median (min - max)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>Right M1 Dia.</td>
<td>2.6 (2.3-3.2)</td>
<td>2.8 (2.3-3.2)</td>
<td>0.277</td>
</tr>
<tr>
<td></td>
<td>Left M1 Dia.</td>
<td>2.6 (2.3-7.1)</td>
<td>2.7 (1.9-3.4)</td>
<td>0.548</td>
</tr>
<tr>
<td></td>
<td>Right M1 Len.</td>
<td>15 (2.6-22.6)</td>
<td>16 (11.4-24.2)</td>
<td>0.208</td>
</tr>
<tr>
<td></td>
<td>Left M1 Len.</td>
<td>15.8 (2.4-23.4)</td>
<td>16.3 (8-22.7)</td>
<td>0.524</td>
</tr>
<tr>
<td>Group 2</td>
<td>Right M1 Dia.</td>
<td>2.4 (2.1-2.9)</td>
<td>2.4 (2-3.1)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Left M1 Dia.</td>
<td>2.5 (1.9-2.7)</td>
<td>2.5 (2.2-3.1)</td>
<td>0.405</td>
</tr>
<tr>
<td></td>
<td>Right M1 Len.</td>
<td>15.5 (12.2-18.6)</td>
<td>16.7 (11.3-21.9)</td>
<td>0.315</td>
</tr>
<tr>
<td></td>
<td>Left M1 Len.</td>
<td>17.1 (10.1-24.4)</td>
<td>16.8 (12-22.5)</td>
<td>0.840</td>
</tr>
<tr>
<td>Group 3</td>
<td>Right M1 Dia.</td>
<td>2.4 (1.6-3.2)</td>
<td>2.5 (2-3)</td>
<td>0.139</td>
</tr>
<tr>
<td></td>
<td>Left M1 Dia.</td>
<td>2.5 (1.6-3)</td>
<td>2.5 (1.9-3.3)</td>
<td>0.086</td>
</tr>
<tr>
<td></td>
<td>Right M1 Len.</td>
<td>14.9 (10.2-21.2)</td>
<td>15.9 (7.2-26.4)</td>
<td>0.250</td>
</tr>
<tr>
<td></td>
<td>Left M1 Len.</td>
<td>16.1 (8.7-18.5)</td>
<td>14.8 (5-23.4)</td>
<td>0.751</td>
</tr>
<tr>
<td>Group 4</td>
<td>Right M1 Dia.</td>
<td>3 (2.5-3.4)</td>
<td>2.6 (2.2-3.5)</td>
<td>0.004*</td>
</tr>
<tr>
<td></td>
<td>Left M1 Dia.</td>
<td>3 (2.5-3.7)</td>
<td>2.7 (2.4-3.3)</td>
<td>0.081</td>
</tr>
<tr>
<td></td>
<td>Right M1 Len.</td>
<td>16.9 (7.6-19.9)</td>
<td>16.8 (12.4-22.1)</td>
<td>0.524</td>
</tr>
<tr>
<td></td>
<td>Left M1 Len.</td>
<td>16.8 (9.7-19.4)</td>
<td>17.6 (14-21.1)</td>
<td>0.251</td>
</tr>
</tbody>
</table>

* = Significant differences at the p<0.05 level; M1 Dia. = Arteria cerebri media diameter; M1 Len. = Arteria cerebri media length.

Table III. Comparison of M1 segment diameter and segment length measurements of MCA between groups.

<table>
<thead>
<tr>
<th>Parameters (mm)</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median (min-max)</td>
<td>Median (min-max)</td>
<td>Median (min-max)</td>
<td>Median (min-max)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>Right M1 Dia.</td>
<td>2.8 (2-3.2)</td>
<td>2.4 (2-3.1)</td>
<td>2.5 (2-3)</td>
<td>2.9 (2.2-3.5)</td>
</tr>
<tr>
<td></td>
<td>Left M1 Dia.</td>
<td>2.7 (1-3.4)</td>
<td>2.5 (2.2-3.1)</td>
<td>2.5 (1.9-3.3)</td>
<td>2.9 (2.4-3.3)</td>
</tr>
<tr>
<td></td>
<td>Right M1 Len.</td>
<td>16 (11.4-24.2)</td>
<td>16.7 (11.3-21.9)</td>
<td>15.9 (7.2-26.4)</td>
<td>16.8 (12.4-22.1)</td>
</tr>
<tr>
<td></td>
<td>Left M1 Len.</td>
<td>16.3 (8.2-22.7)</td>
<td>16.8 (12.2-22.5)</td>
<td>14.8 (5-23.4)</td>
<td>17.6 (14.1-21.1)</td>
</tr>
<tr>
<td>Female</td>
<td>Right M1 Dia.</td>
<td>2.6 (2-3.2)</td>
<td>2.4 (2.1-2.9)</td>
<td>2.4 (1.6-3.2)</td>
<td>3 (2.5-3.4)</td>
</tr>
<tr>
<td></td>
<td>Left M1 Dia.</td>
<td>2.6 (2.3-7.1)</td>
<td>2.5 (1.9-2.7)</td>
<td>2.5 (1.6-3)</td>
<td>3 (2.5-3.7)</td>
</tr>
<tr>
<td></td>
<td>Right M1 Len.</td>
<td>15 (2.6-22.6)</td>
<td>15.5 (12.2-18)</td>
<td>14.9 (10.2-21)</td>
<td>16.9 (7.6-19.9)</td>
</tr>
<tr>
<td></td>
<td>Left M1 Len.</td>
<td>15.8 (2.4-23)</td>
<td>17.1 (10.1-24)</td>
<td>15.1 (8.7-18.5)</td>
<td>16.8 (9.7-19.4)</td>
</tr>
</tbody>
</table>
The aim of this study was to find out whether there were differences between MCA M1 segment diameter and length measurements of hypertensive patients (Group 1), T2DM patients (Group 2), patients with hypertension and T2DM (Group 3) and healthy control group (Group 4). In retrospective morphometric assessments between groups on CTA images of individuals, it was found that there were no statistically significant differences between the bilateral M1 segment diameters of both women and men. As a result of the post hoc analysis performed to find out which group the difference resulted from, it was concluded that right and left M1 segment diameters of group 1, group 2 and group 3 were different from those of group 4 in both sexes. Malignant MCA infarct is an important clinical picture of cerebral circulation that causes death in 70-80% of the cases; moreover, it is associated with long-term disability in survivors. Since aneurysms are frequently seen in areas with branching in MCA, it is important to have information about different artery models, especially for aneurysm-related surgeries.

Hypertension causes hypertrophic formation in cerebral veins, leading to an increase in vascular wall volume, an increase in wall thickness and a decrease in vascular lumen. Hypertension may also cause hardening of the large arteries in the brain, leading to cognitive disorders (Faraco & Iadecola, 2013).

Although there are limited number of studies comparing hypertensive and normotensive individuals, increase in lumen diameter and wall-to-lumen ratio in MCA associated with high blood pressure has been reported in hypertensive rat models (Rigsby et al., 2007). Another experimental study which reported that chronic hypertension causes vascular remodelling in artery wall during the process also supports this information (Pires et al., 2010).

In our study, it was concluded that bilateral M1 diameters of hypertensive patients was statistically narrower than those of the control group. This information supports the literature reviewed. It was concluded that M1 diameter

Fig. 2. Post-Hoc test results of vessel diameter in male and female patients (*: Significant differences at the p<0.05 level, **: Significant differences at the p<0.01 level; M1 diameter: right Arteria Cerebri Media; A and B = female patients; C and D = male patients.)
of group 3 was narrower when compared with that of group 4. Although M1 length measurement of group 3 was shorter than the other groups, this difference was not statistically significant. In literature, short M1 segment of MCA is reported as an important condition that increases the risk of aneurysm (Zurada et al., 2010).

The International Diabetes Federation estimated that 1 in 11 adults aged 20–79 years (415 million adults) had diabetes mellitus globally in 2015. Over 90% of diabetes mellitus cases are T2DM (International Diabetes Federation, 2015). Studies which report that the probability of T2DM associated vascular diseases to cause mortality and morbidity was 80%, T2DM increased the risk of stroke 1.5-3 times and increased short and long term mortality after stroke show the importance of vascular remodelling in T2DM (He et al., 2010).

In their study, Tchistiakova et al. (2014), used magnetic resonance imaging technique to find out how T2DM and hypertension together affected brain vascularization and concluded that in T2DM and hypertension comorbidity, especially hypertension could increase tendency for cerebrovascular event. Huang et al. (2020), reported that when compared with healthy individuals, T2DM patients had higher plaque prevalence, maximum plaque length, maximum wall thickness and maximum lumen stenosis.

Patients with T2DM have increased incidence of atherosclerotic cardiovascular, peripheral arterial and cerebrovascular disease. Comorbidity of hypertension is frequent in patients with T2DM and this can affect cerebrovascular anatomy (Deng et al., 2012). It is thought that insufficient hypertensive control accompanying T2DM makes macro and micro vascular complications more severe and vascular and structural anomalies worse. However, it was concluded in our study that there were no statistically significant differences in diameter and segment length of M1 in group 2 and group 3. This result may show that our patients have sufficient hypertension control.

In our study, it was concluded that in addition to having narrower M1 segment diameter than the control group, group 2 and group 3 also had narrower M1 segment diameter than group 1, which consisted of only hypertensive individuals. We believe that this situation is a result of the fact that the damage of T2DM to vascular structures is more severe when compared with hypertension.

Elevated HT rates in both men and women are closely associated with increased obesity rates. Currently, up to 70% of essential HT cases are associated with T2DM. T2DM affects vascularity in cerebral vessels and causes important conditions such as stroke (Faulkner & Belin de Chantemèle, 2018). In our study, the rate of CVO in the Group 3 group was found to be 32%.

**CONCLUSION**

In the literature, morphometric studies on MCA focus on radiological imaging studies in the presence of plaque or symptomatic sclerosis and it can be seen that there is a deficiency in comparing the length and diameter of M1 segment of MCA with healthy control group in conditions such as hypertension and T2DM. Cerebrovascular Event (CVO) rates of the patients were found to be 23% in Group 1, 27% in Group 2, and 32% in Group 3.

As a result of our study, it was concluded that the diameter of M1 segment of MCA was narrower in female and male hypertensive and T2DM patients when compared with healthy control group, while there were no differences in length. We believe that the results found will be a guide while evaluating the changes in MCA in hypertension and T2DM diseases and will increase the level of micro-anatomic information on surgical treatment of this artery.
M1 derecho e izquierdo del grupo 1, grupo 2 y grupo 3 fue diferente del grupo 4 en ambos sexos (p<0.05). Creemos que este estudio será una guía en las evaluaciones anatómico-radiológicas y también mejorarás el nivel de información microanatómica en el tratamiento quirúrgico al mostrar los cambios morfométricos que ocurren en el segmento M1 de la ACM en las enfermedades con DM2.

PALABRAS CLAVE: Arteria cerebral media; Angiografía por tomografía computarizada; Diabetes mellitus tipo 2; Hipertensión.

REFERENCES


Corresponding author:
Dr. Rukiiye Çiftçi
Gaziantep Islam Science and Technology University
Department of Anatomy
Gaziantep
TURKEY

E-mail: rukiiyekeseiftci@hotmail.com

Rukiye ÇIFTÇI: rukiyyekeseiftci@hotmail.com Orcid Id: 0000-0002-5894-5256
Sayed Toy: sayematoy@karabuk.edu.tr Orcid Id: https://orcid.org/0000-0002-6067-0087
Hilal Er Ulubaba: erhilal44@yahoo.com Orcid Id: 0000-0003-2124-4525
Deniz S Enol: denizanatomi@gmail.com Orcid Id: 0000-0001-6226-9222T
Fahri Safa CINARLI: safacinarli@gmail.com, https://orcid.org/0000-0002-7552-367X
Ahmet Sigircı: ahmet.sigirci@inonu.edu.tr Orcid Id: https://orcid.org/0000-0001-9221-0002