Multiphasic computed tomography angiography and perfusion computed tomography in acute ischemic stroke: an atlas of M2-M3 segments occlusions and related vascular territories

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Aims and objectives

Abbreviations used:

MCA: middle cerebral artery
ED: emergency department

A correct diagnosis of cerebral ischemic stroke, can not be separated from a careful anatomical evaluation of the cerebral arterial branches involved. Although human anatomy seems an "acquired" result of modern medicine, it still leaves some doubts about the correlation between levels of average cerebral artery occlusion (in particular the distal branches at M1) and the areas of cerebral parenchymal ischemia involved.

MCA is divided into a proximal (M1) and a distal (M2 and beyond). M1 has a caliber of about 3.5 mm and originates from the bifurcation of the AIC and ends (usually) forking and giving rise to the M2 segment. Two groups of vessels start from it: the superolateral group consisting in the uncal artery, the polar temporal artery and the anterior temporal artery and the inferomedial artery formed by the lenticulostrate arteries. More problems arise when we talk about the M2 segment. Extremely heterogeneous in its constitution, it can have at its origin a bifurcation (more common), a trifurcation, a dominant branch, an early insertion, etc.. It has a caliber inferior to M1, though in modern literature it is commonly accepted its origin to the bifurcation of M1, some authors tend to identify it not from this point but more distally, that is starting from the beginning of the vertical section of MCA in the sulcus of insula. Subsequently, after a loop, it continues in the silvian slot with the opercular segment or M3. The last tract, called cortical segment or M4, consists of the branches emerging from the silvian fissure on the convex surface of the hemisphere.

Multiphasic computed tomographic angiography (mCTA) and perfusion computed tomography (pCT) are increasingly being adopted to evaluate collateral circulation and ischemic core during ischemic stroke. However, little information is available on the capabilities in the detection of thromboembolism in smaller arteries distal to M1 segment of the middle cerebral artery (MCA).

Given the lack of ubiquitously adopted nomenclature of such arterial segments, a brief - yet comprehensive - review of most used definitions will precede to present existing differences in neuroradiological literature, mainly depending on the different historical attitude of interventional operators on brain vasculature: anatomic dissection for (micro-)surgery vs catheter-angiography for endovascular operators.
The purposes of this Presentation are:

- to review literature and explore main different nomenclature systems with regard to arterial vessels distal to M1 main trunk, thus showing possible overlapping definitions between different systems;

- to present diagnostic accuracy of mCTA in the detection of acute occlusions in the M2-M3 segments of MCA;

- based on a single-centre experience, to trace a comprehensive atlas of cerebral M2-M3 vascular territories at pCT, with or without collateral pial flow activation.
Methods and materials

- Literature was reviewed, including both anatomical/microsurgical studies and works focused on endovascular procedures; search expressions "M2 OR distal AND cerebral AND artery OR segment"

- Starting from a single-centre experience as "Hub" Stroke Center Hospital, mCTA and pCT of more than five hundred consecutive Patients admitted for ischemic stroke were reviewed. All examinations were performed at Emergency Department immediately after neurological complete evaluation, employing a 64-slices multidetector CT scanner. Every patient underwent non-contrast CT of the head, mCTA (using 50 mL of iodine contrast medium bolus at 5 mL/s, scan width 1.25 mm) of epiaortic and intracranial arteries and two subsequent 4-seconds--delayed phases from skull base to vertex, pCT conducted with a section 5 mm, 16 images per scan, total number of scans 28 during injection of 50 mL of iodine contrast medium bolus at 5 mL/s.

Inclusion criteria for this study were:

- the diagnosis of acute occlusion distal to M1 trunk segment of MCA, as seen from first CTA examination in the Emergency Department, before any other subsequent imaging (magnetic resonance and/or catheter-angiography).
- Patients were excluded if a thromboembolism of a proximal intracranial or extracranial vessel was present.

Single-center series: atlas of cerebral vascular territories

Based on the above mentioned selected population, a pictorial review of all cases was carried out. For every Patient, at least two imaging examinations were included:

- from CT performed at ED as first-level stroke evaluation

- baseline (non-contrast) head CT: early ischemic signs
- mCTA: source axial images and/or 3-dimensional volume-rendering reconstructions of intracranial arterial vessels
- pCT: reconstructed maps of Mean Transit Time (MTT) and Tmax

- from CT performed at followup (3-months where available, in other case at 3 to 14 days from stroke onset).
Results

Review of nomenclature

Review of literature brought differences in denomination of some MCA portions distal to the trunk of M1 segment. In particular, the following portion showed controversial nomenclature:

- **M1 segment**: inner portions may be distinguished as **proximal** and **distal trunk, pre-bifurcation** and **post-bifurcation** segment; **pre-insular/insular** M1 divisions.

- **M2 segments**: trunk; **M2 divisions and branches**; **M2 insular (ascending and descending) portions**.

In our research, more agreement was found in consulted literature for defining of arterial vessels going through cerebral opercula as **opercular branches**, though these may be found labeled as **M3** (more commonly) or **M4** (less commonly); accordingly, agreement also resulted in the term **M4** (more commonly) of **cortical branches** going from external limit of opercula toward cerebral vertex, through cerebral convexity.

As far as M1 and M2 segments are regarded, a detailed review of each arterial portion is brought, with focus on possible nomenclature used for each of them. For educational purpose, variety between different works have been categorized into two main groups, the former ("A") oriented to a more traditional view based on anatomic dissection studies and mainly referred to by (micro-) surgical work groups; the latter ("B") includes approaches which have gained more favor in clinical parlance, mainly due to their derivation from neuro-interventional angiographic / endovascular terminology. (Fig. 1 on page 9)

- **from origin of MCA (originating from intracranial end of ICA) to origin of Anterior Temporal Artery (ATA)**
  - Most used nomenclature: **M1 segment, (main) trunk** ["A" system]
  - Other nomenclature: **M1 segment, proximal portion** [" Fig. 2 on page 9 ]

Vessel originating from this segment:

- **Lenticular striatal arteries** (LSAs)
• from origin of ATA to genu of MCA (more commonly at the same site of bi-/trifurcation of MCA and at the limen insulae)
  • Most used nomenclature: M1 segment, distal portion ["A" and "B" systems]
  • When a Holotemporal vessel (i.e. a branch originating from M1 segment, giving itself origin to the ATA and does not divide until it gives branches for the posterior parietal region, thus functioning as "Posterior Parietal Artery") is present (11% of stroke patients in a reported study) a M2 trunk may be defined ["B" system]
  • Note: in a less common proportion of cases, bi-/trifurcation occurs early, so that divisions of MCA are directly involved in the "genu" (literally knee)

This segment divides into 2 to 4 divisions (bi-/tri-(rare) quadrifurcation of MCA). Most common pattern is bifurcation with distinction of a dominant division; also codominance may be the case, regardless from the number of MCA divisions.

• Main divisions of the previous segment, from genu of MCA
  • Most used nomenclature: M2 segment, main divisions (2 to 4 vessels) ["B" ]
  • Less used: M1 segment, main divisions (proximal to central sulcus)
  • When MCA bi-/trifurcation occurs early (before limen insulae), pre-insular segments may be distinguished from insular segments; pre-insular may be referred to as post-bifurcation M1 segments ["A" system] or M2 segments; insular segments are usually referred to as M2.

• Insular vessels (from central sulcus to cerebral opercula)
  • Most used nomenclature: M2 segments [Both "A" and, usually, "B" systems]
  • Less commonly referred to as M3 (insular) segments ["B" system]

These vessels (see Fig. 3 on page 10 ) may give origine to further divisions and perforating branches, in extremely variable manners.

• Opercular vessels (passing through cerebral opercula)
  • Usually labeled as M3 (opercular) segments [Both "A" and "B" systems]
• Less commonly referred to as M4 (opercular) segments ["B" system]

• Cortical vessels (passing through cerebral cortex)
• Usually labeled as M4 (cortical) segments ["A" systems - these vessels are less taken into main consideration from a "B" system perspective]

These vessels give origin to perforating branches and cerebral arterioles.

Single-center series: aggregated data

As for the experience at our Institution, M2-M3 occlusions were diagnosed in 33 Patients. In 3 Patients, mCTA promptly demonstrated delayed contrast enhancement and wash-out in the occluded vessels, later confirmed by catheter-angiography.

Single-center series: atlas of cerebral vascular territories

pCT resulted in an atlas of M2-M3 vascular territories. A representative case of such atlas is brought in the following figures (3 to 8). A complete map of vascular territories beyond occluded M2-M3 vessels is still under development.
Fig. 1: Schematic representation of vascular anatomy of middle cerebral artery, as defined in text as "Modality A"

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Fig. 2: Schematic representation of vascular anatomy of middle cerebral artery, as defined in text as "Modality B"

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**Fig. 3:** Schematic diagram of M2 insular segments as most commonly denominated.

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**Fig. 4:** Non contrast CT scan of a 38 year-old patient presenting with aphasia and hemiplegia of right limbs. Early ischemic signs in left temporal-parietal lobes.

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Fig. 5: MTT reconstructed maps of a 38 year-old patient presenting with aphasia and hemiplegia of right limbs. Perfusional deficits in left temporal-parietal lobes.

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Fig. 6: Tmax reconstructed maps of a 38 year-old patient presenting with aphasia and hemiplegia of right limbs. Perfusional deficits in left temporal-parietal lobes.

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Fig. 7: 3D reconstructed intracranial vessels of a 38 year-old patient presenting with aphasia and hemiplegia of right limbs. Occlusion of a M2 division of the left MCA.

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**Fig. 8:** 3-days followup CT scan of a 38 year-old patient presenting with aphasia and hemiplegia of right limbs. Subacute ischemic lesion in the upper parietal lobe, after successful revascularisation therapy.

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Conclusion

- Given some limitations (retrospective design, lack of correlation with clinical outcome and nervous tissues state assessed with perfusional imaging), the result of this single-center study confirmed the role of multimodal CT in the ischemic stroke triage, by indentifying M2-M3 occlusion and vascular territories, in respect of collateral pial circulation, thus suggesting an emerging role in future diagnostic studies and as a tool to be implemented in controlled clinical studies.

- The depicted review of literature, although not conducted with systematic methods, focused on definitions of M1/M2 segments of MCA, showing heterogeneity and, to some extent, overlap of some terms currently used with slightly variable meaning (M1 segment: distal portion; post-bifurcation M1 portion; trunk of M2; pre-insular, insular M2 segments). Nevertheless, some anatomical references (Lenticular-striatal arteries; Anterior temporal artery; Insular, Opercular and Cortical arterial segments) are constantly taken as defining limits between differently named structures, among consulted nomenclature systems.
References


