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Differences in Local Connected Fractal Dimension (LCFD) Between Native and EDAS Surgery Induced Collaterals

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Learning Objectives

To differentiate anatomical characteristics of native versus surgical collaterals and gain insight in the mechanism of vessel formation after encephaloduroarteriosynangiosis (EDAS)

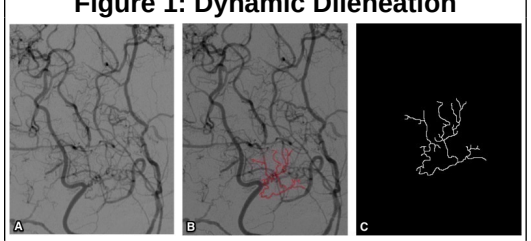
Introduction

EDAS generates new collateral vessels from the external carotid artery to the cerebral circulation in patients with intracranial atherosclerosis (ICAS) and moyamoya disease (MMD).

The mechanisms involved in these neoangiogenesis process are not well understood.

Contrary to native collaterals formed by arteriogenesis, angiogenic mechanisms involve local hypoxia, sprouting, and splitting of vascular structures, leading to a complex branching pattern. We hypothesize that if angiogenesis is the leading mechanism of neovascularization after an EDAS, the angioarchitecture of EDAS collaterals should have greater complexity, manifesting as higher fractal connectivity when compared to native collaterals.

Figure 1: Dynamic Dileneation



A: Selective postoperative ECA lateral injection, B: Branches of STA traced and marked, C: Binary image

Methods

Pre and postoperative digital subtraction angiograms (DSA) were analyzed in patients enrolled in a prospective trial of EDAS surgery.

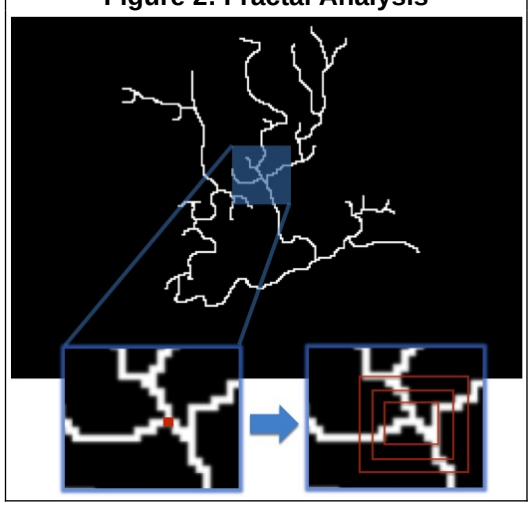
Images were processed using Image J and the Fraclac plugin.

Identified collaterals were isolated by dynamic delineation (figure 1), where selected vessels were followed through the arterial phases of the DSA to establish the continuity of vessels, which were traced and marked, excluding any other overlapping and/or underlying vessels.

LCFD is a fractal analysis that provides an index of complexity by measuring changes in connectivity with varying scales, allowing quantification of non Euclidean geometric patterns.

High fractal connectivity was defined as LCFD greater or equal to 1.2.

Figure 2: Fractal Analysis



Fraclac measures LCFD score by selecting a seed (pixel in the traced vessel), and measuring the total number of connected pixels within a predetermined box. Process is repeated with boxes of increasing sizes and the rate of change of connected pixels is used to calcuated the LCFD. Process is repeated for each pixel, and the average LCFD score is obtained. (Figure 2)

Results

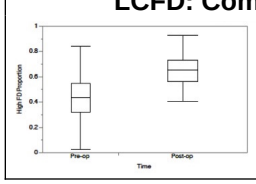
73 angiograms (27 pre-, 46 post-operative) were analyzed.

Study population included 42 patients (69% female), age 4-84 (mean 35, SD 19.2). There were 21 patients with ICAS and 21 with MMD groups.

EDAS collaterals had significantly higher mean LCFD peaks. In general, peak LCFD in innate collaterals was 1.17 (SD 0.1) vs 1.24 (SD 0.08) in EDAS collaterals, P<0.001. In ICAS patients peak LCFD was 1.12 (SD 0.07) vs 1.22 (SD 0.1), P<0.001. In MMD patients peak LCFD was 1.20 (SD 0.11)vs 1.25 (SD 0.07), P=0.04.

The proportion of high fractal connectivity in EDAS collaterals for the complete cohort was significantly higher, mean high LCFD in EDAS collaterals: 0.65 (SD:0.11) vs innate collaterals: 0.47 (SD:0.17), P<0.001.

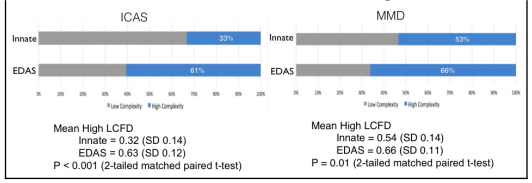
LCFD: Complete Cohort



Mean High LCFD
Innate = 0.47 (SD 0.17)
EDAS = 0.65 (SD 0.11)
P < 0.001 (2-tailed unpaired t test)

For matched groups, EDAS collaterals had significantly greater proportion of high fractal connectivity in both ICAS group (P<0.001) and MMD group (P=0.01).

LCFD: Matched Groups



Mean High LCFD
Innate = 0.32 (SD 0.14)
EDAS = 0.63 (SD 0.12)
P < 0.001 (2-tailed matched paired t-test)

Mean High LCFD
Innate = 0.54 (SD 0.14)
EDAS = 0.66 (SD 0.11)
P = 0.01 (2-tailed matched paired t-test)

Conclusions

Collaterals formed after EDAS have higher local connected fractal dimension (LCFD) compared to innate collaterals in ICAS and MMD patients

Higher LCFDs in EDAS collaterals are consistent with the greater complexity expected in vascular sprouting and splitting associated with angiogenesis

Lower LCFDs in innate collaterals suggest arteriogenesis as the primary mechanism of spontaneous collateral formation both in ICAS and MMD.

References

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