Towards a new geometric approach to assess the risk of rupture of abdominal aortic aneurysms using patient specific modelling

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INTRODUCTION

An abdominal aortic aneurysm (AAA) is an abnormal ballooning of a section of the aorta due to the weakening of the arterial wall (Fig. 1).

Recent patient specific stress analysis [1] has shown that the surgeon’s use of Maximum Transverse Diameter (MTD) as a criterion to decide on elective surgery is inaccurate and unreliable.

Theoretical considerations suggested that a geometric parameter called "Gaussian Curvature" (GC) best captures AAA geometric characteristics. The aim of this study was to examine whether GC could be used as a surrogate for wall stresses in predicting the risk of aneurysm rupture.

HYPOTHESIS

- Gaussian Curvature measures the distortion of a surface in space.
- Surfaces that share the same GC can be transformed into one another without any distortions of distances on the surface (Fig. 2a).
- Transformation of a plane into an aneurysmal geometry inevitably results in distortions on the surface which in turn gives a unique stress distribution on the surface (Fig. 2b).

It is proposed that there exists a direct relationship between an aneurysm’s stress field and its corresponding GC.

METHODS

The patient specific AAA geometry of six patients was reconstructed from their CT scans (Fig. 3). The AAA outer wall was outlined by points. The resulting point cloud was splined by lines creating surfaces and volumes.

The Finite Element Method (FEM) was used to construct a 3-D mesh over the aneurysm’s surface. All AAA models were subjected to a peak systolic internal pressure force of 120 mmHg. The FEM procedure was used to compute the aneurysm’s stress fields.

The GCs over the AAA surfaces were calculated by parameterization of the aneurysms’ surface elements.

RESULTS AND DISCUSSION

Stress distributions of all six aneurysms were compared with the corresponding GCs (Fig. 4). The aneurysms’ maximum stress spots occurred on the inside posterior walls and coincided with points of extrema in GC.

Either regions of local maxima or regions of local minima in GC coincide with high stress levels depending on the aneurysm’s intrinsic geometry.

All six patient specific aneurysms could be classified into two groups:

- Group 1: The aneurysm geometry is such that hyperbolic points (negative GC) correlate with high stress levels (e.g. patients A and B).
- Group 2: The aneurysm geometry is such that elliptic points (positive GC) correlate with high stress levels (e.g. patient C).

GC was correlated with effective stress for patient A along circumferential slices at three different positions; one near the proximal neck and two near the distal side (Fig. 5).

Rupture potentials were estimated using material strength data of pig arteries [3]. Group 1 aneurysms showed highest rupture potentials along the circumference indicating longitudinal tears in case of rupture. Group 2 aneurysms facilitated highest rupture potentials in the longitudinal direction which would give rise to circumferential tears.

CONCLUSION

- A novel methodology was developed by which an aneurysm’s rupture potential may be assessed from its GC distribution.
- Our hypothesis has been validated using a comparative study between stress distributions and GC for six patients.
- Our methodology has the potential to become a standardised method in patient specific screening studies and thus aid in the surgeon’s judgement.

REFERENCES