Data Article

Image, geometry and finite element mesh datasets for analysis of relationship between abdominal aortic aneurysm symptoms and stress in walls of abdominal aortic aneurysm

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ARTICLE INFO

ABSTRACT

These datasets contain Computed Tomography (CT) images of 19 patients with Abdominal Aortic Aneurysm (AAA) together with 19 patient-specific geometry data and computational grids (finite element meshes) created from these images applied in the research reported in Journal of Surgical Research article "Is There A Relationship Between Stress in Walls of Abdominal Aortic Aneurysm and Symptoms?"[1].

The images were randomly selected from the retrospective database of University Hospitals Leuven (Leuven, Belgium) and provided to The University of Western Australia's Intelligent Systems for Medicine Laboratory. The analysis was conducted using our freely-available open-source software BioPARR (Joldes et al., 2017) created at The University of Western Australia. The analysis steps include image segmentation to obtain the patient-specific AAA geometry, construction of computational grids (finite element meshes), and AAA

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stress computation. We use well-established and widely used data file formats (Nearly Raw Raster Data or NRRD for the images, Stereolitography or STL format for geometry, and Abaqus finite element code keyword format for the finite element meshes). This facilitates re-use of our datasets in practically unlimited range of studies that rely on medical image analysis and computational biomechanics to investigate and formulate indicators and predictors of AAA symptoms.

Specifications table

Subject	Biomedical Engineering
Specific subject area	Computational Biomechanics, Stress Analysis
Type of data	Image
	Geometry
	Finite element meshes
How data were acquired	IMAGE ACQUSITION
	Computed Tomography (CT)
	INSTRUMENTS
	Patients 3, 5, 10, 13, 14, 15, 17, 18, 19 and 22: the images were acquired using Siemens SOMATOM Force (Siemens Health, Forcheim, Germany) CT scanner. Patients 1, 4, 7, 9, 20 and 24: the images were acquired using Siemens SOMATOM Definition Flash CT scanner
	Patient 22: the images were acquired using SOMATOM sensation 64 eco CT scanner.
	Patients 21, 23 and 25: the images were acquired at an external hospital. We do not have information about the type of CT scanner used.
	SOFTWARE
	• BioPARR (Biomechanics-based Prediction of Aneurysm Rupture Risk): freely-available open-source software system for analysis of abdominal aortic aneurisms (AAA) using the finite element method (http://bioparr.mech.uwa.edu.au/).
Data format	RAW
	Source images: Nearly Raw Raster Data (nrrd)
	ANALYSED
	Segmented images: Nearly Raw Raster Data (nrrd)
	GEOMETRY
	Stereolitography (STL)
	FINITE ELEMENT MESHES
	Abaqus finite element code keyword (text) input format. For format description see https://www.3ds.com/products-services/simulia/support/documentation/.
Data format	EXTERNAL LOAD, BOUNDARY CONDITIONS, AND MATERIAL PROPERTIES,
	Abaqus finite element code keyword (text) input format. For format description see https://www.3ds.com/products-services/simulia/support/documentation/.
Parameters for data collection	CT images of radiographically clear unruptured Abdominal Aortic Aneurysms (AAAs) were acquired as a part of standard medical procedures from patients undergoing treatment at the University Hospitals Leuven, Belgium and retrospectively selected (random selection) for this study. The images were segmented to extract the information about the AAA geometry to create computational grids (finite element meshes) for computing stress in the AAA wall.

| Description of data collection	CT image acquisition: • Collimation: 128×0.6 mm • Pitch: 0.7 • Rotation time: 0.5 s • CarekV (ref. 100 kV) • CareDose 4D (ref. mAs 110) • Reconstruction parameters: 1 mm + 3 mm axial slices
	The results were obtained using BioPARR open-source software system (http://bioparr.mech.uwa.edu.au/) that integrates all steps required for AAA stress analysis and rupture risk evaluation:
	• Source image segmentation to obtain information about the AAA geometry: *FastGrowCut* algorithm [4,5] available in 3D Slicer open-source software platform for medical image processing and three-dimensional visualisation (www.slicer.org) [3] is called from within BioPARR. • Patient-specific finite element mesh generation: Gmsh open-source generator (http://gmsh.info/) [6,7] is called from within BioPARR. • AAA wall stress computation: Abaqus (version 6.14) finite element code https://www.3ds.com/products-services/simulia/support/documentation/. • AAA wall stress analysis and visualisation of the results: BioPARR open-source software system.
Data source location	Raw data: University Hospitals Leuven, Leuven, Belgium Geometry, finite element meshes: The University of Western Australia, Perth, Western Australia, Australia
Data accessibility	The data are available with the article
Related research article	K. Miller, H. Mufty, A. Catlin, C. Rogers, B. Saunders, R. Sciarrone, I. Fourneau, B. Meuris, A. Tavner, G. R. Joldes, A. Wittek "Is There A Relationship Between Stress in Walls of Abdominal Aortic Aneurysm and Symptoms?", Journal of Surgical Research, **252**, 37-46, https://doi.org/10.1016/j.jss.2020.01.025.

Value of the Data

- The image datasets, geometry data, patient-specific finite element meshes, information about the material properties, boundary conditions, and external load (patient-specific blood pressure) we provide here will enable the readers to reproduce and verify the results we reported in Miller et al. [1].
- Other researchers can use our work and data as a base for conducting further studies in a quest for finding/determining biomechanical indicators of abdominal aortic aneurysm (AAA) symptoms and rupture risk as well as in a wider area of application of methods of computational biomechanics in the AAA analysis.
- As our datasets contain images, geometry and patient-specific finite element meshes in well-established formats supported by open-source software, we envisage the use of these data not only by researchers focusing on abdominal aortic aneurysm biomechanics, but also for potential benchmarking in the fields of medical image analysis and finite element mesh generation.

1. Data description

We provide anonymised datasets for all 19 patients analysed in Miller et al. [1]. Image, geometry and finite element mesh datasets for each patient are organised as shown in Fig. 1. The dataset for each patient contains the following data (Fig. 2):

- Source CT image in the nearly raw raster data (nrrd) format: file CT_cropped.nrrd;
- Abdominal Aortic Aneurysm (AAA) segmentation (from the source CT image) in the nearly raw raster data (nrrd) format: file CT_AAA_label.nrrd;
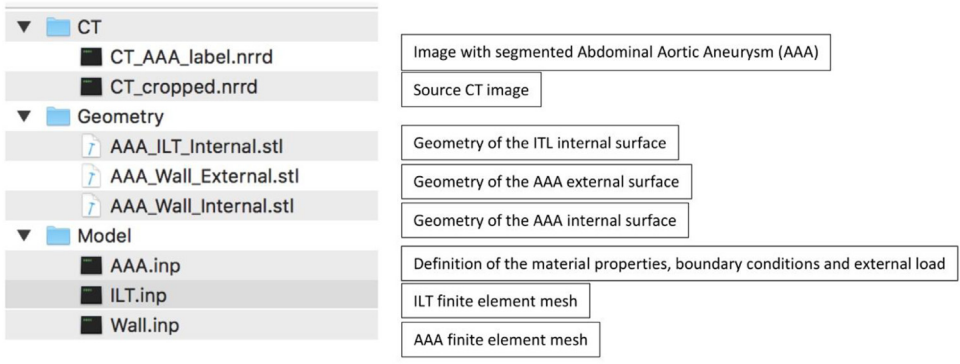
Fig. 1. Structure of our dataset. We provide such dataset for each of the 19 patients (indicated as Case 1, Case 3, Case 4, Case 5, Case 7, Case 9, Case 10, Case 13, Case 14, Case 15, Case 17, Case 18, Case 19, Case 20, Case 21, Case 22, Case 23, Case 24, Case 25) analysed in Miller et al. [1]. More detailed information is in section *Data description* above this figure.
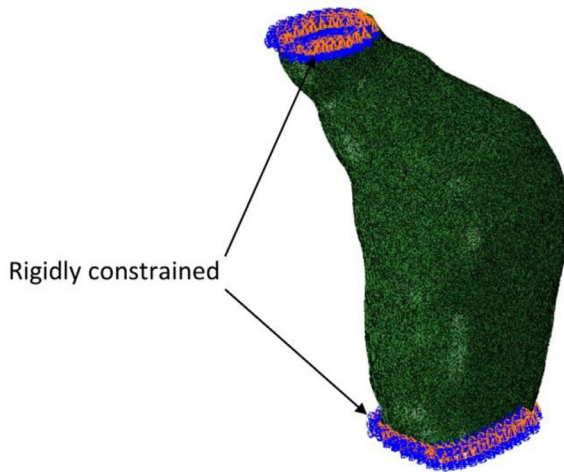
Fig. 2. Boundary conditions for computing stress in AAA wall used in our datasets (files AAA.inp). The AAA superior and inferior surfaces are rigidly constrained.

- Geometry of the intraluminal thrombus (ITL) internal surface in the stereolitography (STL) format: file ILT_internal.stl;
- Geometry of the AAA external surface in the stereolitography (STL) format: AAA_Wall_External.stl;
- Geometry of the AAA internal surface in the stereolitography (STL) format: AAA_Wall_Internal.stl;
- Finite element mesh (4-noded tetrahedral elements) of the AAA in the Abaqus finite element code keyword format: Wall.inp;
- Finite element mesh (4-noded tetrahedral elements) of the ILT in the Abaqus finite element code keyword format: ILT.inp;
- Definitions of the material properties, boundary conditions and external load (in the Abaqus finite element code keyword format) for finite element model for computing stress in the AAA wall: AAA.inp.

2. Experimental design, materials, and methods

2.1. Patient data collection

The images and other patient data in these datasets were collected as a part of standard medical procedures at University Hospitals Leuven (Leuven, Belgium) and retrospectively provided to The University of Western Australia's Intelligent Systems for Medicine Laboratory. The approval was granted by the Ethics Committee of the University Hospitals Leuven (approval no. S59796).

2.2. Stress analysis in abdominal aortic aneurysm (AAA) wall

Complete stress analysis for each AAA was conducted using our freely-available software system BioPARR [2]. The system consists of a collection of programs and scripts that perform the required steps in the AAA analysis workflow, from image segmentation to geometry creation, creation of computational grids (finite element meshes) and finite element analysis. For image segmentation and geometry creation, BioPARR uses the algorithms available in open-source image analysis software 3D Slicer [3]. For finite element meshing, it utilises free open-source software Gmsh [6, 7].

2.2.1. Image segmentation

For segmentation, we used the 3D Slicer extension *FastGrowCut* called from within BioPARR. This extension requires a very limited input from the analyst who only needs to define the region of interest in the image, to crop the image, and to define the seeds for the segmentation [4, 5]. As the segmentation artefacts could not be completely eliminated, the resulting label maps were manually corrected. The reliability of this process has been confirmed in our previous study [2].

2.2.2. Geometry creation

The AAA and ILT geometry was extracted from the label maps using the 3D Slicer *Model-Maker* module [8] called from within BioPARR. The module creates 3D discretised (using triangles) surface models and facilitates surface smoothing. We used Laplacian (i.e. using Laplace filter) smoothing with 100 iterations.

2.2.3. Finite element mesh generation and element type

Mesh generation was performed using open-source meshing software Gmsh [6, 7] called from within BioPARR. Tetrahedral volumetric (3D) meshes were created using the element size specified by the user in such a way that the number of elements in the AAA mesh of each patient was around 500,000. In the previous study, we determined that this mesh density is sufficient to obtain a converged solution (i.e. further increase in the number of elements results only in negligible changes in the predicted stress) [2]. The mesh density was not uniform. We used very small elements on the surfaces to maintain the geometric accuracy. At the same time, we increased the element size inside the ILT volume to reduce the total number of elements along with the consequent computational cost of the finite element analysis.

2.2.4. External load, boundary conditions, and material properties

We used patient-specific mean arterial pressure applied to the ILT surface as the loading. Following Joldes et al. [2], superior and inferior AAA surfaces were rigidly constrained. The ILT was assumed to be 20 times more compliant than the AAA wall; an estimate based on the data from the Di Martino et al. [9], O'Leary et al. [10], and Tong et al. [11].

Conflict of Interest

Acknowledgments

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.dib.2020.105451.

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