An implementation of a real-time finite element algorithm using CUDA technology with application to Endoclamp Balloon expansion

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An Endoclamp Balloon achieves endovascular clamping by means of intraluminal occlusion. Circumventing the need for opening the thoracic cage provides significant benefits in terms of reducing trauma for the patient. This procedure, however, induces risks of damage to the aortic lumen by way of over-expansion of the balloon, exposing aortic tissue to unsafe levels of strain. In patient-specific terms, accurate estimates of stress, strain and damage are required intraoperatively to warn the surgeon and mitigate risk of tissue damage.

Due to the nature of aortic tissue and the physical system in question, the Total Lagrangian Explicit Dynamic[1](TLED) FE formulation, capable of handling geometric and material non-nonlinearities, is used. A 2D plane strain formulation is used to additionally simplify and speed up the execution time by reducing the number of degrees of freedom involved, meanwhile retaining sufficient accuracy for the proposed application. The large amount of computation needed to solve for the stress field is relieved by using dedicated massively parallel hardware. An Nvidia CUDA GPGPU(General Purpose Graphics Processing Unit) is employed to parallelize critical portions of the TLED algorithm.

The fusion of sensory information provided by the Endoclamp Balloon and electromagnetic position sensors, along with a segmented patient-specific aortic mesh provide boundary conditions and localization information for the FE simulation. We present an efficient implementation of the TLED complying with the time constraints imposed by the workflow of the surgical theater. The accuracy of the solution is validated against an industry-proven FE package Abaqus.

1. Grand R Joldes, Adam Wittek, K, Karol Miller. (2006) Total Lagrangian explicit dynamics finite element algorithm for computing soft tissue deformation. Comm. Numer. Meth. Engng 2007; **23**:121–134