The project concerns issues of computational modelling of the abdominal wall in the medical context of ventral hernia. This interdisciplinary research will be conducted by a consortium of Gdańsk University of Technology and the Medical University of Gdańsk. Computational medicine is a fast-emerging field combining the disciplines of engineering and medicine. Nowadays, computational models are widely used to advance the medical treatment of many diseases. Models with predictive capacity can be used to understand and simulate the behaviour of systems, which may be utilized for purposes of personalized medicine, and optimization and design of medical devices.

Ventral hernia repair is a frequently performed surgical procedure that needs to be improved in order to reduce the number of hernia recurrences, and postoperative pain and discomfort. A computational mechanics-based approach to this problem requires a credible model of the human abdominal wall–surgical mesh system. However, one of the obstacles to modelling is the existence of uncertainties. Models aim to represent the behaviour of real systems, but they are not reality. We need to cope with uncertainties that are related to inaccuracies in models and data, and those that are caused by lack of knowledge. In case of natural materials like biological tissue, especially important are also uncertainties related to the natural variability of properties and shapes. The variability of the geometry of the abdominal wall is relatively high. Constructing a model of the abdominal wall with realistic geometry based on medical images is time-consuming. However, numerical studies on ventral hernia based on one specific geometry of the abdominal wall may have limited applicability. The aim of this project is to include variability of the shape of the abdominal wall in computational modelling and study its effect on the behaviour of the abdominal wall-surgical mesh system. A methodology combining statistical shape modelling and uncertainty quantification with sensitivity analysis will be proposed in order to construct a credible model of the abdominal wall-implant system for the purposes of improvement of ventral hernia treatment.

Three-dimensional shapes of real human abdominal walls will be reconstructed based on a number of computer tomography scans. Then, in order to capture geometric variability, a statistical model of the shape of the abdominal wall will be constructed by training on those geometries. Principal component analysis will be employed to find a mean shape and principal modes of shape variation. The statistical shape model will be used to generate geometrical inputs to be applied to finite element (FE) models. The non-linear FE models will predict the mechanical behaviour of the abdominal wall, both healthy and with the surgical mesh. Probabilistic methods will be used to propagate shape variance together with other uncertainties, e.g. in material properties, through the FE models. Application of metamodels will reduce the computational cost of uncertainty quantification to a tractable level. Global sensitivity analysis will be applied to quantify the influence of shape modes and uncertainties on the FE model outcomes that are important from the point of view of further optimization of hernia repair treatment. This will allow ranking of the variables in terms of their importance.

The main results will be:

- a statistical shape model of the abdominal wall. It may be useful not only in the context of ventral hernia, but also in order to answer other medical questions, e.g. issues of abdominal wall closure;
- determination of the effect of shape variability on the behaviour of the abdominal wall with surgical mesh in comparison with uncertainties from other sources, e.g., in material properties;
- establishing an effective methodology for combining statistical shape modelling and uncertainty quantification with sensitivity analysis in the context of constructing credible models.

The final conclusions will be useful from the point of view of surgical practice, for example concerning the treatment of patients with differently shaped abdomens. The project may also lead to further personalization of hernia treatment and patient-specific modelling.