Mechanical-dynamic properties of 3D-printed human middle-ear ligaments

Philipp Hummel, Reutlingen Research Institute, Reutlingen University, 72762 Reutlingen, Germany, Philipp.Hummel@Reutlingen-University.de
Michael Lauxmann, School of Engineering, Reutlingen University, 72762 Reutlingen, Germany, Michael.Lauxmann@Reutlingen-University.de

Introduction

Nowadays, human temporal bone preparations are commonly used as models in hearing research for testing implants and validating numerical results, as their properties are close to those of living humans. Measurements on cadaveric preparations are affected by large measurement uncertainties, which is why the use of technical models as reproducible test environments has significant advantages. Various research groups have pursued this goal, but so far, no adequate model of the middle ear has been achieved because the mechanical-dynamic properties of the ligaments cannot be realised with conventional 3D-printing materials. This is because those materials with a sufficiently low Young's modulus exhibit excessively damped material behaviour, and sufficiently damped material behaviour is associated with an excessively high Young's modulus. The aim of the present work is to develop a multi-material system using additive manufacturing, consisting of different proportions of photopolymer materials and whose dynamic-mechanical property profile corresponds realistically to that of human ligaments.

Methods

Homogeneously distributed multi-material substrates are produced using 3D-Inkjet technology. The mechanical-dynamic properties of these test substrates are analysed by vibration measurements and tensile tests. By a voxel-based definition of systematically varied separate photopolymers, whose individual property profiles range from almost ideal elastic to highly viscous behaviour, is intended to achieve a dynamic-mechanical property profile analogous to that of human middle ear ligaments.

Results

It was found that the material properties of the multi-material substrates can be specifically influenced by the systematic addition of three photopolymers (Tissue Matrix, Vero, Agilus). Mechanical-dynamic properties very close to those of the biological system can be achieved. Densities of 1100 to 1180 kg/m³, Young's modulus of 0.1 to 25 MPa and Poisson's ratio of around 0.3 have been achived. Target values for human ligaments reported in the literature vary, with densities ranging from 1100 to 1200 kg/m³, Young's modulus from 0.05 to 21 MPa, damping ratio from 0.003 to 0.05, and Poisson's ratio of around 0.3.

Conclusion

The use of the 3D-Inkjet method to produce human ligaments enables a realistic representation of the linear, dynamic-mechanical properties. Multi-material printing allows up to eight materials to be processed simultaneously, opening up further possibilities in terms of non-linear properties. The technology offers the potential for further development of technical models of the middle-ear.