Performance of metallic auxetic needle drives

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INTRODUCTION: The aim of this study is the development of a metallic 3D-printed auxetic needle drive for a robot [1] dedicated to interventional radiology and image guided surgery.

METHODS: Auxetic structures were designed with SolidWorks™ (Dassault Systèmes, France) and produced in titanium by selective laser melting (SLM, DMG Mori, Germany) [2]. Quadratic 4-balloon (Fig. 1a) and pentagonal 5-balloon designs (Fig. 1b) with different strut widths and thicknesses were generated, see Fig. 1c and Tab. 1. Due to the auxetic lattice structure of the actuator, axial expansion is achieved at pressure increase of the 4 or 5 inflated catheter balloons located within the unit [3]. The video analysis and modelling tool (*Tracker* software [4]) was used to quantify the performance of the different designs based on 10 s video sequences (3840 x 2160 pixel, 30 fps).

RESULTS: Fig. 2 shows the change in length of different designs with increasing internal pressure. The axial elongation at 4 bar d_{max} is also listed in Tab. 1.

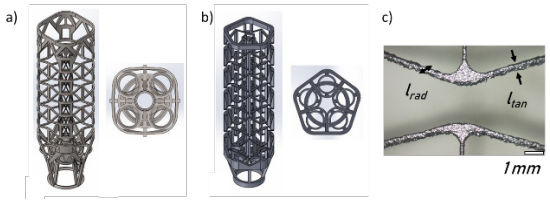

Fig. 1: a) Quadratic and, b) pentagonal auxetic structures with a central guide channel of the biopsy needle. c) Dimensioning of the metallic struts in radial l_{rad} and tangential l_{tan} direction.

Table 1. Design and performance of three versions of quadratic (Q) and pentagonal (P) actuators.

	l_{rad} [mm]	l_{tan} [mm]	*Aspect ratio*	*CS* [mm²]	d_{max} [mm]
Q1	0.54	0.62	0.8:1	0.33	0.16
Q2	0.56	0.40	1.4:1	0.22	0.44
Q3	0.56	0.47	1.2:1	0.26	0.36
P1	1.11	0.28	4.0:1	0.31	1.03
P2	1.14	0.36	3.2:1	0.41	0.57
P3	0.87	0.37	2.4:1	0.32	0.30

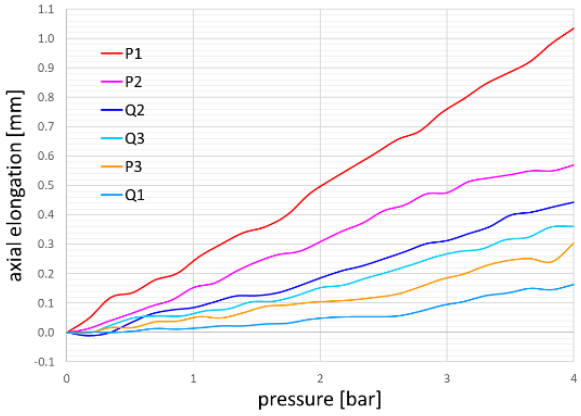

Fig. 2: Axial expansion of pentagonal (P) and quadratic (Q) auxetic titanium actuator variants after increasing the pressure of the inner balloons.

DISCUSSION & CONCLUSIONS: The SLM printing process allows precise production of complex-shaped metallic actuators with different strut geometries in sub-mm precision. The combination of a large ratio of radial to tangential length l_{rad}/l_{tan} with a small cross-sectional area *CS* promotes the movement in the axial direction. This study confirms the pneumatic drive principle of auxetic titanium structures and shows the significant influence of the area moment of inertia of the struts $I_{ax} \cong \frac{l_{rad} l_{tan}^3}{12}$.

REFERENCES: [1] http://spirits.icube.unistra.fr. [2] F. Schuler, P. Renaud, M. de Wild, 3D-printed auxetic structures for bio-medical application, *European Cells and Materials, Online Periodical*, Coll 2, ISSN 1473-2262, 10 (2018). [3] A. Pfeil, L. Barbé, B. Wach, A. Bruyas, F. Geiskopf, M. Nierenberger, et al. A 3D-Printed Needle Driver Based on Auxetic Structure and Inchworm Kinematics. *ASME IDETC 2018;* V05AT07A057. [4] https://physlets.org/tracker/.

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