Comparison of Tactile Properties of Liver Tissue and 3D Printing Materials via Macroindentation

Sarah-Jane Estermann[1,2,3], Christian Müller-Guttenbrunn[1], Dieter Pahr[1,3], Andreas Reisinger[1]

Division Biomechanics, Karl Landsteiner University of Health Sciences, Krems, Austria / www.kl.ac.at

Austrian Center for Medical Innovations and Technology, Wiener Neustadt, Austria / www.acmit.at

Institute for Lightweight Design and Structural Biomechanics, TU-Wien, Vienna, Austria / www.ilsb.tuwien.ac.at

Introduction

Manufacturing anatomical models, made of materials that accurately represent mechanical properties of actual biological tissue, has been a long-standing goal in biomedical engineering. Accurate patient-specific organ replicas are useful in pre-surgical planning [1], while standardized models are essential tools in research and teaching. Models reduce demand of animal tissues and donor organs. Especially extremely soft tissues, like liver or other internal organs, pose a challenge demanding innovative manufacturing processes. 3D printing is a promising tool, as it allows precise control of material composition as well as microstructure of the material phases.

The aim of this study was to establish a method for identifying mechanical parameters that represent the tactile properties – the way a material feels to touch – of porcine and bovine liver tissue, for comparing with artificial materials that could be used in 3D printing.

Methods

A macroindentation setup was developed to simulate the palpation of material samples [2]. A steel ball of 15 mm diameter was utilized to approximate the geometry of a fingertip for indentation with loads that are comparable to human touch (Fig. 1).

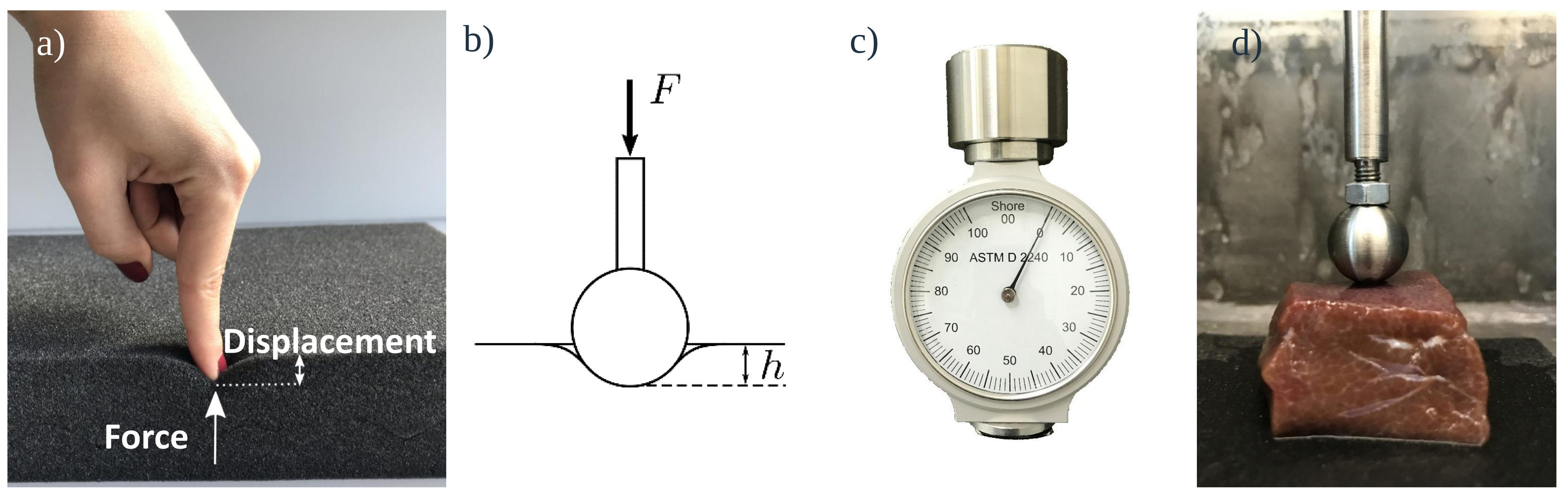

Fig. 1: a) Motivation for setup and b) experimental design with force F and displacement h; c) analogue Shore 00 durometer for measuring hardness (ZwickRoell GmbH & Co. KG); d) liver sample during testing

9 samples (30x30x30 mm) for each experiment of the following materials were tested: Bovine and porcine liver (Fig. 2a) Shore A 13 silicone (Fig. 2b) with different silicone oil concentrations (0%, 10%, 20%, 30%), Shore 00 silicones (00-10, 00-20, 00-30), layered samples consisting of 00-10 sandwiched between two layers of 00-30 (00-313), and TangoPlus (Stratasys Ltd), a soft commercially available 3D printed polymer.

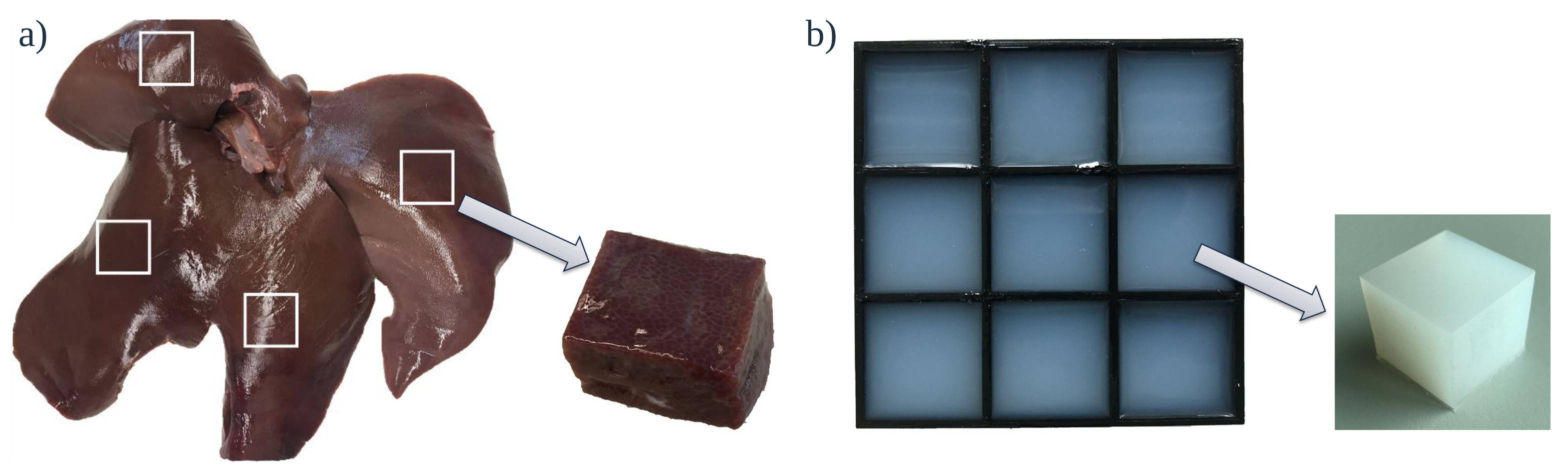

Fig. 2: a) Whole porcine liver exhibiting cites of sample extraction; b) silicone casting mould with silicone sample

- Samples were exposed to a quasi-static loading-unloading sequence up to 5 N. The unloading contact stiffness S and equivalent spring stiffness k were extracted from the force-displacement curves (Fig. 3a).
- A separate set of force relaxation experiments was conducted, aimed at evaluating viscous properties. The loss factor $\tan\delta$ at 1 Hz was calculated based on Prony series approximation of force relaxation and a 3 element generalized Maxwell model [3] (Fig. 3b)
- Additionally, Shore 00 surface hardness H, given in Shore units (SU), was measured with an analogue durometer.

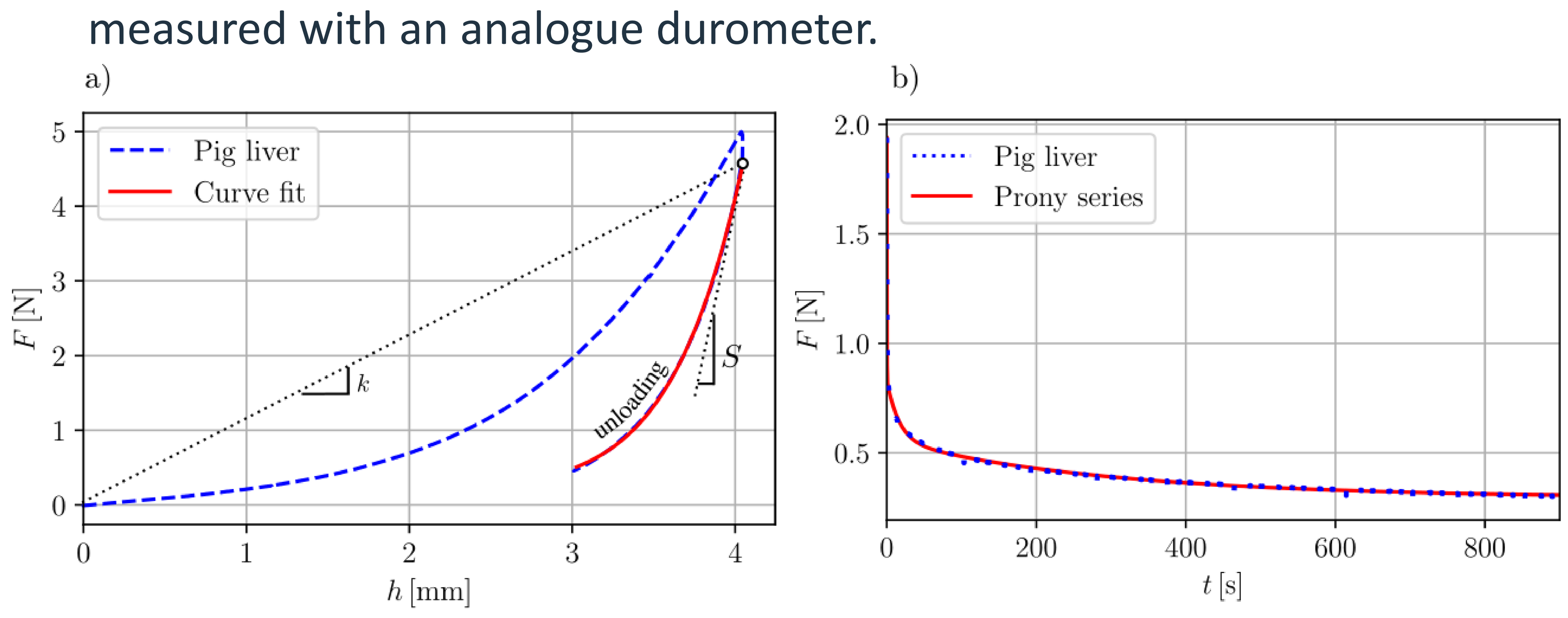

Fig. 3: Typical porcine sample curves for a) force-displacement of quasi-static test, depicting measured data and curve fitted to unloading part, with contact stiffness S and spring stiffness k; and b) relaxation force plotted over time with Prony series fit

Relative mean error Q was calculated for each artificial material (index m), based on how well the mean parameters ($\bar{k}$, $\bar{S}$, $\bar{H}$, and $\overline{\tan\delta}$) corresponded to porcine or bovine liver parameters (index l):

$$Q = \frac{1}{4}\left(\frac{|\bar{k}_m - \bar{k}_l|}{\bar{k}_l} + \frac{|\bar{S}_m - \bar{S}_l|}{\bar{S}_l} + \frac{|\bar{H}_m - \bar{H}_l|}{\bar{H}_l} + \frac{|\overline{\tan\delta_m} - \overline{\tan\delta_l}|}{\overline{\tan\delta_m}}\right)$$

The relative change for each property in reference to liver is given by :

$$D_k = \frac{\bar{k}_m - \bar{k}_l}{\bar{k}_l},\ D_S = \frac{\bar{S}_m - \bar{S}_l}{\bar{S}_l},\ D_H = \frac{\bar{H}_m - \bar{H}_l}{\bar{H}_l},\ \text{and}\ D_{\tan\delta} = \frac{\overline{\tan\delta_m} - \overline{\tan\delta_l}}{\overline{\tan\delta_l}}$$

Results

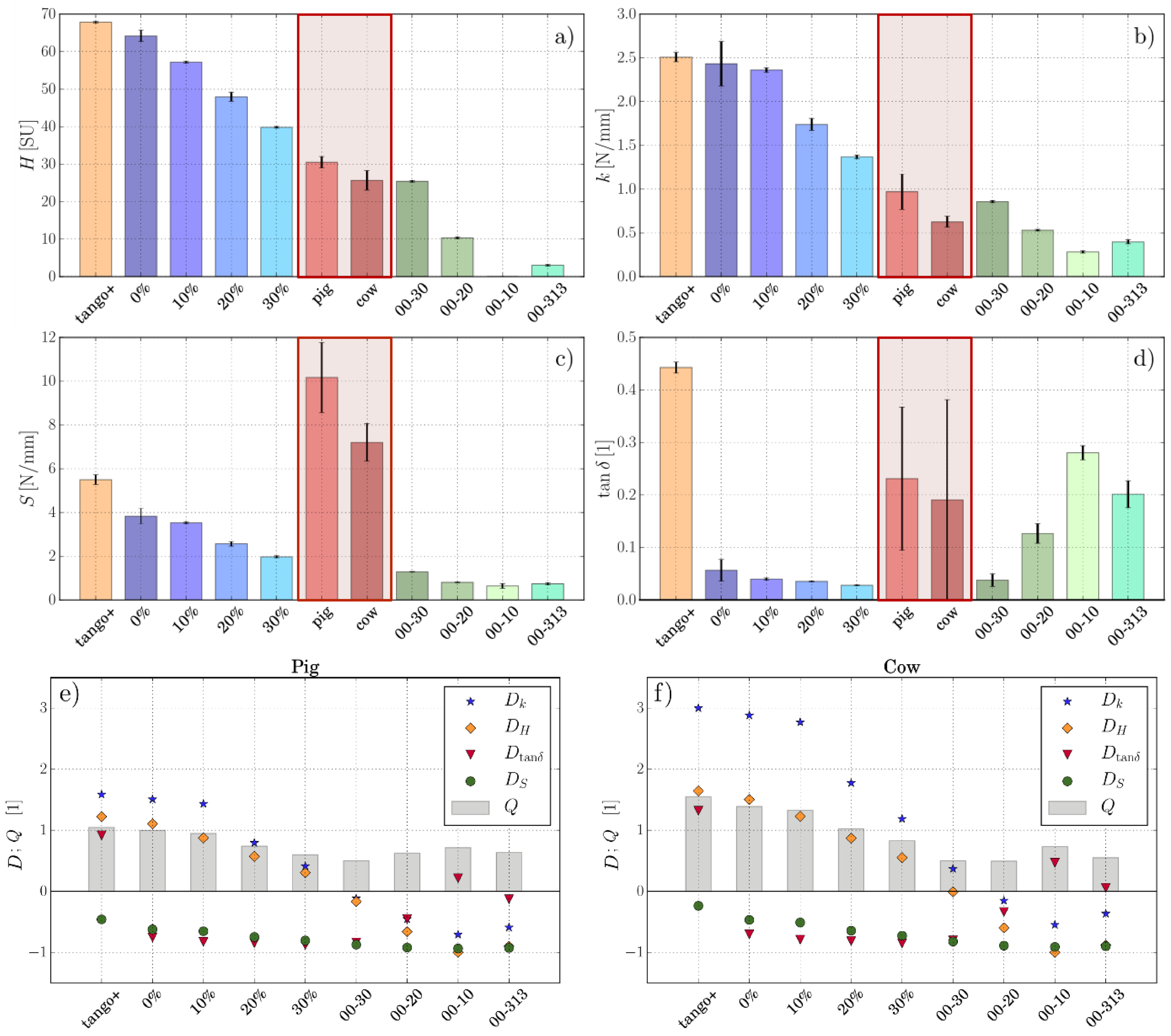

Fig. 4: Results for a) Shore hardness H, b) spring stiffness k, c) contact stiffness S, d) loss factor $\tan\delta$; and mean errors Q and changes D_k, D_S, D_H, and $D_{\tan\delta}$ relative to e) porcine and f) bovine liver

Discussion

According to Fig. 4a and b, silicone with a nominal hardness of 30 SU best represents liver in terms of hardness and equivalent spring stiffness, while TangoPlus is much too hard and not elastic enough. However, concerning the unloading contact stiffness (Fig. 4c), the 3D printed polymer corresponds to liver more than the other tested materials. Viscosity, expressed as loss factor at 1 Hz was too low for most silicones, except for the ultra-soft ones (00-20, 00-10, and layered samples) as well as TangoPlus (Fig. 4d).

Conclusion

The overall error which takes all four parameters into consideration was closest to liver for the 00-30 silicone (Fig. 4e-f). The results show that in order to achieve higher fidelity, the artificial material must not only reproduce the overall elastic properties of liver but also the contact behavior and loss factor, demanding viscoelastic considerations accompanied by an appropriate inner microstructure. Thus, additive manufacturing is a promising tool for attaining these properties.

Acknowledgements

The project was funded by the NFB Science Call Dissertations 2017. The research center ACMIT is funded in the framework of COMET - Competence Center for Excellent Technologies by BMVIT, BMDW as well as the Federal State of Lower Austria and Standortagentur Tirol. The competence center program COMET is managed by the FFG.

References

[1] Zein et al. *Liver Transpl*, 2013(19):1304–1310

[2] Carson et al. *Med Eng Phys*, 2011(33): 3-309

[3] Jalocha et al. Int J Solids Struct, 2015(67-68):169-181

sarah.estermann@kl.ac.at