## Appendix 1

### Prototyping and specification of the printing process

Prior to defining the printing process and the bone model used in the following optimization and evaluation steps, two prototypes were constructed: a generalized pedicle model (Fig. A1a) and a model representing a section of a real-shaped pedicle, derived from CT (Fig. A1b). The prototypes were printed in anterior-posterior (AP) printing direction (see Fig. A1c) in all four material combinations, placed into a container and covered with synthetic soft tissue (red colored gel wax and skin colored foam rubber, see Fig. A1d).

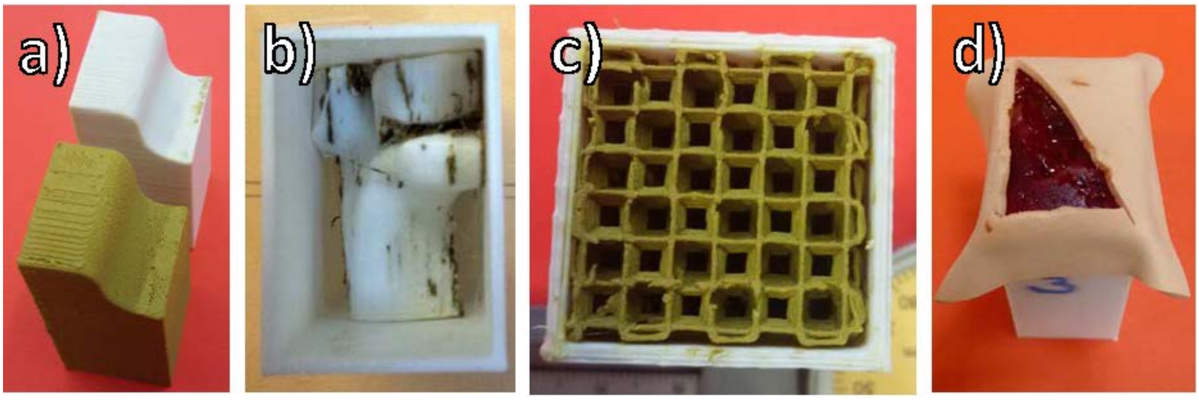


**FIGURE A1.** Prototype models. a) generalized pedicle model, b) real-shaped pedicle model, c) 3D Honeycomb infill printed in AP direction, d) synthetic soft-tissue.

An evaluation by a surgical expert, revealed the following deficiencies:

1. Regarding the generalized pedicle model, the expert was not sure where to puncture the model and in which angle to insert the trocar, due to the generalized form of the pedicle model.
2. Regarding the real-shaped pedicle model, the expert had difficulties to locate the relatively small pedicular structure due to the lack of imaging or direct sight onto the structure.

3. Regarding both models the chosen printing direction results in the infill structure to be open in the AP direction, causing the trocar to drop through the infill in typical insertion trajectories.

Additionally, the expert rated cortical and cancellous structures printed of material W as too soft, and cortical structures of material P as too hard.

**Iterative optimization and evaluation**

In iteration 1, eight models were printed and evaluated. The printing parameters (besides printing direction) for the first set of four models were the same as for the prototype, the printing parameters for the second set of four models were adjusted according to the expert rating of the prototype by increasing perimeters and infill density for material W, resulting in harder cortical and cancellous structures, and decreasing perimeters for material P, resulting in less hard cortical structures.

In iteration 2, models with an overall mean score of $\geq 4$were selected and printing parameters were again adjusted according to the bone quality rating.

Two surgical experts E1 and E2 (trauma surgeons, job tenure E1=10 years and E2=33 years, number of pediculations performed E1>200 and E2>300) participated in the iterative evaluation. The material compositions and evaluation results of the two iterations are given in Table A1. Statements given in the free text area regarding the bone quality, e.g. “Corticalis too hard” or “Cancellous bone a little too soft” are coded in a hardness/softness rating as follows: H=much too hard/too hard, h=little too hard, S=much too soft, s=little too soft.

| Nr | MAT | PER | DENS | Cortical Rating | | | | Mean | Cancellous Rating | | | | Mean | Overall Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Expert1 | | Expert2 | | | Expert1 | | Expert2 | | | |
| Iteration 1 | | | | | | | | | | | | | | |
| 1 | W/P | 3 | 20% | 3 | S | 2 | S | 2.5 | 5 | R | 4 | h | 4.5 | 3.5 |
| 2 | P/W | 3 | 20% | 3 | H | 2 | H | 2.5 | 3 | S | 6 | R | 4.5 | 3.5 |
| 3 | W/W | 3 | 20% | 4 | s | 3 | S | 3.5 | 3 | s | 6 | S | 4.5 | 4 |
| 4 | P/P | 3 | 20% | 2 | H | 6 | R | 4 | 2 | H | 4 | h | 3 | 3.5 |
| 5 | W/P | 5 | 20% | 5 | h | 2 | H | 3.5 | 5 | h | 6 | h | 5.5 | 4.5 |
| 6 | P/W | 2 | 30% | 6 | R | 6 | R | 6 | 6 | R | 6 | R | 6 | 6 |
| 7 | W/W | 5 | 30% | 5 | R | 6 | R | 5.5 | 1 | H | 6 | R | 3.5 | 4.5 |
| 8 | P/P | 2 | 20% | 2 | H | 3 | H | 2.5 | 4 | R | 2 | H | 3 | 2.75 |
| Iteration 2 | | | | | | | | | | | | | | |
| 1 | W/P | 4 | 15% | 3 | S | 2 | S | 2.5 | 5 | s | 4 | R | 4.5 | 3.5 |
| 2 | W/P | 4 | 20% | 6 | R | 1 | H | 3.5 | 4 | h | 1 | H | 2.5 | 3 |
| 3 | W/P | 5 | 15% | 6 | R | 3 | H | 4.5 | 6 | R | 4 | R | 5 | 4.75 |
| 4 | P/W | 2 | 20% | 6 | R | 3 | H | 4 | 1 | H | 4 | R | 2.5 | 3.25 |
| 5 | P/W | 2 | 30% | 5 | s | 3 | H | 4.5 | 6 | R | 3 | H | 4.5 | 4.25 |
| 6 | W/W | 5 | 30% | 6 | R | 1 | H | 3.5 | 6 | R | 2 | H | 4 | 3.75 |
| 7 | W/W | 4 | 30% | 6 | R | 4 | R | 5 | 6 | H | 4 | R | 5 | 5 |

**TABLE A1.** Iterative optimization evaluation results: Expert rating (E1, E2) scores are on a 7-point Likert scale, Hard/Soft denotes hardness/softness rating. Printing parameters: MAT denotes the material combination used, PER the number of perimeters and DENS the infill density.

According to the overall mean score, the top three models (no. 3, 5 and 7) of iteration 2 were selected for the final evaluation of the haptic appearance.