Capstone Design: Preparation of the Subtalar Joint in TTC Arthrodesis

MacKenzie Campbell, Michael De Biasio, Kevin Wang, Irina Zhu

December 2, 2020

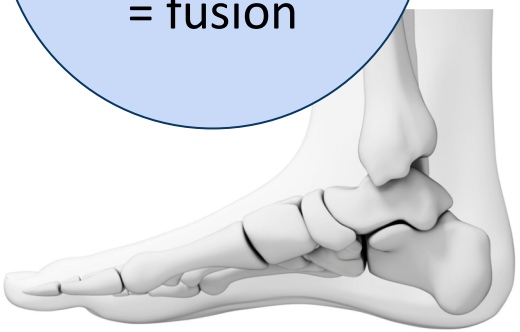
Institute of Biomaterials & Biomedical Engineering
UNIVERSITY OF TORONTO

St. Michael's
Inspired Care.
Inspiring Science.

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

Background: Surgical Procedure

Tibiotalocalcaneal (TTC) arthrodesis = fusion



=

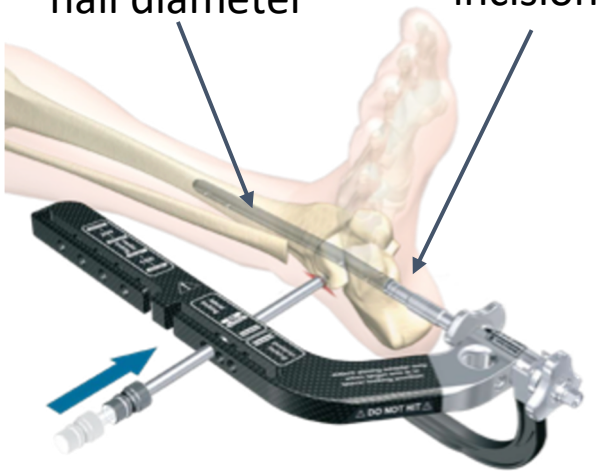
~100mm incision

Joint preparation

+

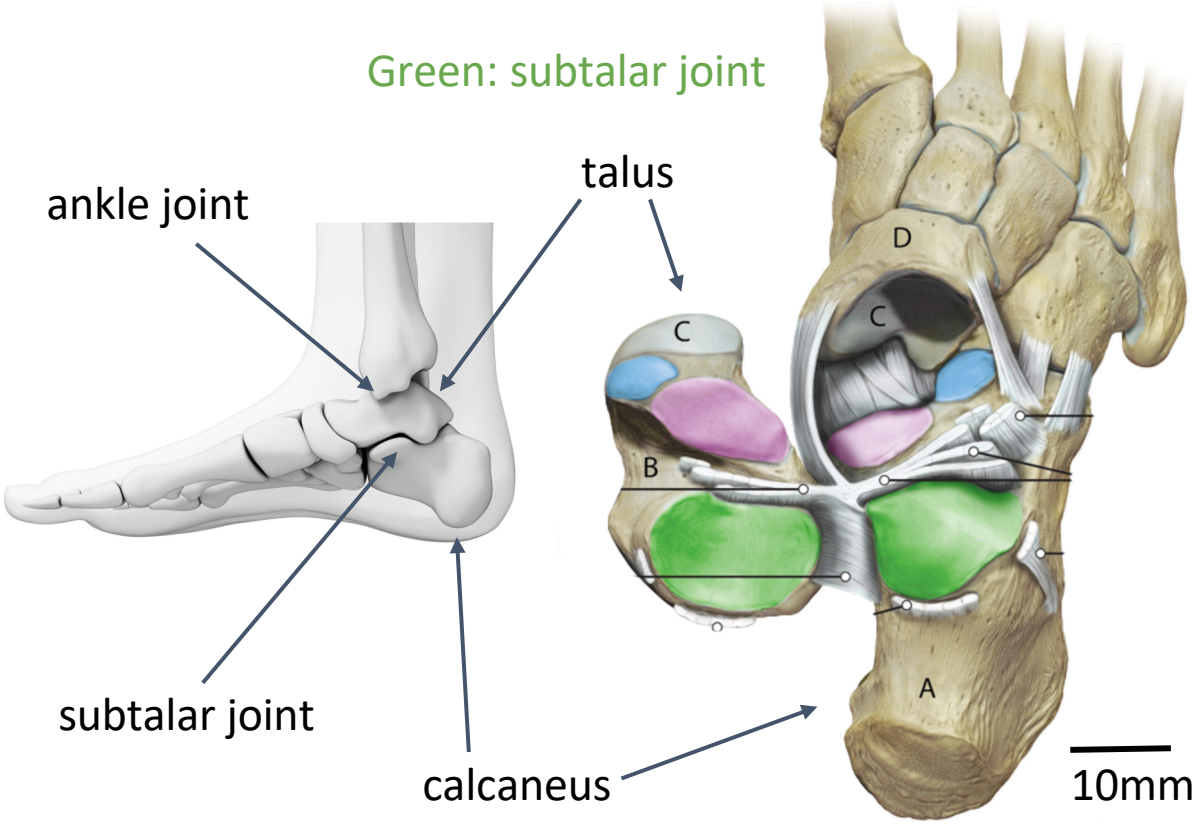
11-14mm nail diameter

~30mm incision

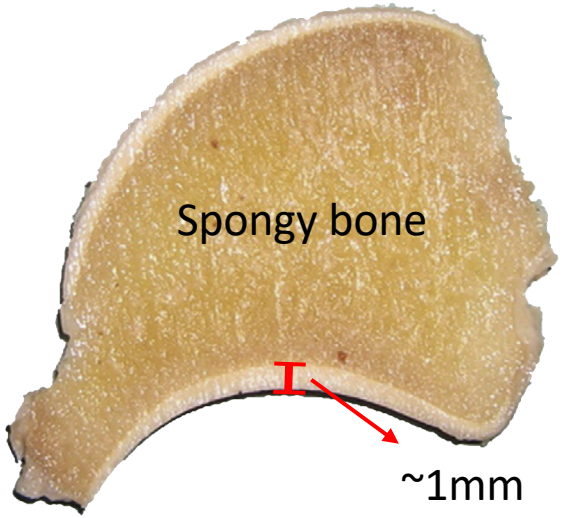


Ankle Fixation

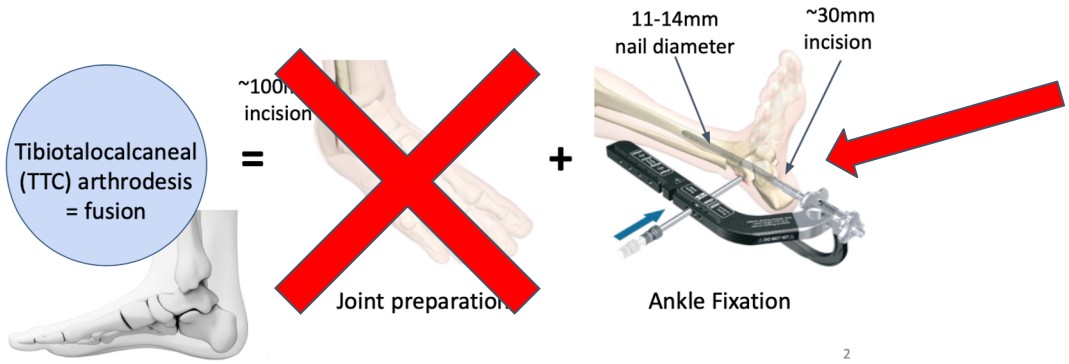
Background: Subtalar Joint Anatomy



Cross sectional slice of the **talus** bone



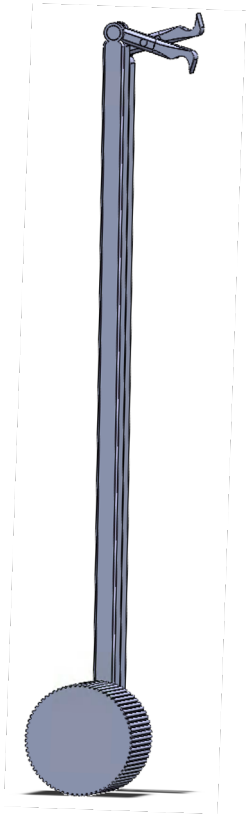
A way to prepare the **subtalar joint** through a **plantar incision** in patients undergoing TTC nailing in a **trauma setting** that improves **bone fusion rates**



A way to prepare the **subtalar joint** through a **plantar incision** in patients undergoing TTC nailing in a **trauma setting** that improves **bone fusion rates**

- Space & Visualization Constraints
- Cost to Produce <$100 CAD
- Maximize surgeon confidence
- Cartilage and bone disruption
- Minimize surgical time & # of steps
- Compatible with bone graft use

Proposed Solution Overview

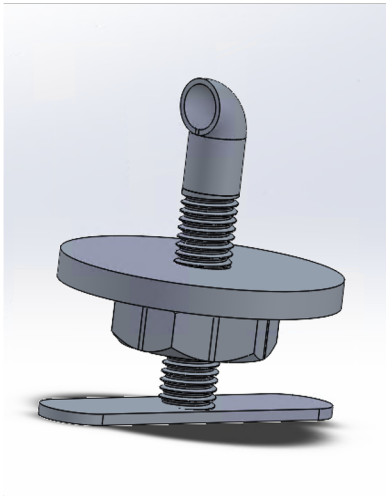


1. Ream Hole → 2. Insert Guide tube → 3. Adjust guide tube position

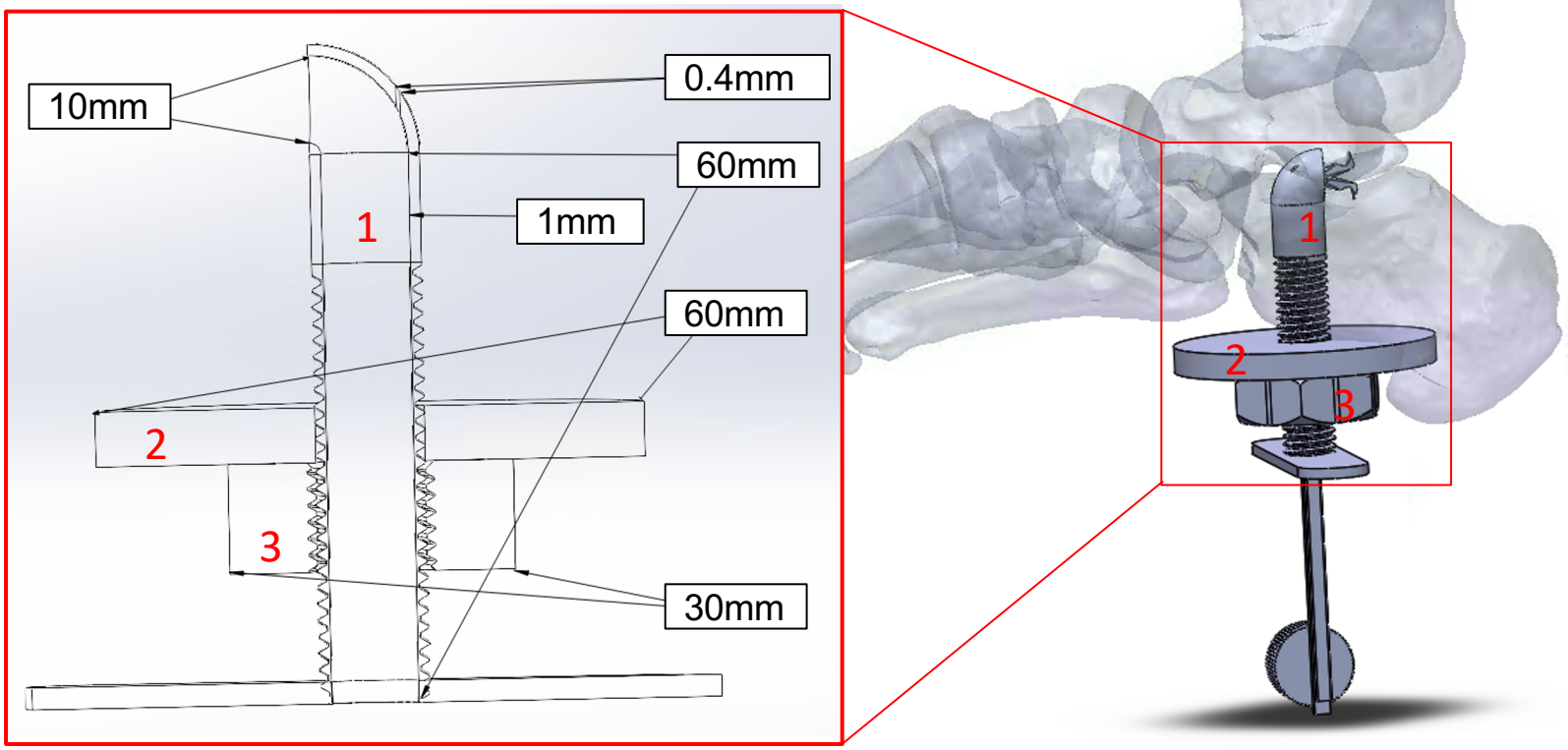
4. Insert cutting tool into joint space → 5. Expand cutting cool → 6. Cut cartilage/ subchondral bone with cutting tool

7. Remove tool → 8. Remove cut tissue with suction → 9. Repeat 4-8 for subchondral bone

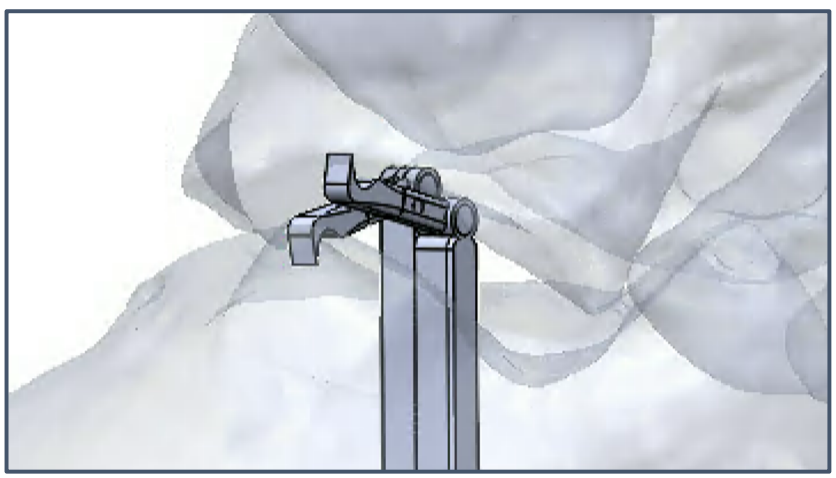
10. Inject bone graft (optional) → 11. Remove guide tube → 12. Start nail prep

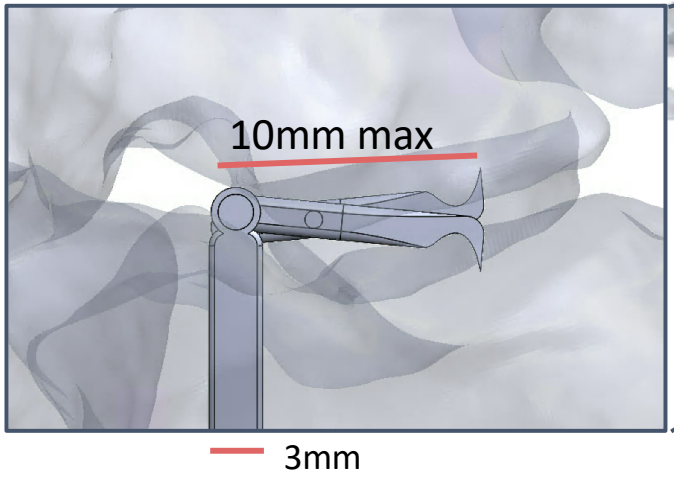


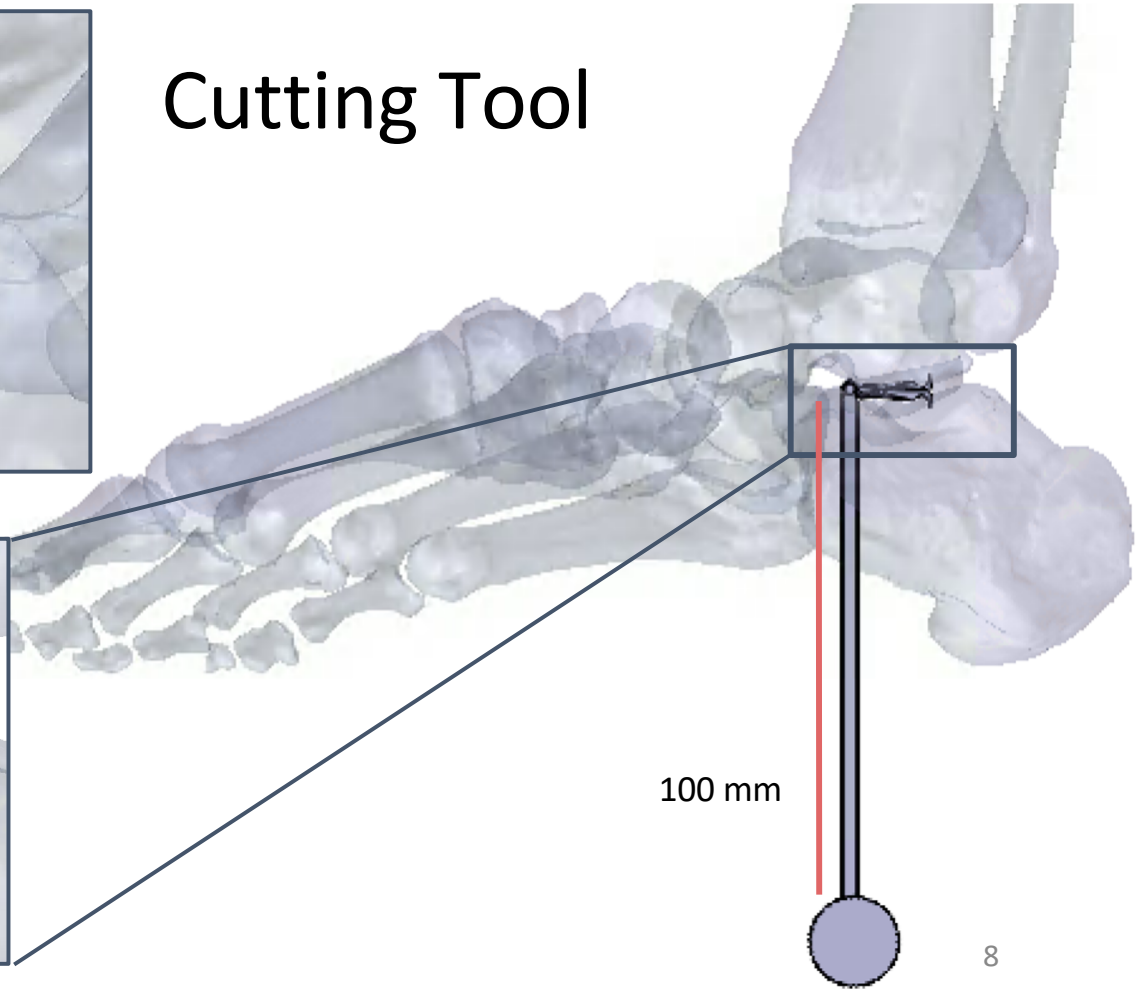
Guide Tube



Cutting Tool







Guide Tube and Cutting Tool

Proposed Solution: Materials and Cost

Materials

Martensitic 400-series **stainless steel** with blade made of **tungsten carbide**.

Costs

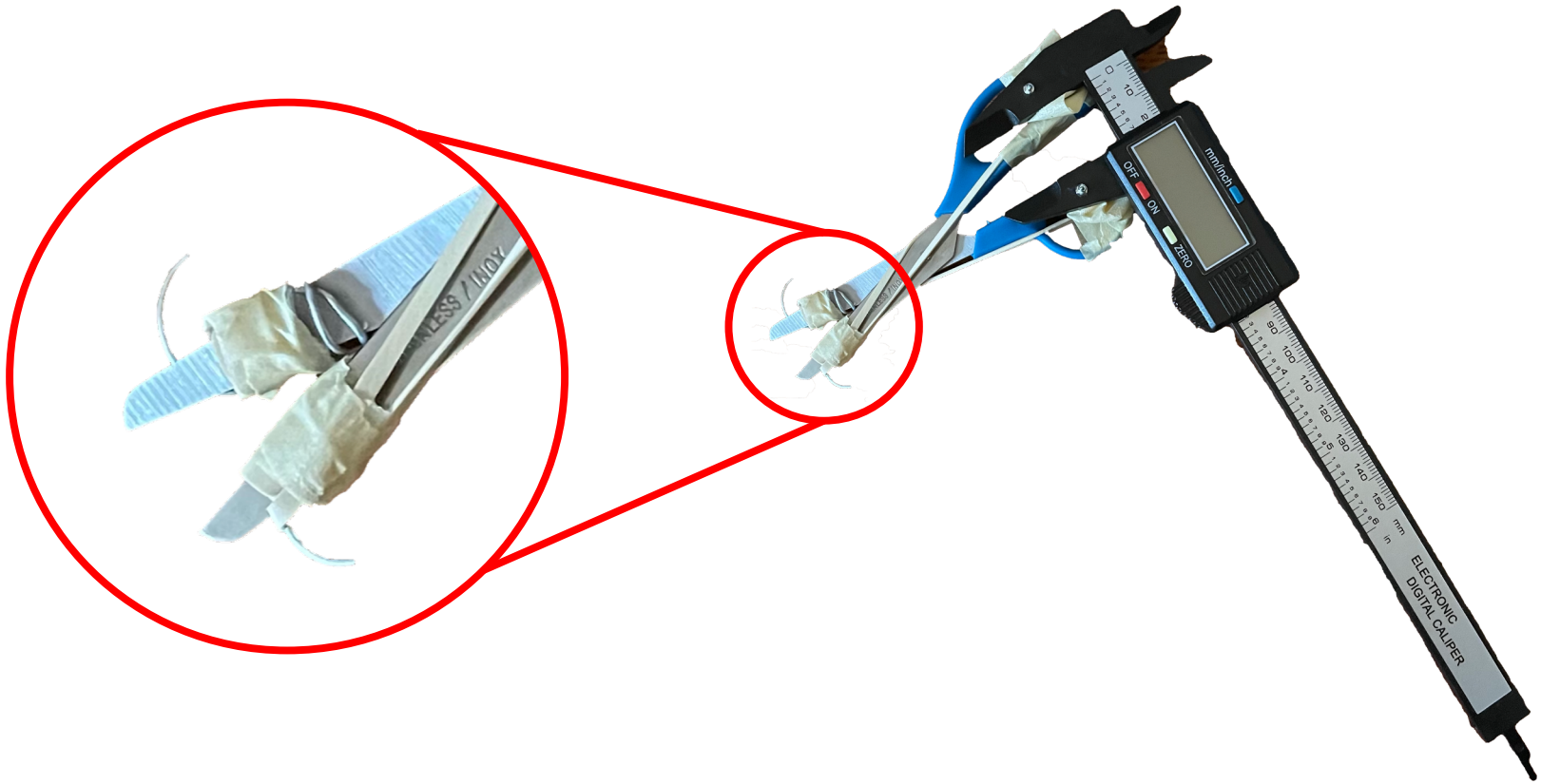
1mm-thick 400-series stainless steel: **USD $0.815/lb**. (current mkt value).

Tungsten carbide: **USD $9-12.00/lb**. (approx. mkt value).

Manufacturing: ~ **USD $30.00/tool**.

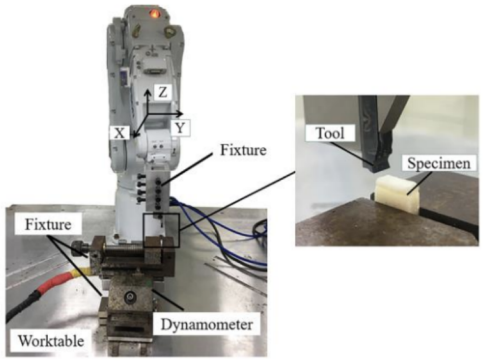
Total cost: ~ **CAD $40.60/tool**

Low fidelity Prototyping

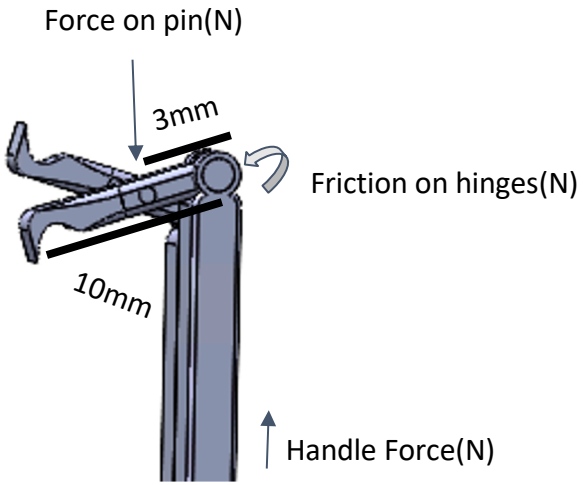


Force Calculations

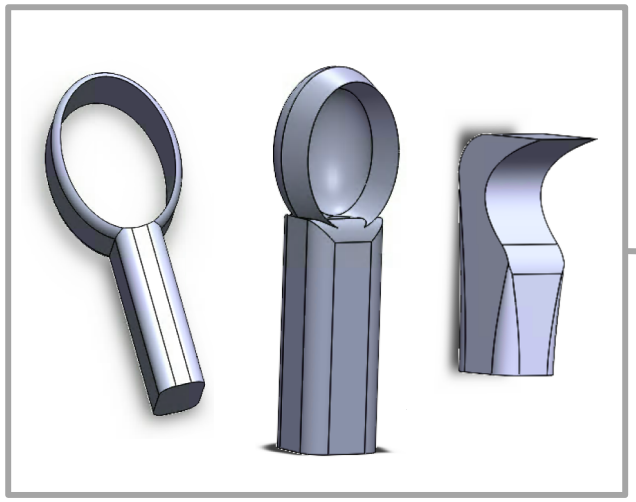
Friction on Hinges (N)	**6.18e-09**
Max force required to cut (N)	**27.6N**
Handle Force (N)	**9.17**
Force on Pin (N)	**3.93**



Experimental setup for cartilage cutting and force measurement



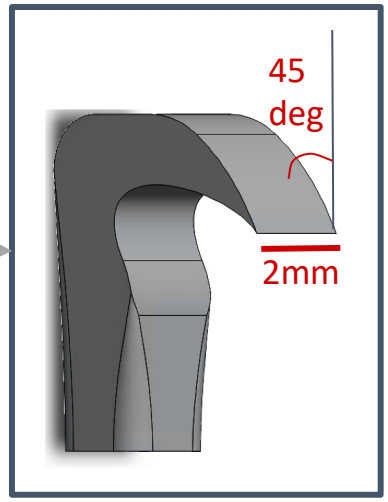
Blade Selection



Open curette

Closed curette

Anterior lesion curette



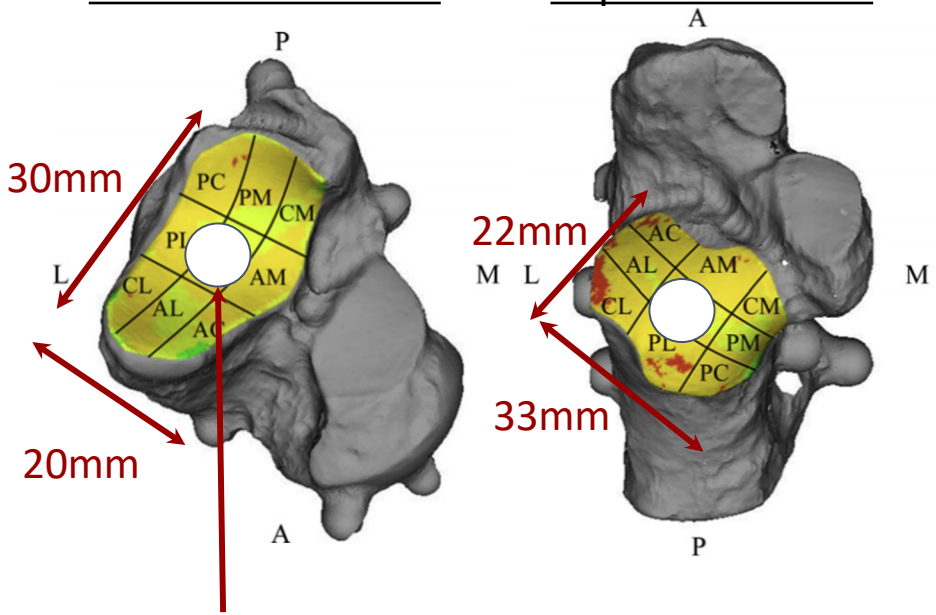
Modified anterior lesion curette

Force (N)	15		50	
Length to fixed end (mm)	5	10	5	10
Max Stress (N/m^2)	6E7		2E8	
Max Displacement (um)	1.7	5.7	2.7	9.1

Tungsten carbide yield strength: 3.35 - 5.30E8

Factor of safety: 2.5-8

Surface Area Calculations

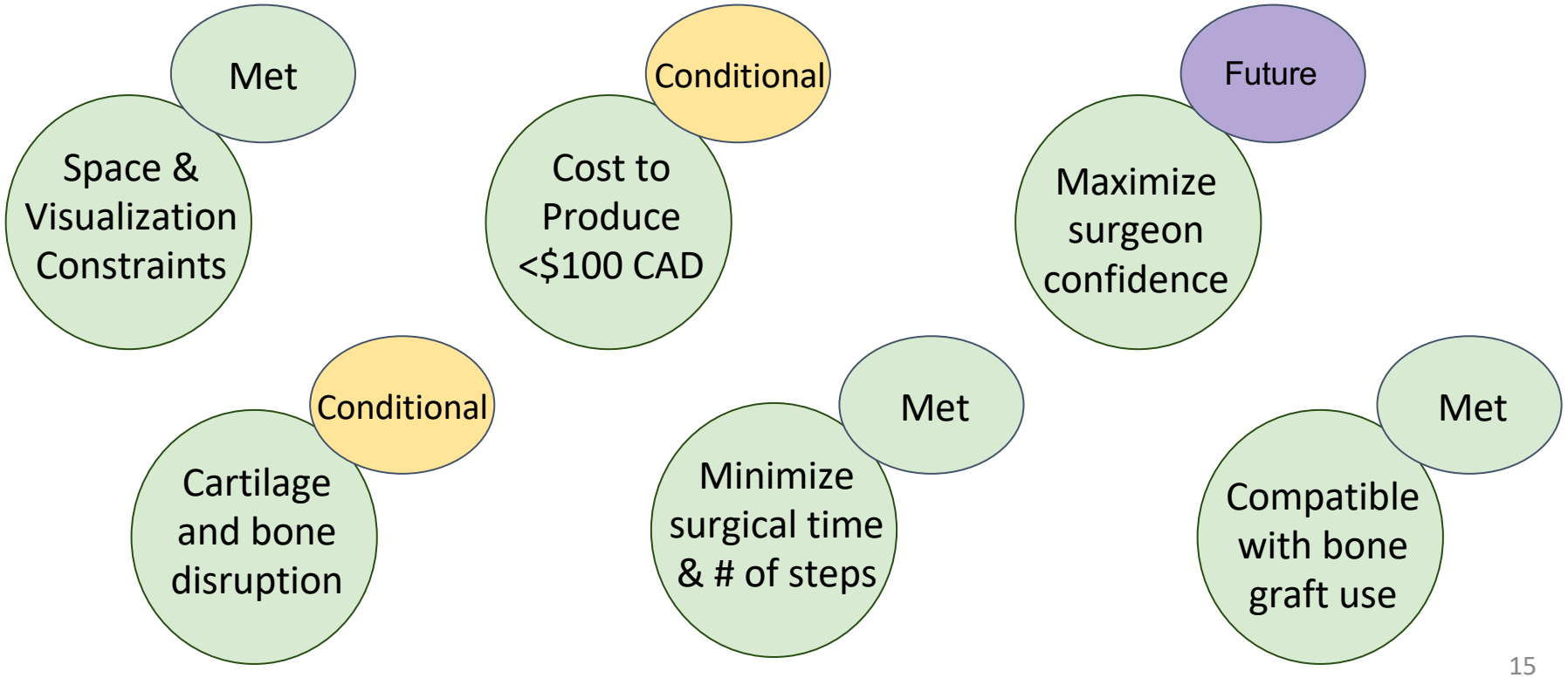


1 *Talus Area*: 600 mm²
Calcaneus Area: **726 mm²**

2 With scrapes of size 2mm x 10mm x 1mm:

SA scraped (%)	# of scrapes required
25%	7.5
50%	16.5

Summary, Design Successes and Failures



Next Steps

- Make a higher-fidelity prototypes
  - Give to surgeons, test forces and cartilage scraping
- Gather more feedback from surgeons
- Evaluate subtalar fusion rates

Acknowledgements

Dr. Spencer Montgomery, MD

Dr. Amit Atrey, MD

Dr. Amir Khoshbin, MD

Professor Chris Bouwmeester

Karly Franz

Gary Hoang

Dr. Jeremy LaMothe, MD

Dr. Mansur Halai, MD

Institute of Biomaterials & Biomedical Engineering
UNIVERSITY OF TORONTO

St. Michael's
Inspired Care.
Inspiring Science.

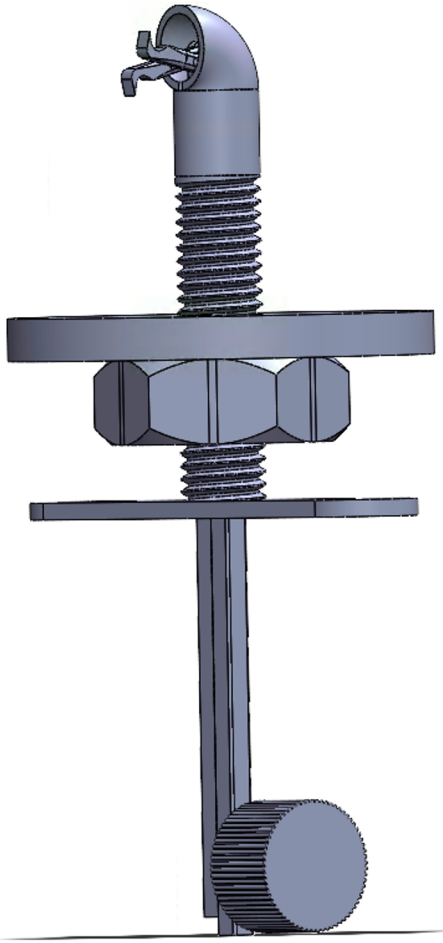
UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

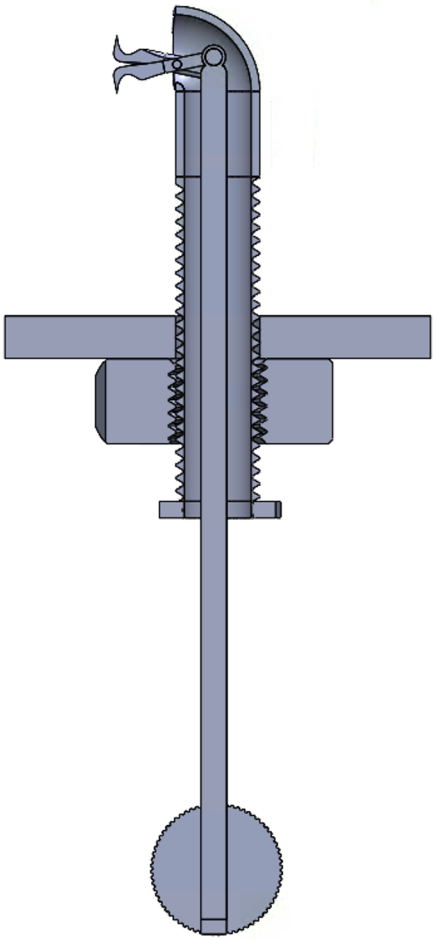
References

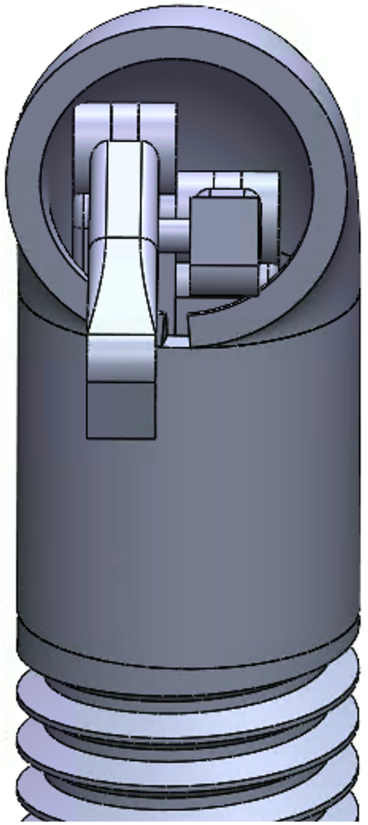
- K. Yoshimot, et al., “Does Preparation of the Subtalar Joint for Primary Union Affect Clinical Outcome in Patients Undergoing Intramedullary Nail for Rheumatoid Arthritis of the Hindfoot and Ankle?,” The Journal of Foot & Ankle Surgery, vol. 59, no. 5, pp. 984-987, 2020. Available: https://www.jfas.org/article/S1067-2516(20)30165-4/fulltext
- C. L. Brockett and G. J. Chapman, “Biomechanics of the ankle,” Orthopaedics and Trauma, vol. 30, no. 3, pp. 232-238, 2016. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4994968/.
- G. E. Quill, “Tibiotalocalcaneal Arthrodesis With Medullary Rod Fixation,” Techniques in Foot and Ankle Surgery, vol. 2, no. 2, pp. 135-143, 2003. Available: https://journals.lww.com/techfootankle/Abstract/2003/06000/Tibiotalocalcaneal_Arthrodesis_With_Medullary_Rod.9.aspx.
- B. H. Lee, C. Fang, R. Kunnasegaran, and G. Thevendran, “Tibiotalocalcaneal Arthrodesis With the Hindfoot Arthrodesis Nail: A Prospective Consecutive Series From a Single Institution,” The Journal of Foot & Ankle Surgery, vol. 57, no. 1, pp. 23-30, 2018. Available: https://www.jfas.org/article/S1067-2516(17)30358-7/fulltext.
- K. Akiyama, T. Sakai, N. Sugimoto, H. Yoshikawa, and K. Sugamoto, “Three-dimensional distribution of articular cartilage thickness in the elderly talus and calcaneus analyzing the subchondral bone plate density,” Osteoarthritis and Cartilage, vol. 20, no. 4, pp. 296-304, 2012. Available: http://www.sciencedirect.com/science/article/pii/S1063458412000209.
- Stryker, “Ankle Arthrodesis Nail: Operative Technique”, pp. 1-31, 2009. Available: https://www.strykermeded.com/media/1602/t2-ankle-arthrodesis-nail.pdf.

References

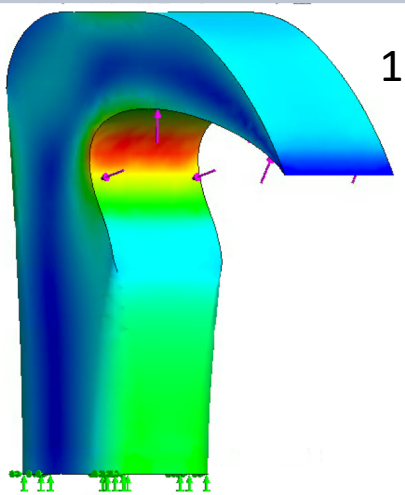
- P. Chen, J. Sui, and C. Wang, “Cutting Force Analysis of Bovine Acetabular Cartilage,” Procedia CIRP, vol. 89, pp. 189-193, 2020. Available: https://www.sciencedirect.com/science/article/pii/S2212827120305163.
- M. Mahvash, L.M. Voo, D. Kim, K. Jeung, J. Wainer, and A.M. Okamura, “Modeling the forces of cutting with scissors,” IEEE transactions on bio-medical engineering, vol. 55, no. 3, pp. 848-56, 2008. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2709828/.
- G. L. Bennett, B. Cameron, G. Njus, M. Saunders, and D. Kay, “Tibiotalocalcaneal Arthrodesis: A Biomechanical Assessment of Stability,” Foot & Ankle International, vol. 26, no. 7, pp. 530-536, 2005. Available: https://pubmed.ncbi.nlm.nih.gov/16045843/.
- Y. Yasui, C. P. Hannon, D. Seow, and J. G. Kennedy, “Ankle arthrodesis: A systematic approach and review of the literature,” World Journal of Orthopaedics, vol. 7, no. 11, pp. 700–708, 2016. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5112338/.
- M.M. Van Meter and R.A. Adam, “Costs associated with instrument sterilization in gynecologic surgery”, American Journal of Obstetrics & Gynecology, vol. 215, no. 5, 2016. Available: https://www.ajog.org/article/S0002-9378(16)30358-1/pdf.
- “ACUFEX Curettes,” Smith & Nephew. Available: https://www.smith-nephew.com/canada/products/extremities-and-limb-restoration/acufex-curettes/

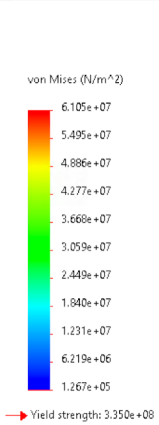


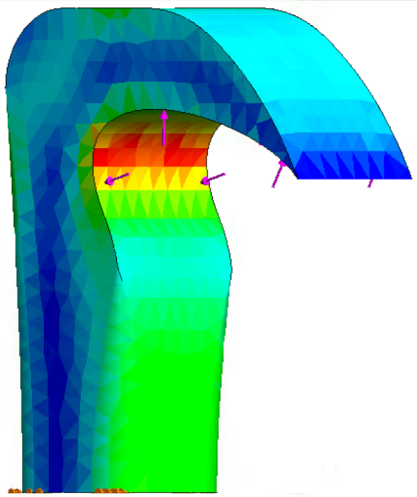


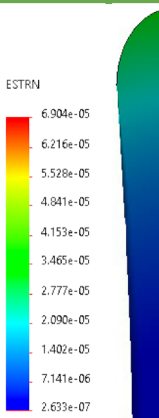


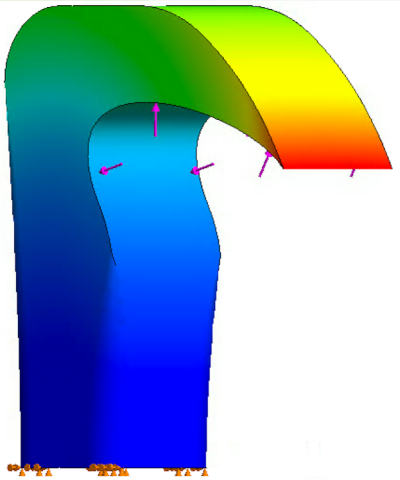
15N

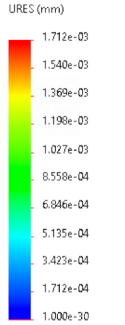



von Mises (N/m^2)
6.105e+07
5.495e+07
4.886e+07
4.277e+07
3.668e+07
3.059e+07
2.449e+07
1.840e+07
1.231e+07
6.219e+06
1.267e+05
Yield strength: 3.350e+08

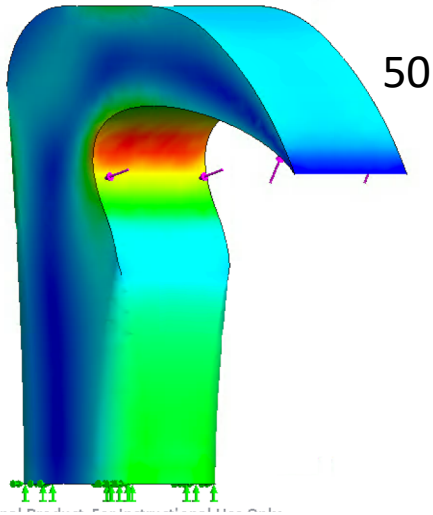


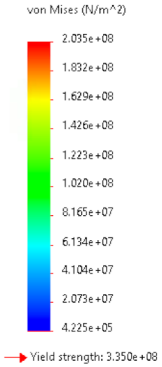

ESTRN
6.904e-05
6.216e-05
5.528e-05
4.841e-05
4.153e-05
3.465e-05
2.777e-05
2.090e-05
1.402e-05
7.141e-06
2.633e-07

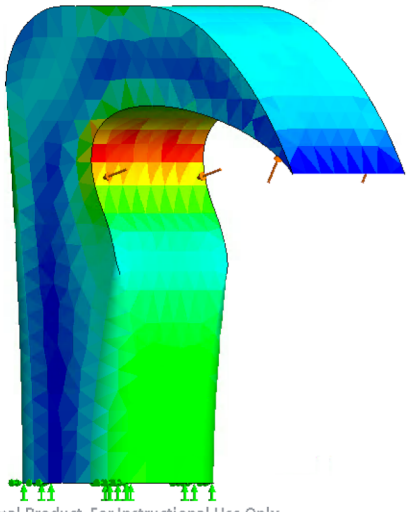


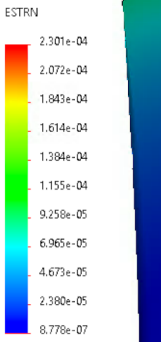

URES (mm)
1.712e-03
1.540e-03
1.369e-03
1.198e-03
1.027e-03
8.558e-04
6.846e-04
5.135e-04
3.423e-04
1.712e-04
1.000e-30

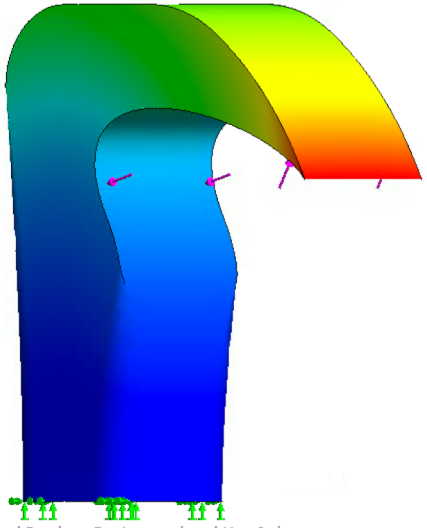
50N

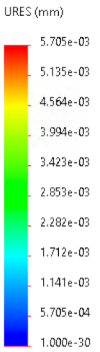



von Mises (N/m^2)
2.035e+08
1.832e+08
1.629e+08
1.426e+08
1.223e+08
1.020e+08
8.165e+07
6.134e+07
4.104e+07
2.073e+07
4.225e+05
Yield strength: 3.350e+08

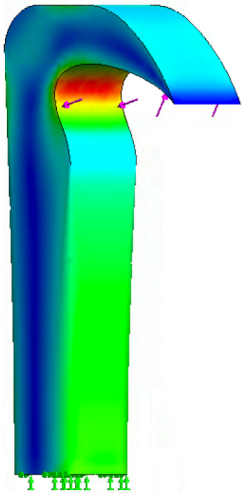


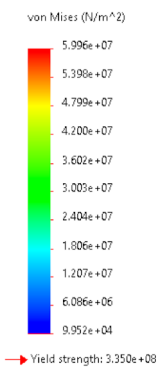

ESTRN
2.301e-04
2.072e-04
1.843e-04
1.614e-04
1.384e-04
1.155e-04
9.258e-05
6.965e-05
4.673e-05
2.380e-05
8.778e-07

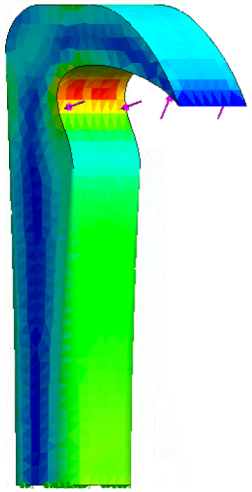


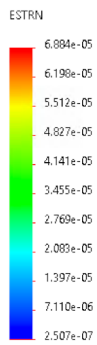

URES (mm)
5.705e-03
5.135e-03
4.564e-03
3.994e-03
3.423e-03
2.853e-03
2.282e-03
1.712e-03
1.141e-03
5.705e-04
1.000e-30

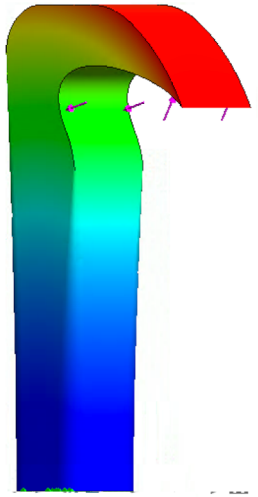
15N

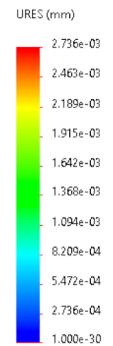



von Mises (N/m^2)
5.996e+07
5.398e+07
4.799e+07
4.200e+07
3.602e+07
3.003e+07
2.404e+07
1.806e+07
1.207e+07
6.086e+06
9.952e+04
Yield strength: 3.350e+08

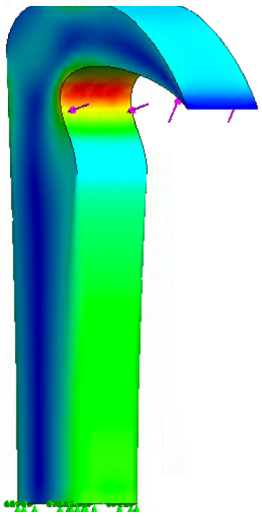


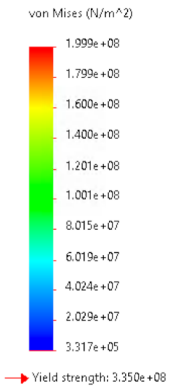

ESTRN
6.884e-05
6.198e-05
5.512e-05
4.827e-05
4.141e-05
3.455e-05
2.769e-05
2.083e-05
1.397e-05
7.110e-06
2.507e-07

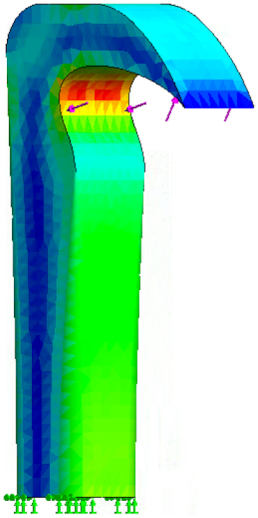


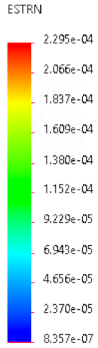

URES (mm)
2.736e-03
2.463e-03
2.189e-03
1.915e-03
1.642e-03
1.368e-03
1.094e-03
8.209e-04
5.472e-04
2.736e-04
1.000e-30

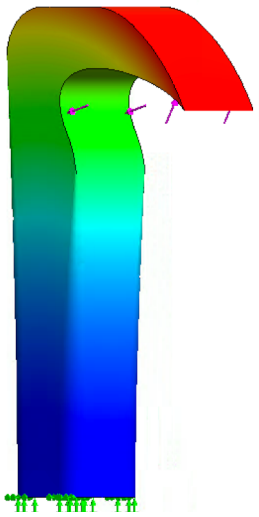
50N

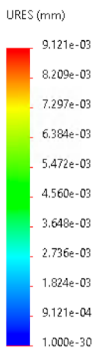



von Mises (N/m^2)
1.999e+08
1.799e+08
1.600e+08
1.400e+08
1.201e+08
1.001e+08
8.015e+07
6.019e+07
4.024e+07
2.029e+07
3.317e+05
Yield strength: 3.350e+08




ESTRN
2.295e-04
2.066e-04
1.837e-04
1.609e-04
1.380e-04
1.152e-04
9.229e-05
6.943e-05
4.656e-05
2.370e-05
8.357e-07




URES (mm)
9.121e-03
8.209e-03
7.297e-03
6.384e-03
5.472e-03
4.560e-03
3.648e-03
2.736e-03
1.824e-03
9.121e-04
1.000e-30