

Evaluation Of Mechanical Strength Of 3D-Printed L-Strut Implants In Septal Reconstruction Using Finite Element Analysis

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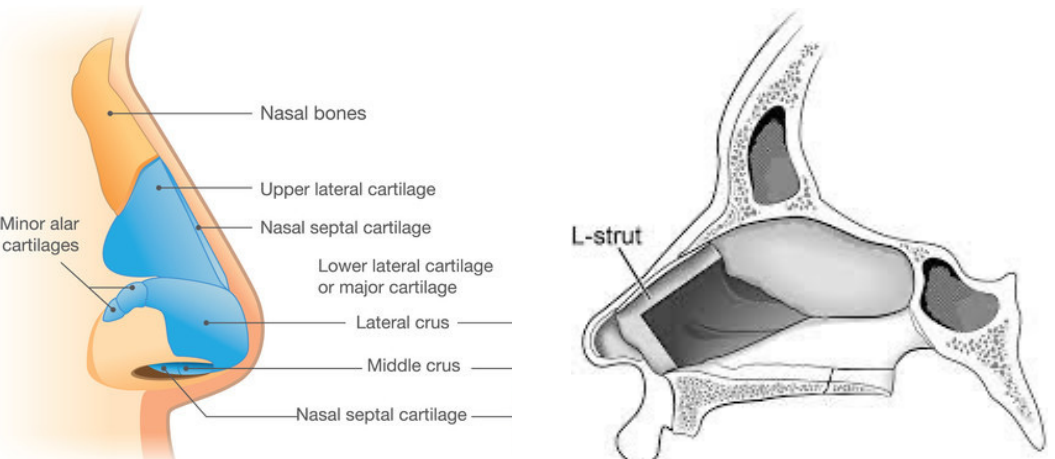
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BACKGROUND

- Autologous nasoseptal cartilage grafts can correct nasal asymmetry and deviation in rhinoplasty
- When there is limited autologous septal cartilage available (e.g., severe nasal deformations), options for reconstruction are limited and carry drawbacks
- 3D-printed L-strut implants may provide a solution but their mechanical strength is understudied
 - Silk fibroin-gelatin (SFG), polycaprolactone (PCL), and polylactide (PLA) are bioinks with potential to be used in nasoseptal constructs
- Computational simulations can evaluate 3D-printed implant strength and their potential to replace septal cartilage in septorhinoplasty.



PURPOSE

- We present Finite Element Analysis (FEA) models comparing the mechanical strength of 3D-printed SFG, PCL, and PLA implants with nasoseptal cartilage grafts
- We tested each material strategically at the “keystone” region, a critical location of nasal dorsum support
 - Keystone region represents where the perpendicular plate of the ethmoid bone, septal cartilage, nasal bones, and lateral nasal cartilages meet

METHODS

GEOMETRY

- Single layer, uniform solid body L-strut CAD model was created using ANSYS
- Dorsal limb width: 10mm; Caudal limb width: 15 mm
- To mimic nasal cartilage mechanical behavior, scaffold models had:
 - 50% porosity
 - 116 μm pore size
 - 90° lay-down angle between layers
 - Regular cubic lattice design with cylindrical fibers.

MATERIAL PROPERTIES

- All materials assumed to observe isotropic behavior
- All materials were modeled assuming linear elastic behavior

	Native Nasal Septal Cartilage	Silk Fibroin-Gelatin (SFG)	Polycaprolactone (PCL) Solid	Polycaprolactone (PCL) Scaffold	Polylactide (PLA)
Young's Modulus [MPa]	1.702	6.049	159.9	99.37	1482
Poisson Ratio (ν)	0.375	0.500	0.400	0.342	0.328
Density [kg/m ³]	1100	-	-	1130	1243

Table 1. Material properties of Nasal Septal Cartilage, Silk-Fibroin Gelatin (SFG), Polycaprolactone (PCL), and Polylactide (PLA).

RESULTS

Figure 2. Comparison of Total Deformation of Nasal Septal Cartilage Graft, Silk-Fibroin Gelatin (SFG), Polycaprolactone (PCL), and Polylactide (PLA) 3D Printed Solid Implants.

Red indicates the region of highest total deformation
Blue regions show minimal deformation.

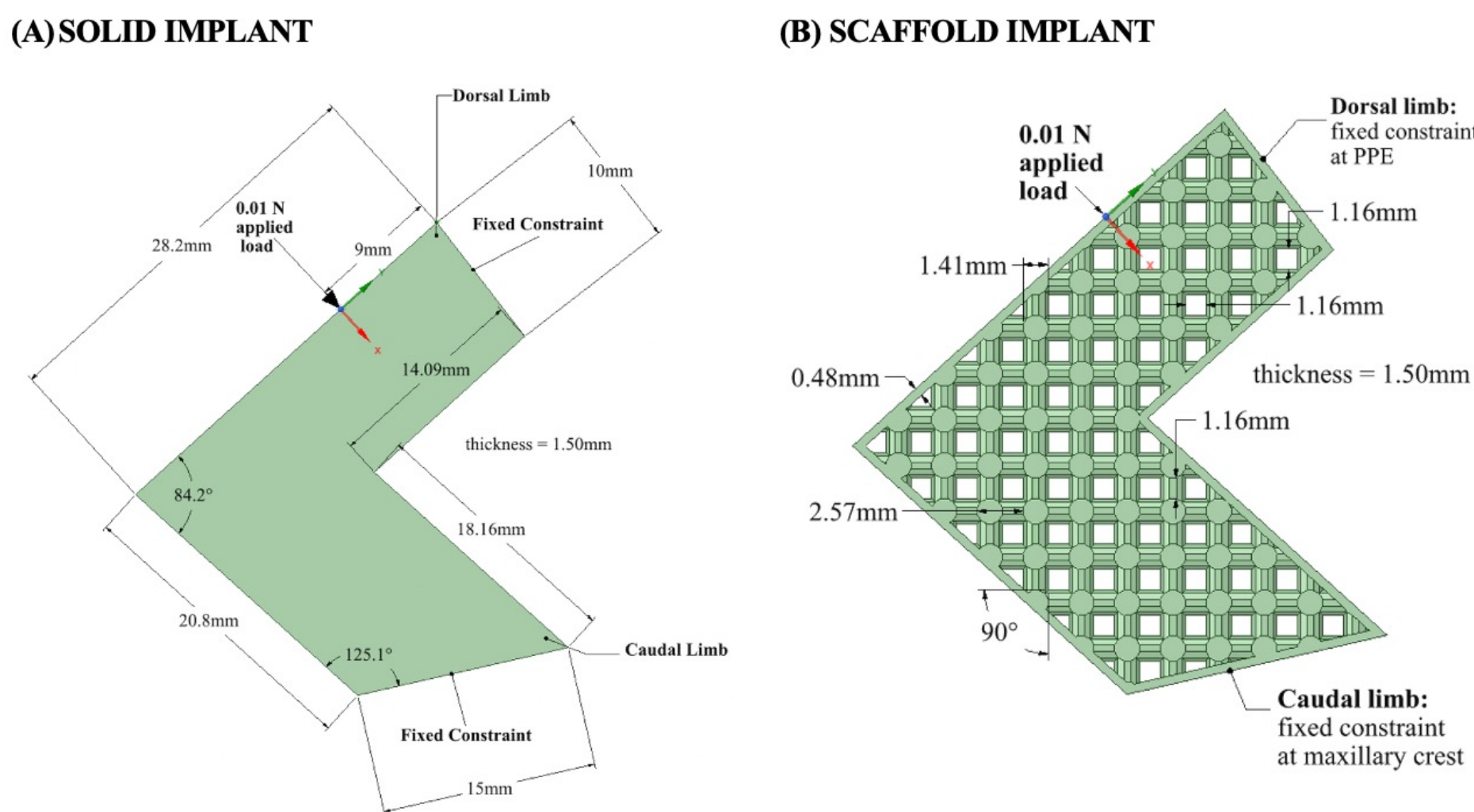
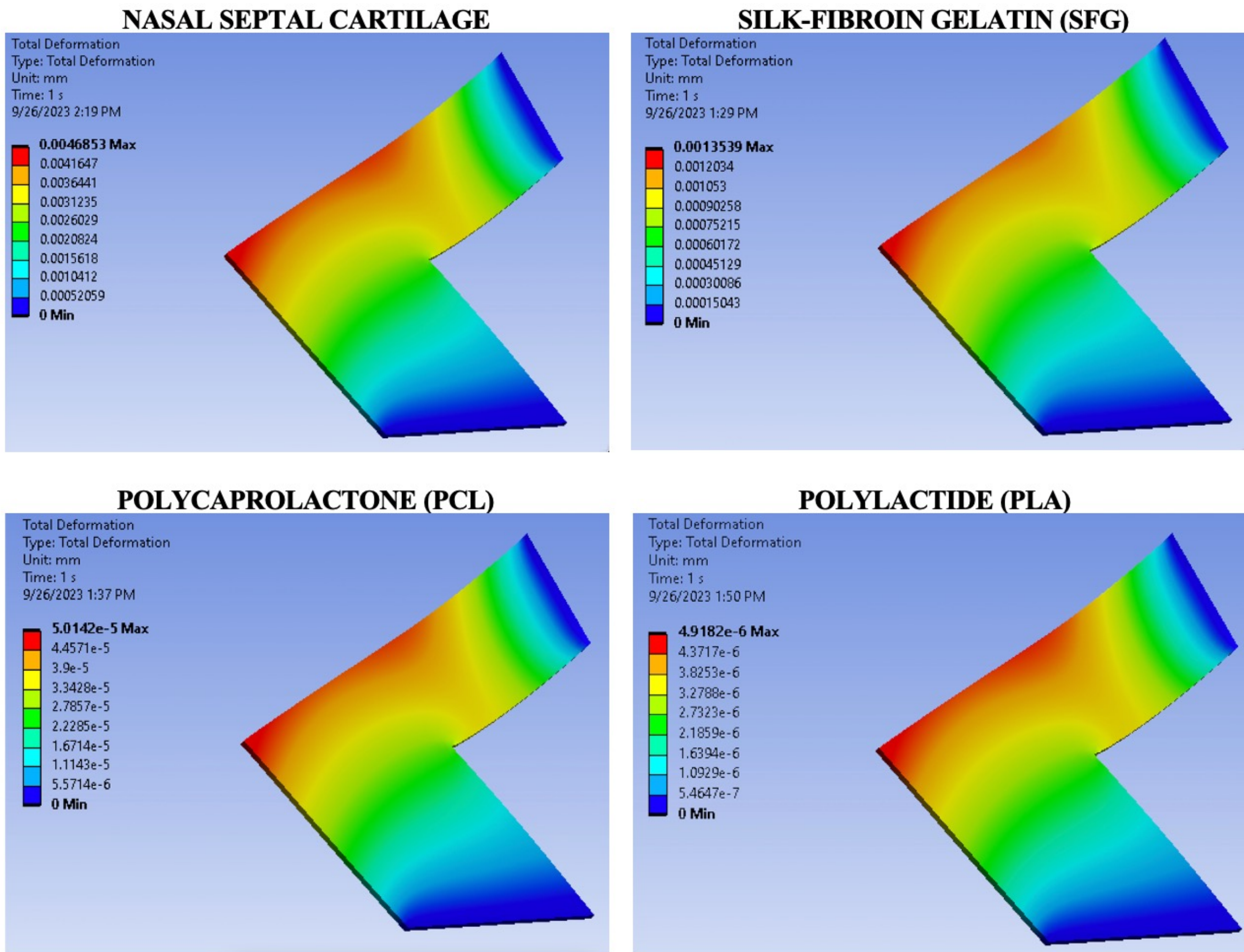


Figure 1: L-strut Computer-Aided Design Solid and Scaffold Models and Dimensions

FEA MODEL

- FEA was performed using ANSYS Mechanical
- Hexahedral mesh for solid and scaffold models
- The boundary conditions included fixed supports at the proximal faces of the dorsal and caudal limbs simulating fixation to the PPE and maxillary crest respectively
- A 0.01 N unidirectional load was applied at 9 mm from the proximal edge of the dorsal limb simulating the skin and subcutaneous tissue exerting a daily force at the average “keystone” region

	Material	Maximum Total Deformation [mm]	Maximum von-Mises Equivalent Stress [MPa]
SOLID	Native Nasal Septal Cartilage	4.685×10^{-3}	0.001270
	Silk-Fibroin Gelatin (SFG)	1.354×10^{-3}	0.001281
	Polycaprolactone (PCL)	5.014×10^{-5}	0.001265
	Polylactide (PLA)	4.918×10^{-6}	0.001283
SCAFFOLD	Silk-Fibroin Gelatin (SFG)	5.411×10^{-2}	0.008079
	Polycaprolactone (PCL)	3.424×10^{-3}	0.008157
	Polylactide (PLA)	2.165×10^{-4}	0.008127

Table 2: Maximum Total Deformation and Maximum von-Mises Equivalent Stress Results

DISCUSSION & IMPLICATIONS IN PRS

- 3D-printed solid SFG, PCL, and PLA and scaffold PCL and PLA models demonstrated lower deformations compared to cartilage.
 - Solid SFG balanced strength and flexibility.**
 - The maximum stress was below all materials' yield stresses suggesting their deformations are unlikely permanent under a daily load.
 - Our FEA models suggest that 3D-printed L-strut implants carry promising mechanical strength.
 - Solid SFG's results mimicked cartilage's mechanical behavior.
 - Scaffold SFG merits further optimization for potential use as cartilage replacement.**
 - 3D-printed septal cartilage replacement implants potentially enhances surgical management of patients with severe septal deformations in select settings.
- PLA exhibits the least deformation when compared with both the standard of care of nasal septal cartilage and 3D printed solid PCL and SFG implant materials.
 - All solid models and scaffold PCL and PLA experienced lower deformation than the nasal septal cartilage
 - Among solid models, PLA is the stiffest and septal cartilage is most flexible as expected
 - All scaffold models had higher deformations than their solid model counterparts with PLA being the stiffest and SFG is most flexible.
 - All maximum von-Mises stress results are well below any individual material's yield stress signifying potential to withstand a single daily physiological force without permanent deformation.

REFERENCES

- Kim DW, Gurney T. Management of naso-septal L-strut deformities. Facial Plast Surg. Feb 2006;22(1):9-27. doi:10.1055/s-2006-939948
- Wang H, Wang Z, Liu H, et al. Three-Dimensional Printing Strategies for Irregularly Shaped Cartilage Tissue Engineering: Current State and Challenges. Front Bioeng Biotechnol. 2021;9:777039. doi:10.3389/fbioe.2021.777039
- Chang B, Reighard C, Flanagan C, Hollister S, Zopf D. Evaluation of human nasal cartilage nonlinear and rate dependent mechanical properties. J Biomech. Feb 13 2020;100:109549. doi:10.1016/j.jbiomech.2019.109549
- Glass GE, Staruch RMT, Ruston J, East CA, Tan PJ. Beyond the L-Strut: Redefining the Biomechanics of Rhinoplasty Using Topographic Optimization Modeling. Aesthet Surg J. Nov 13 2019;39(12):1309-1318. doi:10.1093/asj/sjy301
- Griffin MF, Premakumar Y, Sefalian AM, Szarko M, Butler PE. Biomechanical characterisation of the human nasal cartilages; implications for tissue engineering. J Mater Sci Mater Med. Jan 2016;27(1):11. doi:10.1007/s10856-015-5619-8
- Yi HG, Choi YJ, Jung JW, et al. Three-dimensional printing of a patient-specific engineered nasal cartilage for augmentative rhinoplasty. J Tissue Eng. Jan-Dec 2019;10:2041731418824797. doi:10.1177/2041731418824797
- Paul N, Messinger K, Liu YF, Kwon DI, Kim CH, Inman JC. A Model to Estimate L-Strut Strength With an Emphasis on Thickness. JAMA Facial Plast Surg. Jul 1 2016;18(4):269-76. doi:10.1001/jamafacial.2016.0136
- Liu YF, Messinger K, Inman JC. Yield Strength Testing in Human Cadaver Nasal Septal Cartilage and L-Strut Constructs. JAMA Facial Plast Surg. Jan 1 2017;19(1):40-45. doi:10.1001/jamafacial.2016.1180
- Lee JS, Lee DC, Ha DH, Kim SW, Cho DW. Redefining the septal L-strut in septal surgery. PLoS One. 2015;10(3):e0119996. doi:10.1371/journal.pone.0119996

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