EMS690U - Integrated Design Project

Individual Detailed Design Report

Octopus Inspired Soft Robotic Gripper for Heart Surgery

Overall Design & Prototyping

Author: Shannen Venethethan

Student ID: 210478226

Advisor: Dr S.M.Hadi Sadati

April 2025

Abstract

This report presents an FDM 3D Printed surgical soft robotic gripper for MICS CABG. The design is inspired by the octopus vulgaris and features passive conical suction cups which act as a fail-safe for the vacuum system also used to enhance adhesion. It is printed using ISO 10993-certified TPU 85A.The gripper can be produced for as low as £0.30 of material. Passive adhesion tests were successful; however, the bending test was limited by the stiffness of the part and the use of a single pump. Future improvement includes Ansys simulation, Silicone prototypes using 3d printed moulded parts, brick layering slicing and SLA/DLP printing. Throughout the project, adherence to both the IMechE and Engineering Council Codes of Conduct was maintained. With further refinement the design could democratize access to safer and lower cost cutting edge surgical techniques.

Table of Contents

List of Symbols

Symbol	Meaning	Page
M_1	Material index	12
E	Young's modulus	12
ε_y	Elongation at yield	12

1. Introduction

1.1 Background and context

While there have been many advances in the medical field, such as in imaging, diagnostics, and surgeries techniques , tools for tissue manipulation have practically remained stagnant. The current standard is a relatively hard suction cup coupled with an open vacuum system mounted on a robotic arm. Although these designs are tried and tested, they often lack flexibility and sensitivity when interacting with delicate tissues, such as a human heart. This poses a significant risk of accidental damage during surgeries, which could result in patient casualties. During surgeries, especially those involving soft organs and/or minimally invasive approaches, the need for adaptable and gentle instruments is critical. Current devices are not only comparatively rigid but are also costly, both in terms of upfront cost and ongoing maintenance. These high costs keep these lower-risk surgeries out of reach in many lower-GDP or developing countries. This project aims to address these challenges by seeking inspiration from nature, specifically the Octopus vulgaris (Common Octopus), with its soft and flexible limbs that operate to grasp in a fluid and adaptable motion with its soft and flexible limbs which operate to grasp in a fluid and adaptable motion. Its suckers have also inspired modern surgical suction cups, as well as elements of this project's design. A soft robotic device inspired by this creature could help in both the stabilization of the tissue and positioning in minimally invasive surgeries. One of the main goals of this paper is to propose an open-source, 3D printable vacuum-based gripper that can be printed on demand anywhere in the world with access to a relatively low-cost 3D printer and access to electricity. This could lead to broader global access and experience with minimally invasive surgical techniques.

1.2 What is MICS CABG?

Minimally Invasive Coronary Artery Bypass Grafting (MICS CABG) is a proven surgical technique which was introduced in the mid-1990s to reduce trauma and recovery times compared to a traditional sternotomy. Dr Randal K. Wolf was among the first to perform a thoracoscopic internal mammary artery harvests in 1995. This later became known as the "Wolf technique" [1]. MICS CABG uses a small thoracotomy incision, typically grafting the left internal mammary artery (LIMA) to the left anterior descending (LAD) artery. The benefits of MICS CABG encompass reduced pain, faster recovery and shorter hospital stays. These benefits make it ideal for both first and repeat coronary bypass cases [2].

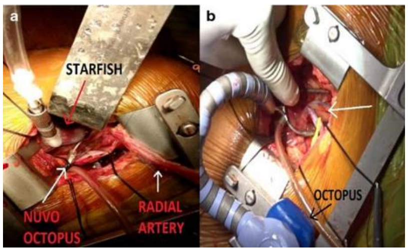


FIG 1. MICS CABG [2]

1.3 Octopus Bio-inspiration

The common octopus scientifically known as the Octopus vulgaris, is a master of adaptability due to its soft and flexible limbs as well as its suction cups which grip to most underwater surfaces allowing it to travel on the ocean floor with minimal effort. Despite having no rigid skeleton its tentacles can bend, elongate stiffen and conform to surfaces while also providing enough force to propel itself hance it combines strength and compliance with precision. Its suction cups driven by muscular hydrostats provide reversible adhesion and fine control under water. Given blood heterogeneous mixture made up of 90% water [4], drawing inspiration from the Octopus vulgaris for a delicate surgical gripper is a scientifically grounded and logical design approach.

FIG 2 Octopus vulgaris [3]

1.4 MSF and Third world

Médecins Sans Frontières (MSF) is a global operation who operate in conflict prone region and ones where 'out-of-pocket healthcare spending can harm the house's budget' [5]. While advance procedure like MICS CABG is magnitude of time more effective in terms of patient recovery, they are often no feasible due to 'financial sustainability of national health systems' [5]. However, if the need for specialized equipment was minimised or even eliminated by being able to 3D print these medical grade tools; it could increase global adoption of more minimally invasive surgeries. The use of 3D printing is also relevant to MSF doctors as they could potentially print medical equipment on demand at point of care minimizing unused equipment hance expedition payloads.

MEDECINS SANS FRONTIERES

FIG 3 MSF logo [6]

1.5 3D printing

3D printing is transforming the healthcare industry as it makes prototyping and tool development cheaper and faster, as stated: '3D printing technology could revolutionize the world... a fast, reliable, and repeatable means of producing tailor-made products' [7]. This technology offers rapid and cost-effective production of medical-grade equipment that can be 'customized on demand at the point of care' [8]. The technology already allows soft prosthetics to be produced for under £30, compared to thousands via traditional manufacturing [9], albeit for specific scenarios. With desktop FDM 3D printers designed to be easy to use by companies such as Bamboo Lab [10] and starting from £169 [10] at the time of writing, it could make it accessible in lower GDP countries to design and manufacture medical-grade equipment using appropriate filaments and sterilization techniques.

FIG 4 Bamboo Lab A1 [10]

1.6 Report structure

This report is structure to guide the reader through the research and development for a novel design heart positioner and stabilizer hybrid for MICS CABG. In Section 2 a relevant and current literature review will be presented covering prior work in this field as well as key innovation. Section 3 will outline the design process from concept to modelling and iteration through to simulations and manufacturing. Section 4 offers a detailed analysis of the prototypes and testing concluding with an ethical assessment of the paper. Section 5 provides a discussion and future work recommendations. Finally concluding with section 6 to summarize the key insight of the paper.

2. Literature Review

2.1 InstaGrasp [11]

The instagrap present in this paper is a Hobby FDM 3D printable vacuum based robotic gripper. This prototype was printed in multiple parts on a Prusa MK3s which is a very common desktop 3d printer. The materials used in the parts PLA and NinjaFlex TPU 95A both of which are readily available. The use of TPU 95A means that the contact points are deformable which allows it to conform to different sized objects. The part was tested to have a lifespan of around 86,000 repetitions before any PLA parts needed to be replaced. The actuation of the prototype mechanical based on servos which retract a tendent to grasp. This paper highlights the capabilities of 3d printing as a rapid prototyping solution to complex problems.

FIG 5 InstaGrasp [11]

2.2 Thermal Post-Processing [12]

This paper demonstrates also uses Hobby grade FDM 3D printers referred as FFF printers; however, it prints its parts with polypropylene (PP). This paper highlights a very real prominent issue when trying to use FDM parts with vacuum system namely porosity and outgassing under vacuum. To combat this issue this paper uses heat treatment at 400°C and 98% infill overlap. The specific heat treatment used in the paper avoid the deformation which would normally occur if oven treated. It can be shown that a relatively successful vacuum was pulled at 0.4 mTorr which could make it viable for medical application. The relative success with 3d printed parts and vacuum suggest low- resource fabrication is feasible.

FIG 6 PP suction cup [12]

2.3 Pneumatic fingers[13]:

The gripper featured in this paper is a soft vacuum actuated one meaning its comparatively safer for human interaction. It is can also be printed on a hobby grade 3d printer. It is made from TPU and is shown to be able to hold a vacuum and deform linearly. It can also be noted TPU is bio compatible. This design features localised bending due to the slits ingrained in its design. This paper also used Finite element modelling to predict the behaviour of the gripper pre-prototyping. In the paper the proposed gripper can be observed to grasp a variety of object differing in shape. The pneumatic system used to actuate this specific gripper is considered low pressure hance reducing the risk of failure and improving operational safety.

FIG 7 Pneumatic fingers [13]

2.4 SORO soft robotics [14]

This paper also features a vacuum actuated soft robotic gripper also take bio inspiration from marine life; however, in this case it's the fern sporangium. This gripper is also made from Ninja flex TPU. The design was also simulated using FEM tool to check how it would behave. This gripper was able to apply a force of 16N when tested and has a payload to weight ratio of 26:1. The gripper also made to run on 5.45Hz bandwidth for the fasted dynamic response. It was also able to stay usable up to 123,00 repetitions. Vacuum based actuation avoids the bulging is common in positive pressure systems. This design could be adapted directly applicable for a soft surgical tool for confined and delicate spaces.

FIG 8 SORO soft robotics [14]

2.5 Linear Soft Vacuum Actuators (LSVA) [15]

Linear Soft Vacuum Actuators (LSVA) are robotic actuators that act in a linear motion. The actuator presented in the paper is 3d printed out of TPU on a hobby grade 3d printer. It was observed that the prototype in the paper was able to achieve up to 27N of blocked forces with high actuation speed due to the bandwidth of 6.49 Hz under 95.7% vacuum. Given it soft body structure it is generally considered safe to use with delicate tissue except the fact it operates on an open vacuum thus not making it suitable for MICS CABG. In can also be noted that the design presented is scalable and if the scaled to 30mm in diameter it is capable of producing up to 60.58 N of force.

FIG 9 LSVA [15]

2.6 Actuators with integrated resistive sensors [16]

In this paper a prototype for a soft pneumatic actuators (SPA) is presented which can be printed on a hobby grade multi material grade 3d printer. The material used was two type of TPU one Vario Shore TPU (VTPU) at a shore hardness of 67A and CTPU 92A. Vario shore TPU allows hobby grade 3d printers to print much more flexible TPU by altering the print temperature at the nozzle. This prototype used the filament additive manufacturing as an advantage and embedded sensors during the print by pausing it and restarting. Finite element modelling (FEM) in Ansys [16] was also used to simulate the motion of the gripper prior to prototype making. This prototype is actuated using negative pressure. In the testing section in can be observed that the part was resilient during the 10 dynamic actuation. This prototype cam also be successfully adapted into a rehabilitation glove, showing its medical resilience.

FIG 10 actuators with integrated resistive sensors [16]

2.7 Octopus-Inspired Underwater Soft Robotic Gripper [17]

This design is closely inspired by the Octopus vulgaris. It is made to imitate the octopus's motion when swimming and crawling as well as its grasping capabilities. The design features 6 tapered arms and 5 suction cups per arm each capable of exerting positive pressure for grip release and negative pressure for adhesion. The tentacle can bend up to 161⁰ degrees when under 120 Kpa of vacuum. The suckers were able to achieve an adhesion ratio of up to 7.16 and grasping force reached 3.8N. Finite element analysis (FEA) was also carried out to simulate the motion of the prototype pre-production. The prototype shown was also able to move at around 25 mm/s and weights a total of approximately 1 Kg. Material used was a soft silicone elastomer.

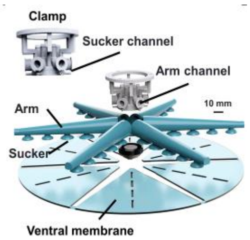


FIG 11 Overview [17]

2.8 Octopus sucker bio inspiration [18]

In this paper the Author FDM printed an Octopus vulgaris sucker in polylactic acid (PLA) to a high degree of detail internally and compared it to simpler internal structures. It can be observed that the octopus internal geometry performed the traditional cuboidal and cylindrical ones, as it was able to withstand a force of 24.47 Mpa compared to around 17 Mpa for the other 2 tested geometries. The octopus inspired internal structure was also able to absorb 61.38% higher energy which is essential when working around delicate tissues. In Finite element analysis (FEA) the octopus inspired one had a much more uniform stress distribution and a greater surface area both of which are essential for vacuum efficiency.

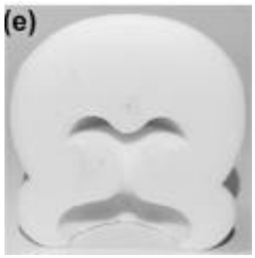


FIG 12 cross section view [18]

3. Design Process

3.1 Objectives and Constraints

This project aims to develop a prototype for an open-source soft robotic gripper that can be used for Minimally Invasive Cardiac Surgery Coronary Artery Bypass Grafting (MICS CABG). The prototype must be cheaper to manufacture compared to currently used tools such as the Octopus Nuvo [19] and the Starfish NS [20] which approximately cost around a thousand GBP [19]. It will also be designed to replace both tools such that less incision will need to be performed. The gripped must be designed for print in place manufacturing and must try to reduce post processing. It must also take design inspiration from the Octopus vulgaris. The actuation mechanism chooses for this project was a negative vacuum, hance the 3D printed part must also be fully sealed and airtight. To take a step forward in innovation the gripper will also feature a camera in the centre of the gripper, where the beak of an octopus would be. This will allow surgeons to have eyes on the operation site further reducing the amount of incision required. To allow for more repeatable adhesion as well as the suction cups a medical grade adhesive will be used at edge of the suction cup. All part of the gripper must be bio-compatible to the ISO 10993 standard [21].

FIG 13 Octopus Nuvo [19]

FIG 14 Starfish NS [20]

3.2 Initial design

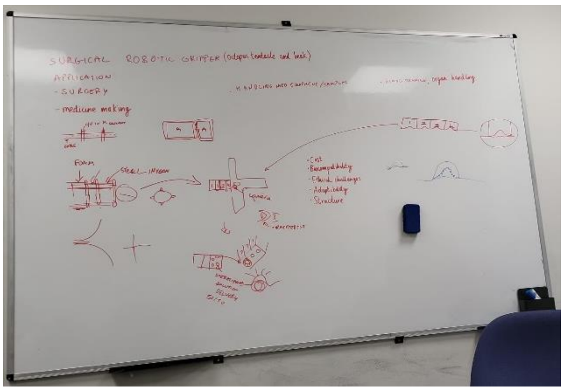


FIG 15 original brainstorm

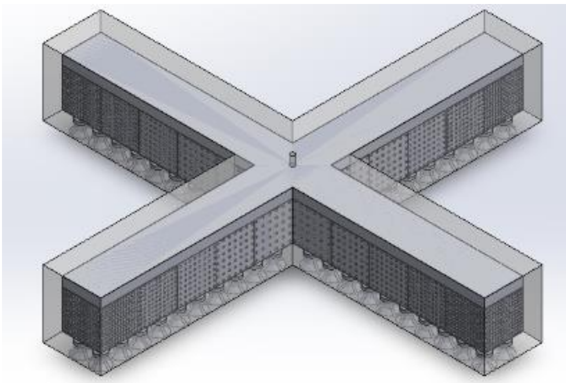


FIG 16 First CAD model [22][23]

So at the start of the project, we were given the brief of making some sort of gripper. As a team it was decided that a medical gripper would be the focus of the project as highlighted in FIG 15. Given the inspiration from our advisors Dr S.M.Hadi Sadati paper on Gripe-Needle [24] as a team it was agreed the project would also draw inspiration from the octopus vulgaris. In the brainstorming phase inspiration was also drawn from the paper on granular jamming [25] hance the original design consisted of multiple varied stiffness foams arranged in a linear pattern in order of stiffness. Where the least stiff would be placed closer to the middle and the stiffest would be placed at the extremity of the tentacle. This would then be encased in silicone which would make it airtight. When a vacuum would then be consequently applied the extremities would come together under the centre of mass. This design then progressed into CAD FIG 16 where it was then decided that 3D printing would be an integral part of this project. Hance the original design was adapted. The foam cubes were then replaced with TPU structures with evenly spaced hole as to allow a vacuum to be pulled while simultaneously varying the stiffness as it reached the extremity of the tentacle. A PETG Plate was then added to the top of the TPU cubes to provide a stiffer side such that when a vacuum would be applied the structure would deform in the desired direction. This piece was designed to be printed separately, then added with a pause print such that it would be integrated in the final piece. It can be noted that with current linear slicing FDM 3d printing the proposed TPU cubes would be impossible to manufacture. This could be solved by using non-planar slicing [26].

3.3 Design progression

Following the second iteration seen in the previous section. The part was complexly redesign as to miniaturize it so it would suit the project aim of being used in MICS CABG. Given the confined size requirement, the TPU blocks and PETG back plate was scraped and in place the part was now designed to be completely made of TPU. This forced us to get creative on how to make the make the wanted actuation possible. The part also went from having multiple rows of suction punch to having only 4 places the extremities of the tentacle. This is also when the decision to have a closed loop vacuum system was adopted as the suction cup has a thinner layer of TPU which would deform under vacuum allowing it to adhere to the substrate.

V3:

This design is the main one that was iterated until the final prototype. It features 2 chambers with connection at the top of the part for vacuum to be pulled. The top one in this case is incorrectly designed as the slope in the middle of part would make it contract upward instead of downwards. The second chamber below it, was design such that the 4 suction cups receive equal vacuum force.

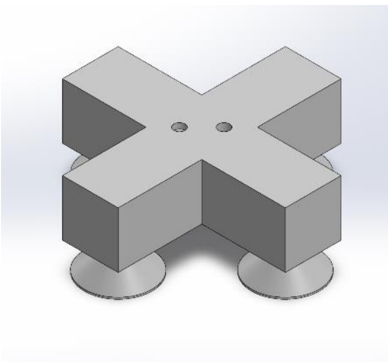


FIG 17 isometric V3 [23]

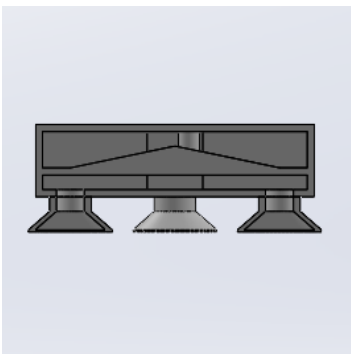


FIG 18 Front middle slice [23]

V4:

This version is much more compact and still features the 2-chamber design, It is apparent however that the second chamber cannot be connected to a vacuum source which is a design iteration error.

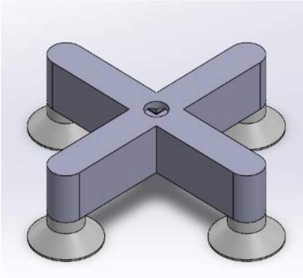


FIG 19 isometric V4 [23]

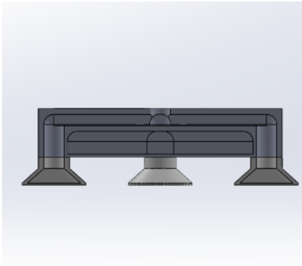


FIG 20 Front middle slice v4 [23]

V5:

This version of also opts for the 2-chamber design however this time although more compact that v3 it fixes the pitfall of V4 and the vacuum source can now be connected this was done by adding circular section in the middle of the design. This version is the first to be able to house the camera that will be integrated in the final prototype.

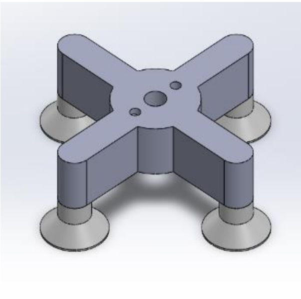


FIG 21 Isometric v5 [23]

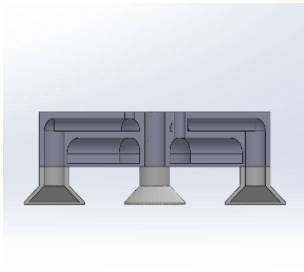


FIG 22 Front middle slice v5 [23]

V6:

Version 6 is the first one that uses a single vacuum chamber and places the splitting of the vacuum pressure outside the design. This can be done using tube splitters. This allows the part to be 3d printable as the feature between the two chambers was not able to be printed as it would have to be printed in mid-air. Finally, the second most important addition to this version is that the suction cup now features flaps that are curved up. This allows the suction cup to seal better when vacuum is applied as the upward flap would now be in contact with the substrate.

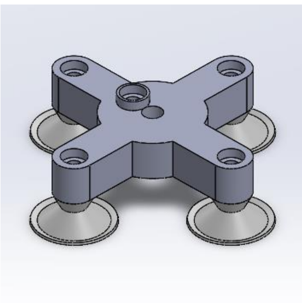


FIG 23 Isometric v6 [23]

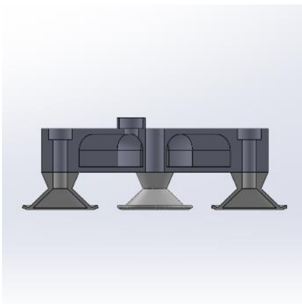


FIG 24 Front middle slice v6 [23]

V7:

The next iteration stays mostly consistent except for suction cup now being conical instead of flat. This allows the gripper to act as a normal suction cup on initial contact and then once onto the substrate pull negative vacuum and adhere even more. This in theory would act as a fail-safe mechanism in the even the vacuum source malfunctions, The gripper would still be holding in place. This is critical in a surgical environment.

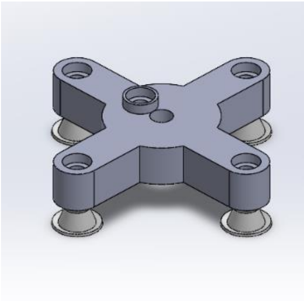


FIG 25 Isometric v7 [23]

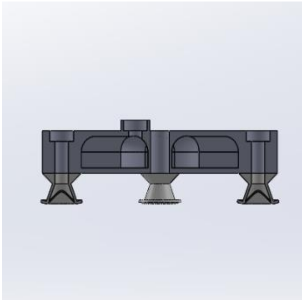


FIG 26 Front middle slice v7 [23]

V8:

This is a side iteration of version 6 to test methods to make the bottom of the vacuum chamber more bendable while maintaining structural integrity and air tightness when 3D printing

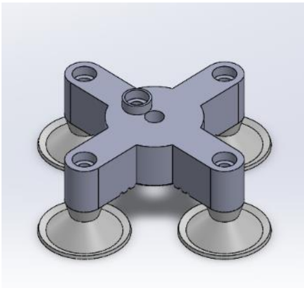


FIG 27 Isometric v8 [23]

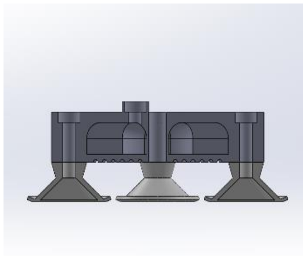


FIG 28 Front middle slice v8 [23]

3.4 Material selection

Given the design constraints, 3d printable filaments were researched and the choice of TPU 85A was reached using Ganta Edu pack [27]. A material index (M_1) was chosen to be Young's modulus (E) over elongation at yield (ε_y). To keep to the constraints, it was limited by price at a maximum of 4 GBP /Kg of material as well as the need to be biocompatible FIG 29. TPU 85A option from multiple manufacturers were considered from Siraya tech [28] and Ninja flex [29]. The Siraya tech [28] was chosen due to its availability and ISO 10993 certification FIG 30.

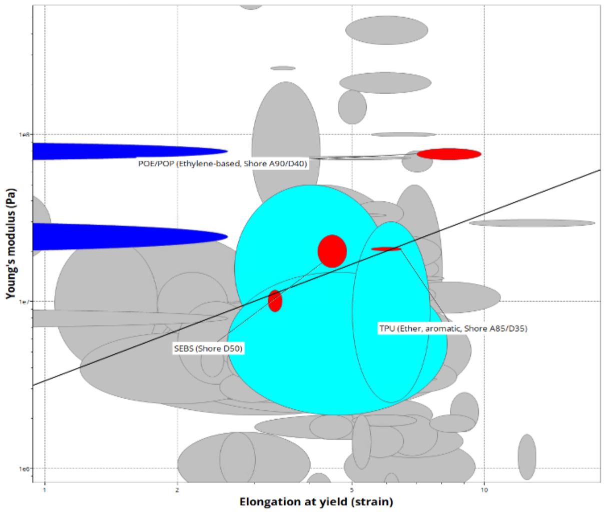
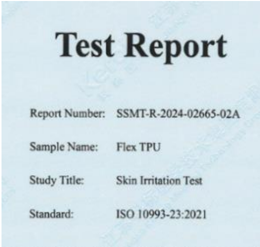


FIG 29 Ashby diagram [27]


Test Report

Report Number: SSMT-R-2024-02665-02A

Sample Name: Flex TPU

Study Title: Skin Irritation Test

Standard: ISO 10993-23:2021

FIG 30 ISO 10993 certification [30]

$$M_1 = \frac{\varepsilon_y}{E}$$

EQ 1 Material index

3.5 Current Prototype

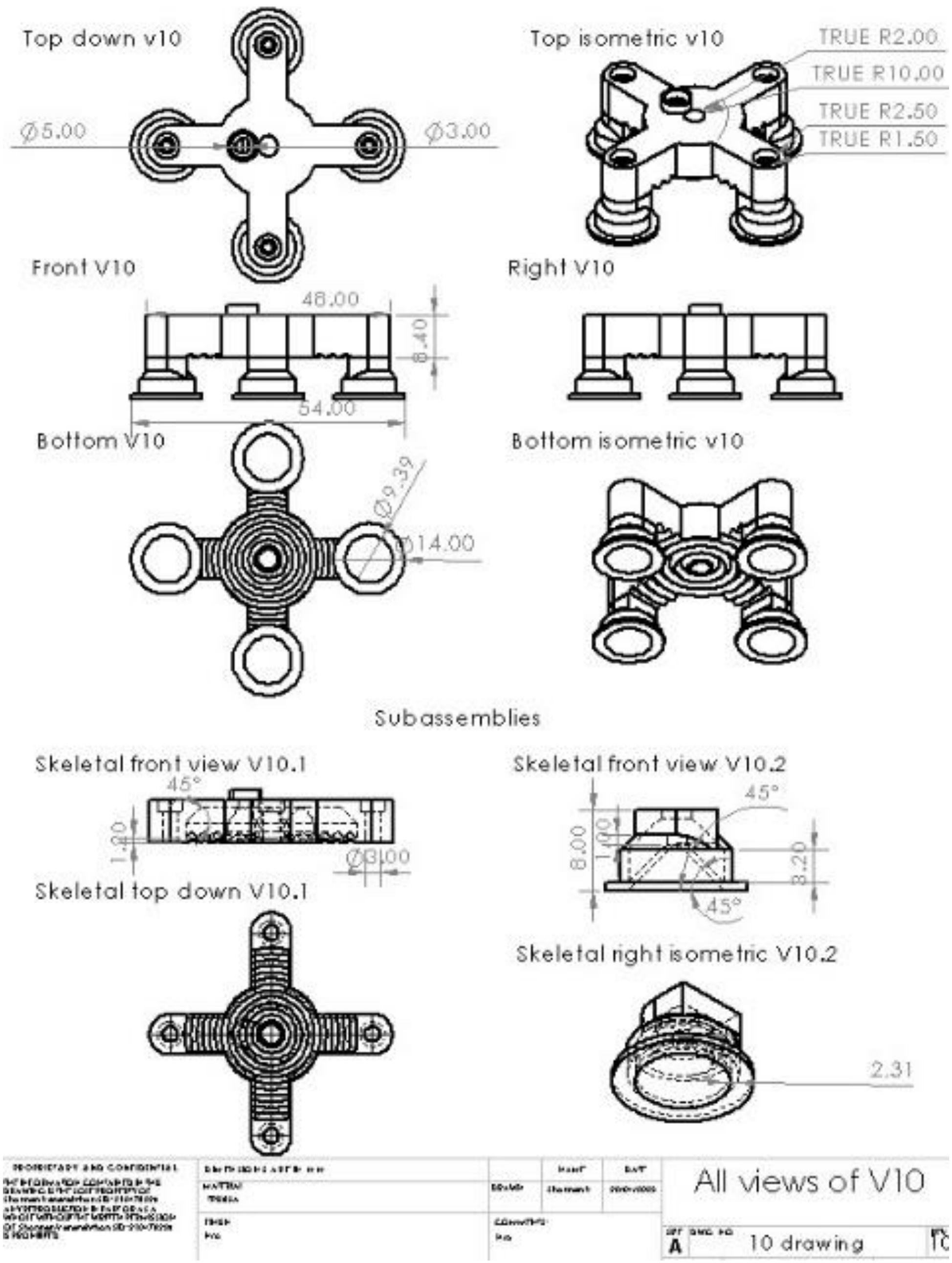


FIG 31 Engineering drawing V9 [23]

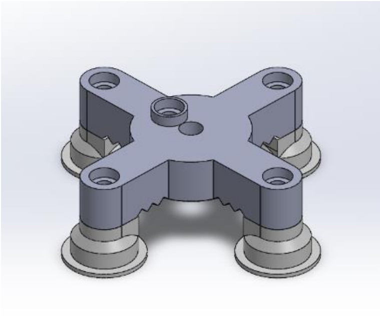


FIG 32 Isometric v9 [23]

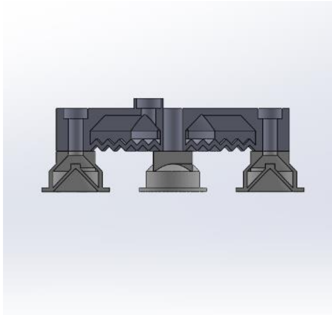


FIG 33 Front middle slice v9 [23]

Given all the previous iteration the final pre-manufacturing version aims to address all the concerns of the design constrains with added functionalities. The final version is similar in dimensions to v6 and includes the raised slots for the vacuum tubing to be attached. It also keeps to the design of single chamber with non-integrated vacuum distribution. The part is design to be printed all in once piece like all the previous iteration except version 1 and 2. The hole for the camera has also been integrated in the centre of the gripper. The upper walls of the cavity have been chamfered to 45 degrees to allow the part to be 3D printed with no support in the cavity [31]. The part also features an Octopus inspired cavity in the suction cup which as the paper [18] suggested it would increase its adherence potential. The walls of the 3D print are 0.8 mm both suction cup and main body this was a design choice a its 2x the printing nozzle size of 0.4 mm this allows for a wall thickness of 2 which increases it air tightness potential. Finally, the zig-zag circular pattern at the bottom of the vacuum chamber was designed to be less resistant to bending, hance when a vacuum is to be pulled it is design to contract allowing the tentacle extremities of the part to come together under the part.

3.6 Simulation analysis

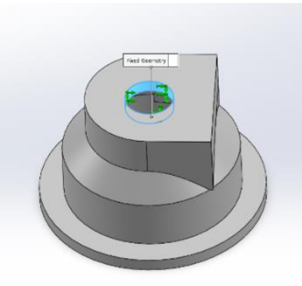


FIG 34 Fixed geometry suction cup [23]

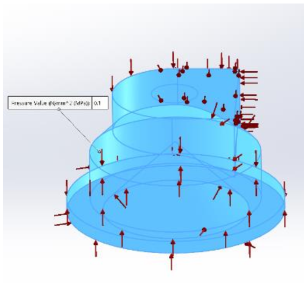


FIG 35 Surface pressure suction cup [23]

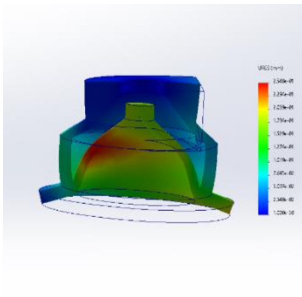


FIG 36 Simulation deformation suction cup [23]

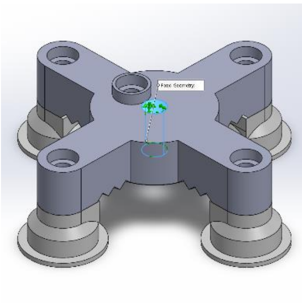


FIG 37 fixed geometry V9 Assembly [23]

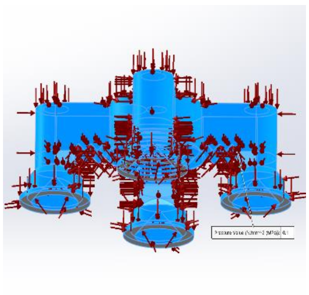


FIG 38 surface pressure V9 Assembly [23]

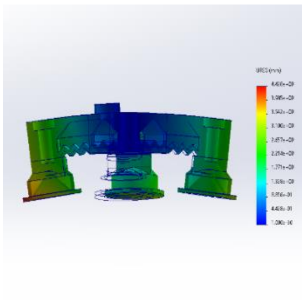


FIG 39 Deformation V9 Assembly [23]

To validate how the part would behave in real-life an Finite element analysis (FEA) was performed using the built-in tool in Dassault system SolidWorks [23]. To more accurately analyse the parts deformation two separate simulation were ran. One on the overall assembly and one on the suction cup design. Looking at FIG 34 we can observe that the fixed geometry parameter was applied to the inner wall of the top of the suction cup as its where the part is 'connected' to the main body. FIG 35 a surface pressure of 0.1 MPa was applied to the all the surfaces of the suction cup. This is because at absolute vacuum there would be nothing inside the cavity hance the air outside the part would exert a force of 1 atm at sea level on the surface [32]. 1 atm is approximately 0.101325 Mpa. Absolute pressure in such a system cannot be physically achieved hance the use of 0.1 as an approximation.
It can be observed that the deformation of the suction cup is upwards of 3mm. it can also be observed that the brim on the suction cup bends downward, and hance would provide better sealing.
Lastly a similar simulation was run for the whole assembly having the fixed geometry being the camera opening. The same pressure was applied all over the part as shown by the arrows. It can be observed that the part flexes downwards mimicking an octopus the maximum deformation was of 4.4 mm which is significant. While the inbuilt simulation tool is useful and has been show in studies to be up to only 1% inaccurate [33] this is mostly true for non-soft robotic application. So, it can be estimated that the simulation result can be up to 20% inaccurate for this specific case.

3.7 Manufacturing

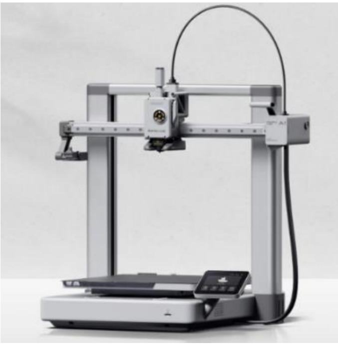


FIG 40 Bamboo Lab A1 [34]

FIG 41 build plate glue [35]

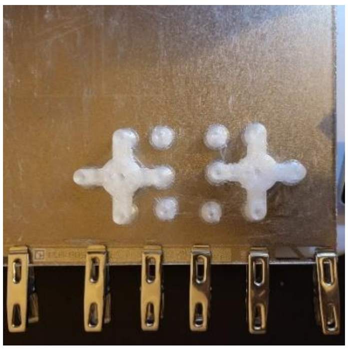


FIG 42 Printed prototypes

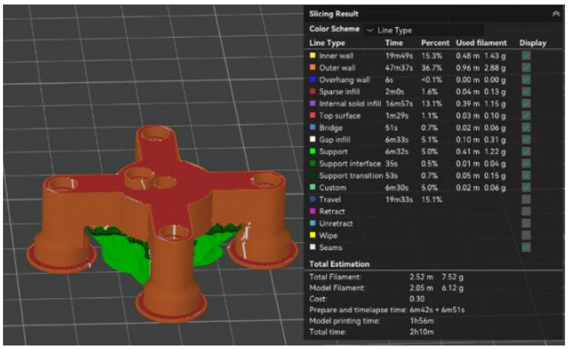


FIG 43 Slicing [36]

The final prototype was then printed using a Bamboo lab A1 on standard TPU settings FIG 40[34]. The printer is shipped with a textured build plate, however for this project a smooth build plate is required. The textured build plate introduces micro gaps which allows air to escape hance a seal does not form. To circumvent this a piece of acrylic sheet is used by attaching it to the build plate via some clips. A layer of Glue stick adhesive [40] is used then used on the acrylic sheet as a release agent. The slicing software indicated the part weight a total of 7.53 g and costs £0.30 excluding the cost of electricity. This is several magnitude cheaper than the currently used tools.

4. Analysis

4.1 Testing

FIG 44 gripper no adhesive no vacuum on glass

FIG 45 gripper no adhesive and no vacuum on acrylic upside down

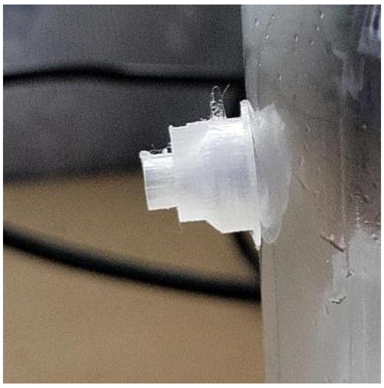


FIG 46 suction cup no vacuum on cylindrical bottle glass

FIG 47 simple vacuum test suction cup

The Gripper was then tested without vacuum to test for the passive adhesion. The gripper produced enough suction to hold itself vertically on a glass surface without the need for a vacuum pump FIG 44. It was also able to sustain its weight when held upside down on a piece of acrylic FIG 45. The suction cup was tested also for passive adhesion, and it was able to hold its own weight while also conforming to a glass bottle FIG 46. To test for how airtight the part is, a surgical needle body was attached to the test suction cup FIG 47. The part was able to resist a reasonable amount of vacuum without leaking.

4.2 Integration

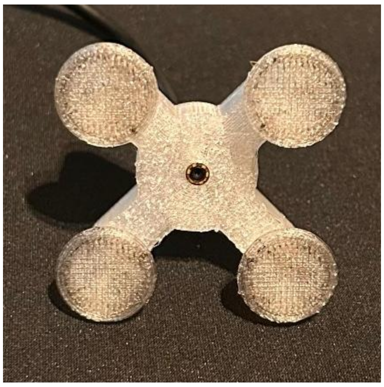


FIG 48 camera integration
bottom view

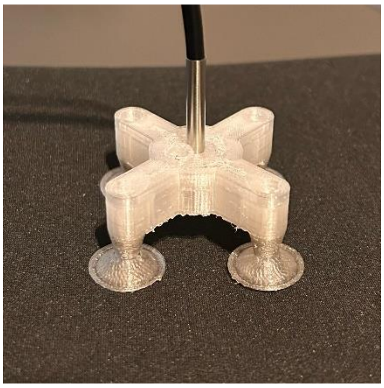


FIG 49 camera integration
front view

Camera:

The camera easily slots into the middle of the gripper. This allows a live feed of the operation to be viewed by the surgeon.

Vacuum System:

FIG 50 All vacuum inputs
connected using splitters

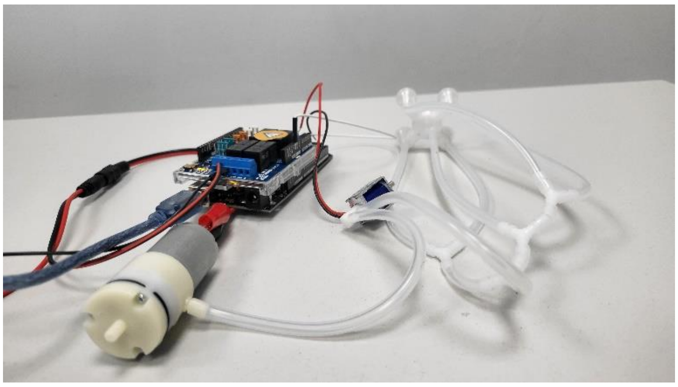


FIG 51 complete vacuum
system with microcontroller

The gripper was connected to the vacuum system. The griper however leaked, a second gripper was then used from the same batch of printing. This gripper did not have a vacuum leak. The gripper did not bend as simulated when tested with the vacuum system. It can be suspected that the part was too stiff leading to the part not bending as designed. The vacuum system was also operated with a single pump rather than two. This gripper was designed to use 2 vacuum sources one to make it bend and one to make it adhere this acts as a fail-safe aswell as provide more vacuum for actuation.

4.3 Ethical Implications

Given the nature of this project, it is empirical ethical issues are considered and prioritized. This is in adherence with the engineering Council [37] and IMechE [38] code of conduct. In this project the aim is to 'Prioritize the health, safety and wellbeing of the public' [37] by developing a cheaper gripper for MICS CABG such that it can be more globally adopted, and patience recover from this type of surgery quicker. This paper also abides by 'Act with integrity and fairness.' [38] as when the project did not yield the predicted result is it clearly highlighted, and a solution is provided. Lastly this paper also conforms to ' hold paramount the health and safety of others.' [37] as special consideration was taken when selecting a material to ensure it was ISO 10993 compliant.

5. Discussion and Recommendations

The final prototype presented in this paper successfully integrates all the required features needed for a MICS CABG while adhering to the set constraints. It features a conical suction cup to improve adhesion and provide a fail-safe if the pump fails. It uses ISO 10993 certified materials namely Siraya tech's 85A TPU [28] making the prototype bio compatible.

The prototype however did not act as simulated in SolidWorks [23] due to the stiffness of the part, the use of a single pump for both adhesion and bending. To further validate the mechanical behaviour of the part, it could be run on alternate software such as Ansys work bench [39]. To address the leaking concerns Thermal post processing could be used [12]. The design could also be printed using SLA/ DLP [40] printers using Elastomer-X [41] which is higher resolution meaning less gaps and potentially softer at 43A. The 3D printing element could also be used to make a mould for biocompatible silicone gripper. Lastly the prototype could be improved by using brick layering a patent slicing technique [42] which mis-matches the layer height by half between adjacent walls which could make the print more leak resistant and more reliable to FDM print.

6. Conclusion

This project effectively proposed and developed an open source FDM 3D printable soft robotic gripper, aimed at improving access to minimally invasive surgical tools in low GDP countries more specifically MICS CABG. Current tools cost thousands, whereas the gripper in this project was made for only £0.30 of TPU. The design draws inspiration from the common octopus (Octopus vulgaris) due to its flexible tentacles and delicate, yet strong suction based gripping mechanism. By integrating these mechanism, the gripper allows for gentle stabilization and positioning of the heart replacing the two current tools. The final prototype features a conical suction cup which allows for passive suction and therefore act as fail-safe if the vacuum pump fails. The material selected for the part is the Bio compatible and ISO 10993 adhering Siraya tech 85A TPU [28] which print on standard hobby grade 3D printers. The gripper was able to withstand its own weight when placed upside down only using passive suction. It fell short when connected to the vacuum system in the bending test, this is mostly due to it stiffness but partly due to the use of one pump for both bending and adhesion.

Areas of improvement for this design would be validating SolidWorks simulation [23] in Ansys workbench [39]. Thermal post processing could also reduce vacuum leakage[12]. Slicing the model with patented bricklaying technique [42] could also improve reliability. The project consistently adheres to both IMechE and Engineering Council code of conduct by prioritizing patient safety and presenting findings with integrity. Given the low cost of this technology, it could one day be used by MSF doctors [6] by printing necessary tools at point of care.

In conclusion this prototype shows promising capabilities but not without its flaws, which could be solved with further refinement and iterations.

7. Acknowledgement

I would like to extend my profound gratitude to this project's advisor, Dr S.M.Hadi Sadati. His in-depth knowledge of soft robotic and bio inspired design was invaluable throughout the course of the project. Whenever we encountered any challenges during the project, he would consistently offer a variety of potential solution, allowing us freedom to shape the project while learning independently.

I would also like to thank my team members for this project as they were very committed to the project from the very beginning through to the completion. They showed professionalism and outstanding teamwork by always delivering their work on time.

8. References

1. Wolf RK, Ohtsuka T, Wurnig P, Flege JB. Our experience with minimally invasive coronary artery bypass grafting and thoracoscopic internal mammary artery harvest with the Harmonic scalpel. 2010;
2. Rajput NK, Kalangi TKV, Andappan A, Swain AK. MICS CABG: a single-center experience of the first 100 cases. Indian J Thorac Cardiovasc Surg. 2021 Jan;37(1):16–26.
3. Picchiottino D. brown and black dragon in water [Internet]. Unsplash.com. Unsplash; 2021 [cited 2025 Apr 23]. Available from: https://unsplash.com/photos/brown-and-black-dragon-in-water-dW0gfo__uU8
4. Ostadfar A. Chapter 1 - Fluid Mechanics and Biofluids Principles [Internet]. Ostadfar A, editor. ScienceDirect. Academic Press; 2016. p. 1–60. Available from: https://www.sciencedirect.com/science/article/abs/pii/B9780128024089000016
5. Stepovic M. GDP Growth and Health Care Expenditures Worldwide. TOPHARMEJ. 2019 Aug 30;7(1):9–18.
6. MSF. Médecins Sans Frontières (MSF) International [Internet]. Médecins Sans Frontières (MSF) International. 2024. Available from: https://www.msf.org/
7. Gokhare VG, Raut DDN. A Review paper on 3D-Printing Aspects and Various Processes Used in the 3D-Printing. International Journal of Engineering Research. 2017;6(06).
8. Saggiomo V. A 3D Printer in the Lab: Not Only a Toy. Advanced Science. 2022 Sep;9(27):2202610.
9. He Y, Xue G huai, Fu J zhong. Fabrication of low cost soft tissue prostheses with the desktop 3D printer. Sci Rep. 2014 Nov 27;4(1):6973.
10. Bambu Lab | Unleash Your Creativity with Bambu Lab 3D Printers - Bambu Lab [Internet]. Bambulab.com. 2023. Available from: https://bambulab.com/en-gb
11. Zhou X, Spiers AJ. InstaGrasp: An Entirely 3D Printed Adaptive Gripper with TPU Soft Elements and Minimal Assembly Time. In: 2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) [Internet]. Detroit, MI, USA: IEEE; 2023 [cited 2025 Apr 21]. p. 4555–61. Available from: https://ieeexplore.ieee.org/document/10341385/

12. Mayville PJ, Petsiuk AL, Pearce JM. Thermal Post-Processing of 3D Printed Polypropylene Parts for Vacuum Systems. JMMP. 2022 Sep 8;6(5):98.
13. Chahine M, Bedran R, Ghady Zeghondy, Charbel Tawk. A 3D Printed Soft Gripper Featuring Pneumatic Fingers with Local Bending Joints. 2024 Jul 15 [cited 2024 Dec 15];1633–8.
14. Tawk C, In Het Panhuis M, Spinks GM, Alici G. Bioinspired 3D Printable Soft Vacuum Actuators for Locomotion Robots, Grippers and Artificial Muscles. Soft Robotics. 2018 Dec;5(6):685–94.
15. Tawk C, Spinks GM, In Het Panhuis M, Alici G. 3D Printable Linear Soft Vacuum Actuators: Their Modeling, Performance Quantification and Application in Soft Robotic Systems. IEEE/ASME Trans Mechatron. 2019 Oct;24(5):2118–29.
16. Lalegani Dezaki M, Sales R, Zolfagharian A, Yazdani Nezhad H, Bodaghi M. Soft pneumatic actuators with integrated resistive sensors enabled by multi-material 3D printing. Int J Adv Manuf Technol. 2023 Oct;128(9–10):4207–21.
17. Wu M, Afridi WH, Wu J, Afridi RH, Wang K, Zheng X, et al. Octopus-Inspired Underwater Soft Robotic Gripper with Crawling and Swimming Capabilities. Research. 2024 Jan;7:0456.
18. Dixit A, Das M, Singh H, Panda SK, Pugno NM, Katiyar NK, et al. Unleashing Enhanced Compressive Strength: 3D Printed Octopus-Inspired Suction Cups Using Topological Engineering. ACS Appl Polym Mater. 2023 Nov 10;5(11):9236–44.
19. Medtronic. Medtronic Octopus® Nuvo Tissue Stabilizer For Minimally Invasive Heart Surgery [Internet]. Medtronic.com. 2020. Available from: https://europe.medtronic.com/xd-en/healthcare-professionals/products/cardiovascular/revascularization-surgical/octopus-nuvo-tissue-stabilizer.html
20. Medtronic. Medtronic Starfish® Heart Positioner for Minimally Invasive Heart Surgery [Internet]. Medtronic.com. 2020 [cited 2025 Apr 24]. Available from: https://europe.medtronic.com/xd-en/healthcare-professionals/products/cardiovascular/revascularization-surgical/starfish-ns-heart-positioner.html
21. International Organization for Standardization. ISO 10993-1:2018 [Internet]. ISO. 2018. Available from: https://www.iso.org/standard/68936.html
22. Venethethan S, Voong EJC, Warfa A, Muthuperiyanayagam K. Octopus-inspired soft robotic gripper for MICS CABG [unpublished project]. London: Queen Mary University of London; 2024.
23. Students [Internet]. SOLIDWORKS. 2019. Available from: https://www.solidworks.com/product/students

24. Joymungul K, Mitros Z, Da Cruz L, Bergeles C, Sadati SH. Gripe-needle: a sticky suction cup gripper equipped needle for targeted therapeutics delivery. Frontiers in Robotics and AI. 2021 Nov 19;8:752290.
25. Mitsuda T, Otsuka S. Active bending mechanism employing granular jamming and vacuum-controlled adaptable gripper. IEEE Robotics and Automation Letters. 2021 Feb 12;6(2):3041-8.
26. Nayyeri P, Zareinia K, Bougherara H. Planar and nonplanar slicing algorithms for fused deposition modeling technology: A critical review. The International Journal of Advanced Manufacturing Technology. 2022 Mar;119(5):2785-810.
27. Ansys. Ansys (CES) Granta EduPack | Software for Materials Education [Internet]. www.ansys.com. Available from: https://www.ansys.com/en-gb/products/materials/granta-edupack
28. Siraya Tech Flex TPU - 85A Filament [Internet]. Siraya Tech. 2024 [cited 2025 Apr 25]. Available from: https://siraya.tech/products/flex-tpu-85a-filament
29. NinjaFlex 3D Printer Filament (85A) [Internet]. NinjaTek. Available from: https://ninjatek.com/shop/ninjaflex/
30. TPU 85A and 95A biocompatibility - Google Drive [Internet]. Google Drive. 2024 [cited 2025 Apr 25]. Available from: https://drive.google.com/drive/folders/1-UA7FJ3LHeOVtR9DWj2wzeMINwzQwaNa
31. Osman RB, Alharbi N, Wismeijer D. Build angle: does it influence the accuracy of 3D-printed dental restorations using digital light-processing technology?. International Journal of Prosthodontics. 2017 Mar 1;30(2).
32. Leck JH, Leck JH. Total and partial pressure measurement in vacuum systems. Glasgow London: Blackie; 1989.
33. Solid Solutions. FEA Simulation: Validating SOLIDWORKS Static Simulation Results [Internet]. Solidsolutions.co.uk. Solid Solutions; 2023 [cited 2025 Apr 25]. Available from: https://www.solidsolutions.co.uk/blog/2023/08/fea-simulation-validating-solidworks-static-simulation-results
34. Bambu Lab A1 3D Printer [Internet]. Bambu Lab USA Store. 2024 [cited 2025 Apr 25]. Available from: https://uk.store.bambulab.com/products/a1?srsltid=AfmBOorm9owA_prFnMgycaeWpURHesySH4pcmqGY7-TcozJVghbgxId0
35. Glue Stick for Build Plate [Internet]. Bambu Lab USA Store. 2025 [cited 2025 Apr 25]. Available from: https://uk.store.bambulab.com/collections/supplement-a1-series/products/glue-stick-for-build-plate?srsltid=AfmBOooK-frOs0l4KPLccGx_Js8gLFuZn5b8mGU3-2uEOSWLG5dVShDU

36. Software Studio - Bambu Lab [Internet]. bambulab.com. Available from: https://bambulab.com/en/download/studio
37. Engineering Council. Statement of Ethical Principles [Internet]. Engc.org.uk. 2017. Available from: https://www.engc.org.uk/standards-guidance/guidance/statement-of-ethical-principles/
38. Revised 2021 CODE OF CONDUCT INSTRUCTIONS Improving the world through engineering [Internet]. [cited 2022 Oct 3]. Available from: https://www.imeche.org/docs/default-source/1-oscar/About-us/governance/code_of_conduct_instructions_02_10.pdf?sfvrsn=2
39. Ansys Workbench | Simulation Integration Platform [Internet]. www.ansys.com. Available from: https://www.ansys.com/en-gb/products/ansys-workbench
40. Finnes T. High definition 3D printing–comparing SLA and FDM printing technologies. The Journal of Undergraduate Research. 2015;13(1):3.
41. Elastomer-X [Internet]. 3DJake. 2025 [cited 2025 Apr 25]. Available from: https://www.3djake.uk/liqcreate/elastomer-x
42. Ali A. Primary Examiner -Joseph S Del Sole [Internet]. 2022. Available from: https://patentimages.storage.googleapis.com/6f/10/98/8e9ed53fc39b27/US11331848.pdf

9. Appendix

Print setting TPU 85A bamboo labs studio

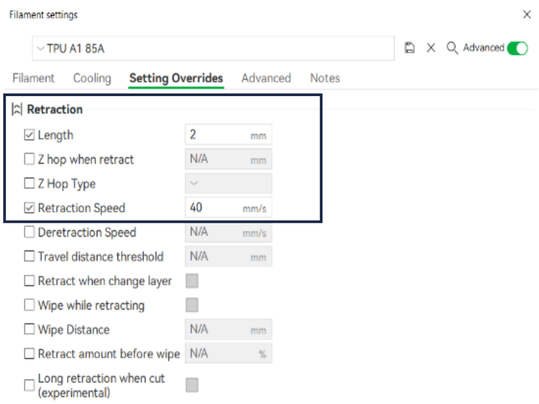


FIG 52 retraction settings

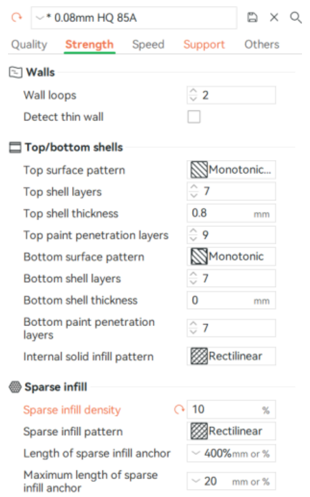


FIG 53 wall loops and sparse infill

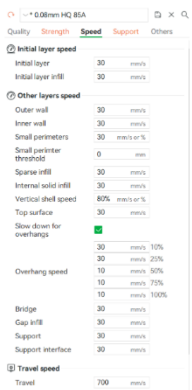


FIG 54 Speed settings

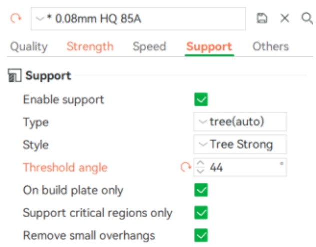


FIG 55 Support settings