



SVEn - An Economical Open-Source Approach for Syringe-Based Direct Ink Writing of Biomaterials Compatible with Bed Slinger 3D Printers

Andreas Engels^{1,4}(✉), Lennard Shopperly², Kerimcan Bagci¹, Leon Bruder³, Andreas Greiner³, Wolfgang Ertel², Michael Sittinger¹, Jacob Spinnen², and Tilo Dehne¹

¹ Tissue Engineering Laboratory, Department of Rheumatology and Clinical Immunology, Charité—Universitätsmedizin Berlin, Charitéplatz 1/Virchowweg 11, 10117 Berlin, Germany
Andreas.Engels@charite.de

² Centre for Trauma- and Reconstructive Surgery, Charité—Universitätsmedizin Berlin, Hindenburgdamm 30, 12200 Berlin, Germany

³ Department of Vascular Surgery, Charité—Universitätsmedizin Berlin, Hindenburgdamm 30, 12200 Berlin, Germany

⁴ Technical University of Applied Sciences Wildau, Hochschulring 1, 15745 Wildau, Germany

Abstract. The availability of consumer-grade 3D printers has sparked innovative applications in research, particularly in engineering and medicine. Fused filament fabrication (FFF) has drastically accelerated iterative prototyping, while direct ink writing (DIW) of, e.g., hydrogels holds promise in medical applications. However, commercial bioprinters are not yet available at low cost.

The primary objective was to establish a cost-effective and easily accessible system, reducing barriers for researchers to engage in biomaterial- and bio-printing for small-volume extrusions (SVEn). A Creality Ender 3 V2 was used as a base due to the machine's open-source nature, the availability of software and hardware files, and its wide popularity and availability. All structural parts were printed via FFF, and the necessary mechanical components are cheap, widely available, and typically found in 3D printers. No modifications to the electrical wiring were required, and firmware adaptations were implemented via g-code commands prior to printing. The extruder was designed to fit the Ender 3 mounting plate. With adaptations to the mounting mechanism, it can be used on other cartesian-style 3D printers. The DIW extruder system is designed to be operated with a 5 mL syringe. Conventional cell culture ware (well plates and Petri dishes) and FFF 3D printed surfaces and textiles can be used as printing surfaces. Printed substrates (e.g., alginate, gelatin, pastes) represent a variety of processable viscosities and enable the processing of viable cells. The extrusion system presented herein may constitute a valuable tool for developing novel treatments in the medical field.

Keywords: 3D biomaterial printing · bioprinting · open-source · high viscose material processing · syringe extruder

1 Introduction

In recent years, additive manufacturing has evolved into an accessible and user-friendly technology. The affordability of entry-level machines, priced at just a few hundred euros, has empowered professionals and individuals to swiftly develop iterations of products or prototypes within a limited budget. The growing enthusiasm for this technology has led to enhanced accessibility and lower costs, further promoting awareness and reducing the barrier to entry for this now-accessible field. Consequently, scientists and researchers have seamlessly integrated 3D printing techniques into their respective domains, contributing to the establishment of a self-sustaining ecosystem of 3D printing technology. Notably, the research fields of material science, biotechnology, and medical applications have reaped the benefits of this widespread availability and diversity of machines, complemented by a supportive community that continues to expand.

3D printing begins with creating a digital 3D model using computer-aided design (CAD) software. This digital model is then sliced into thin horizontal cross-sections using specialized slicing software, which generates a set of instructions (g-code) for the 3D printer to follow. Before printing, the appropriate material (such as thermoplastics, resins, or metals) is loaded into the printer, and the printer itself is calibrated to ensure proper operation. The printing process varies depending on the technology used but generally involves gradually adding material layer-by-layer to construct the final object. Cooling, curing, or solidification steps may be incorporated as needed [1].

The growing importance of tools for rapid prototyping in research is evident, as shown by the plentiful literature available, and spans from modular labware to microscopes and microfluidic devices [2]. Furthermore, 3D printers were modified into direct ink writing (DIW) extruders [3], electrical discharge machines [4], and histological slide autostainers [5], to name a few projects that emerged from open-source hard- and software. While these projects are all based on relatively easy-to-operate and -modify 3D printer machines, the complexity and difficulty of such heavily modified printers is inherent to the technology moving in three-dimensional space.

3D bioprinting describes the use of additive manufacturing technologies to print biomaterials, often in combination with cells, growth factors, or encapsulated drugs [6, 7]. By employing these methods, researchers can better approximate *in vivo* tissue environments than traditional 2D monolayer or 3D spheroid cell culture studies [8]. Consequently, this can reduce the need for animal testing and contribute to the 3R principle of reducing, refining, and replacing animal studies. The most frequently used bioprinting methods include extrusion-based bioprinting, jetting, stereolithography, and laser-assisted bioprinting [9]. In extrusion bioprinting, or DIW, the substrate (or bioink) is loaded into a cartridge and dispensed continuously through a nozzle, akin to fused filament fabrication (FFF) 3D printing. The bioink can be dispensed either by a mechanically actuated piston or pneumatically [6]. Many biomaterials can be employed in extrusion bioprinting, over a wide viscosity range of 30 to 6×10^7 mPas [10]. Depending on the crosslinking mechanism of the bioink, pre- or post-printing treatment of bioink or printed constructs with a crosslinking solution may be necessary. For example, alginate, a polysaccharide found naturally in brown algae, is easily extruded over a wide concentration range when in solution, and forms a hydrogel after exposure to Ca^{2+} -ions via electrostatic interactions [11]. Alginate is a highly researched biomaterial and

has been investigated in various forms (fibers, foams, hydrogels, microspheres, micro-capsules, and sponges) and for use in various biomedical applications e.g. bone and spinal cord injuries, among others 2D and 3D applications [12–15]. Due to its low price, ubiquitous availability, ease of handling, a large body of literature and a simple, non-toxic crosslinking mechanism, alginate is a highly suitable hydrogel to enter the field of bioprinting.

A recent study named *3D Culture's Tissue Scribe* as the most economical commercially available 3D bioprinter, costing ~ 1 500 \$. More advanced solutions are priced at ~ 5000 \$, and the freeform reversible embedding of suspended hydrogels (FRESH) certified Lulzbot 3D Bioprinter starts at ~ 10 000 \$ [16]. Different approaches for do-it-yourself DIW printers have been published, with varying focus sets. From large volume extruders (LVE) attached to 3D printers that have been discontinued [17] or have significant dead volume [18] to systems with two extrusion heads, which include extensive hard- and software modification [19].

SVEn aims to provide easy and economical access to DIW of a wide range of substrates with as little as possible dead volume, lowering the barrier to entry for 3D bioprinting.

2 Methods

2.1 Design, Additive Manufacturing, and Additional Materials

STEP files provided by the manufacturer were used as reference during the design process. The aim was to retain as much as possible with minimal modifications. Modification to the electrical wiring and firmware could be avoided. The design parts are easily printable with a conventional FFF 3D printer.

The parts were printed from Polyethylene Terephthalate Glycol (PETG) (Material 4 Print GmbH & Co. KG) due to improved chemical resistance (compared to poly lactic acid and acrylonitrile butadiene styrene), resilience to UV radiation, and mechanical properties [20]. A non-modified Creality Ender 3 V2 was used to print the parts for the syringe extruder. The 3D models were sliced by SuperSlicer v2.3 with the following settings: 0.4 mm nozzle, 0.25 mm layer height with 8 bottom and top layers, 30% gyroid infill, 4 perimeters, 245 °C hot-end and 75 °C bed temperature, 65 mm/s print speed, and the part cooling fan at 35%. SuperSlicer estimates the filament usage to be slightly below 250 g, including support material. The files necessary to print and the recommended orientation on the printbed are shown in Fig. 1. The material cost for the complete assembly of the SVEn is listed in Table 1.

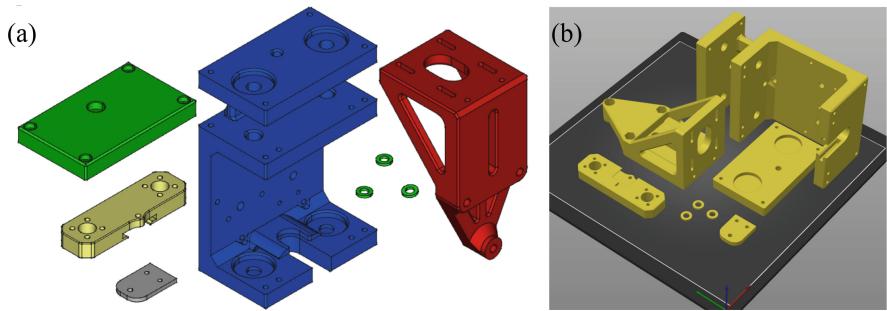


Fig. 1. 3D-designed parts for additive manufacturing for assembly of SVEEn. (a) Design files of parts. Top cover (green), syringe piston holder (yellow), x-axis end-stop (gray), main body (blue), stepper motor mount (red). (b) Recommended alignment on the print surface for FFF. (Color figure online)

Table 1. Summary of materials and costs for the assembly of the syringe extruder.

Part	Part Number	Quantity	Price per piece [€]	Source	Price [€]
M5 × 45 mm DIN 912	P002023	5	0.21	RST-Ver sand	1.05
M5 nut DIN934	014271	4	0.07	EdelStahl24	0.28
M3 × 16 DIN 912	S-A2-DIN912-M3X16-PAPA	12	0.05	RST-Ver sand	0.60
2× TR8 × 2 200 mm & T8 brass nuts	B0C5M694W3	1	9.99	Amazon	9.99
Ball bearing 608 2RS	608-2RS	4	0.69	Kugellager-express	2.76
3× GT2 toothless idler pully (20t)	B0CKW5X34P	1	7.79	Amazon	7.79
2× GT2 × 6 mm 40 teeth; 8mm bore	B08ZSLHSRZ	1	7.99	Amazon	7.99
GT2 6 mm 334 mm closed belt	Turmberg3D-LL-2GT-0334	1	9.99	Amazon	9.99
Nema 17 38 mm 0.9° Stepper	B0B9MGL9H3	1	13.99	Amazon	13.99
PETG Blue 0.75 kg	SW10034.2	1	27.94	Material4print	27.94
3D printer	Ender 3 V2	1	209.00	Creality	209.00

2.2 SVE_n Assembly, Installation, and Calibration

The extruder System was designed with FreeCAD (Link Branch), and all necessary files are available on the GitHub repository (<https://github.com/AnEn030/SVEn>).

Setting Up the Creality Ender 3 V2 for SVE_n: After all parts have been FFF printed, the filament hot-end extruder of the FFF printer must be unmounted. Two M3 screws on the backside of the x-axis hot-end bracket are unscrewed, loosening the fan enclosure covering the hot-end (Fig. 2a). The hot-end itself can be unscrewed from the x-axis hot-end bracket by loosening the two M3 screws (Fig. 2b). The Bowden tube for the filament must be uninstalled by removing the blue locking clip on the pneumatic adapter, pressing the spring joint in, and removing the tube (Fig. 2c). Additionally, the pneumatic connector must be unscrewed for additional clearance on the x-axis. Furthermore, the M5 screws holding the rollers can be removed, and the M5 nuts set aside for later assembly (Fig. 2, green arrows).

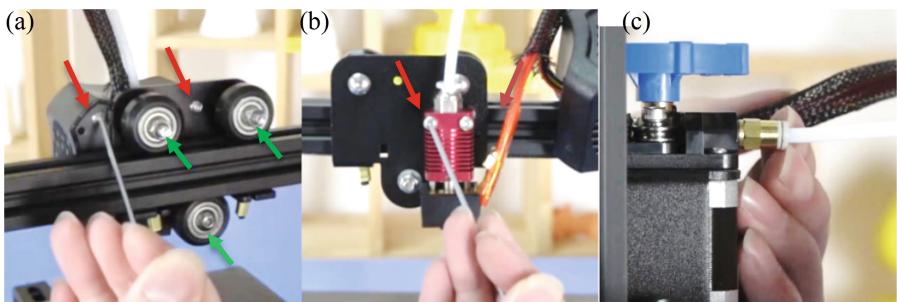


Fig. 2. Manufacturer's instructions for removing the stock filament hot-end. (a) Removal of the screws holding the fan enclosure. (b) Removal of the stock hot-end and (c) removal of the Bowden filament tubing and pneumatic connector [21]. (Color figure online)

SVE_n Assembly: The main body houses the 4x 608 ball bearings (Fig. 3a). The T8 nuts are placed into the syringe piston holder and locked with at least one M3 screw (Fig. 3b and c). Each TR8 rod (130 mm) is inserted through the upper ball bearing from the top, passing the GT2 40 teeth pulley. The T8 nuts are inserted into the lower ball bearing (Fig. 3d). Then the top cover (green) and the closed GT2 belt with the toothless idler pulley are installed with one M5x45 mm screw and fixed with 4 M3 × 16 mm on the corners (Fig. 3e).

The second part is to place the NEMA 17 stepper motor into the corresponding position of the stepper body and lightly screw down the 4 M3 × 16 mm screws (Fig. 4). The GT2 20 teeth pulley can be installed on the shaft of the stepper motor and the toothless pulley can be installed on the corresponding holes at the corners with 2 × M3 × 10mm (Fig. 4). To enable the stepper body to connect with the main body, two M5 nuts must be inserted into the corresponding cavities under the stepper motor position. Finally, the 3 1.5 mm spacers can be glued to the stepper body.

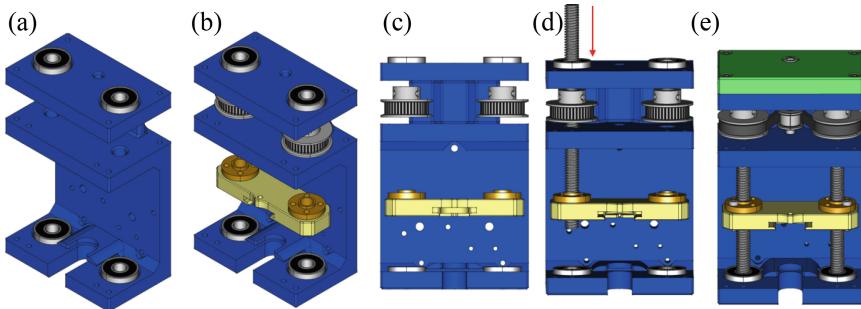


Fig. 3. Assembly of SVEn main body. (a) Isometric view of inserted 608 ball bearings into the corresponding cavities. (b) Iso and (c) front view. Two TR8 nuts inserted into the piston holder (yellow), and the GT2 40 teeth pulley placed at the corresponding position. (d) TR8 \times 2 inserted (130 mm) through the top ball bearing, pulley, T8 nut, and into the lower ball bearing for both sides. (e) Installed GT2 close belt and top cover with the toothless idler via M5 \times 45 mm. (Color figure online)

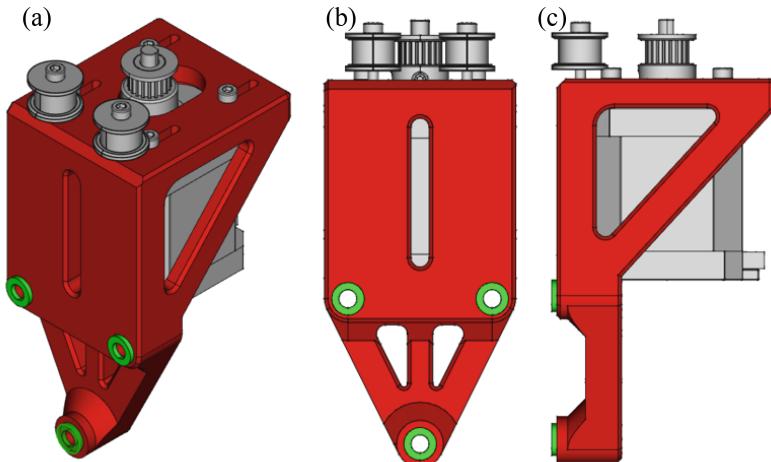


Fig. 4. Assembly of SVEn stepper body. The stepper motor holder (red) with installed stepper motor (black) mounted using 4 \times M3 \times 10 mm screws, the two toothless pulleys (M3 \times 30 mm), and the 3 \times M5 \times 1.4 mm spacer (green) glued on for easier installation onto the printer carriage. (a) Isometric, (b) front, and (c) side view. (Color figure online)

The main body with the closed GT2 belt and the stepper body is ready to be installed on the x-axis bracket of the FFF printer. The 2 M5 \times 45 mm screws can be inserted from the main body side, aligning with the top two rollers. Then, the third M5 \times 45 mm screw can be inserted from the stepper body side (Fig. 5a, b). After assembly of these three parts, the GT2 belt must be installed on the stepper motor's pulley. The belt tension can be increased by moving the stepper motor within the 10 mm slot and tightening the screws (Fig. 5c). To make the system useable, the x-axis end-stop must be moved from underneath the x-stepper motor cover onto the x-axis aluminum profile (Fig. 5d). The

extruder stepper motor cable must be connected to the SVEn motor. We recommend increasing the height of the z-axis end-stop to compensate for the length of the syringe and nozzle/needle.

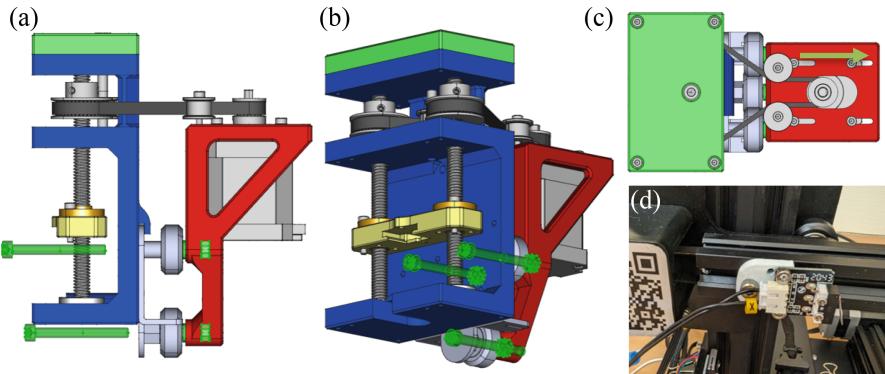


Fig. 5. Main body and stepper body installed on printer's x-axis bracket. M5 screws and nuts position (light blue) for installing the 3D parts in (a) side view and (b) angled view. (c) Tensioning of the closed-loop GT2 belt by increasing the distance between the pulleys (green arrow). (d) X-axis end-stop repositioned onto the x-axis aluminum profile. (Color figure online)

This printer modification allows the filament Bowden extrusion system to remain in place to enable switching back to filament extrusion without significant hardware modifications. Furthermore, it is not necessary to disconnect the hot-end from the mainboard; hence, no modifications to the mainboard need to be made. Additionally, the modification functions with the original firmware. However, some g-code commands must be implemented prior to printing (e.g., stored in the slicer section) for custom g-code commands. Alternatively, an initial setup g-code is created and saved onto the system or connected PC.

Printer Calibration: As the extrusion system has been changed, the stock firmware setting for the extruder must be adapted. The steps per mm for lead screw movement is a multiplication of different values (stepper motor's steps per revolution, micro-stepping, pitch of the lead screw, and gear ratio) and is calculated as follows for this system.

$$\frac{400 \text{ steps}}{1} * \frac{32 \text{ microsteps}}{\text{step}} * \frac{1}{2 \text{ mm}} * \frac{2}{1} = 6400 \frac{\text{microsteps}}{\text{mm}} \quad (1)$$

The start-up g-code includes various changes, including the previous calculation steps per mm, enabling the extruder stepper motor to operate outside typical FFF hot-end temperatures and restricting the max feed rate.

```

G92 E0      ; Reset Extruder
G28 X Y     ; Home X and Y.
G91         ; Absolute positioning
M83         ; Extruder relative positioning
M302 S0     ; allow cold extrusion.
M92 E6400   ; set steps per mm for SVE with 5 mL syringe.
M203 E1.5   ; set max. feed-rate for extruder to 1.5 mm/s

```

Due to variances in nozzle height and print surfaces, we strongly recommend manually setting the $z = 0$ mm height prior to every print via control software (e.g., Pronterface), which enables terminal inputs to process g-code commands. Alternatively, the g-code commands could be saved onto the printer's SD card.

For the z -height alignment, insert the syringe into the corresponding cavities and move the nozzle of the extruder set up into the print area (e.g., petri dish) (Fig. 6a and b). Carefully lower the nozzle until approximately 0.1 mm over the print surface. This offset of 0.1 mm has worked well during our experiments. The following g-code commands are used to set this current position as new $z = 0$ mm height and then move the nozzle up. After, the printer is ready to start printing by selecting the sliced file via PC and corresponding software or the on-machine user interface.

```

G92 Z0      ; Define z-axis zero point
G0 Z30     ; Linear move z-axis to z 30

```

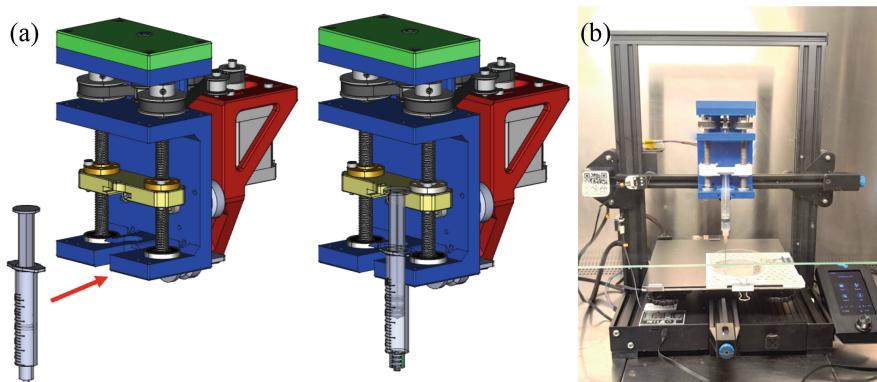


Fig. 6. Inserting the 5 mL syringe into SVEn, shown as CAD-model (a), and the manufactured and assembled extruder on a Creality Ender 3 V2 under a sterile work hood (b).

After SVEn is ready for use, it is highly recommended that the line width be calibrated to enable compensation on demand. The line width herein was analyzed using different substrates extruded in a zig-zag pattern with repeating 10 mm horizontal and 3 mm vertical lines (theoretical width: 0.84 mm; 18G). Three points of measurement were taken per horizontal line and one per vertical line for a total of 15 points per substrate. This analysis was performed with different alginate concentrations (5, 10, 15%, and

5% pre-crosslinked), procine minced meat, and mayonnaise representing high and low viscosity printing substrates.

2.3 Alginate Hydrogel Preparation

Alginate (Sigma-Aldrich; W201502) was dissolved in dH₂O at 1%, sterile filtered with a 0.22 µm filter (Millipore; S2GPU02RE), then lyophilized until dry (Thermo Scientific, Heto Power Dry LL1500) and stored at -20 °C. The lyophilizate was reconstituted in an adequate volume of dH₂O to obtain alginate solutions at 5, 10, and 15%. Alginate solutions were rolled for 1–2 h on a roller until fully redissolved and ready to be printed. To encapsulate cells in alginate, the alginate lyophilizate was reconstituted with cell culture medium instead of dH₂O, resulting in an 8% alginate stock solution. Alginate polymerization was induced by covering printed constructs with a 4% CaCl₂ solution.

2.4 Cell Cultivation of C2C12 Cells and Cell Encapsulation in Alginate Hydrogels

To print cells encapsulated in the alginate hydrogels, C2C12 (mouse myoblast cell line, German Collection of Microorganisms and Cell Cultures GmbH) cells were cultivated at a cell density of 2000 cells/cm² in T175 culture flasks (Greiner, E23073FM). Dulbecco's modified eagle medium (DMEM) was supplemented with GlutaMAX high glucose (Gibco, 61965-026), 10% (v/v) fetal bovine serum (FBS, Sigma, F7524), 20 mM HEPES (Sigma-Aldrich, H0887), 100 U/mL penicillin, 100 µg/mL streptomycin (Sigma-Aldrich, P433) and 2 mM L-alanyl-L-glutamine (Sigma-Aldrich, 39537-23-0). Before reaching confluence, cells were harvested using 10% trypsin/EDTA (Bio&Sell, BS.L2153), and the cell number was determined using the trypan blue (Sigma-Aldrich, T8154) dye exclusion method. Cells were re-plated at 2000 cells/cm² in a cell culture flask until sufficient cell numbers were obtained. A cell stock solution of 8 × 10⁶ cells/mL was prepared and mixed into the alginate hydrogel solution at a volumetric ratio of 1:1, resulting in a 4% alginate with 4 × 10⁶ cells/mL bioink.

The cell-laden bioink was resuspended five times with a pipette and placed on a roller for 1 h before printing to ensure an even cell distribution within the hydrogel. The bioink was carefully and slowly drawn up in the syringe to avoid air bubbles.

2.5 Viability Staining with Fluorescein Diacetate/propidium Iodide

Bioprinted constructs were stained for live and dead cells using fluorescein diacetate/propidium iodide (PI/FDA). The staining solution consisted of 6 µg/mL FDA and 0.05 mg/mL PI in PBS. Bioprinted constructs were incubated in 100 µL staining solution for 5 min and analysed via fluorescence microscopy (filter settings: 488/590 nm (PI), 485/514 (FDA)). Manually deposited 15 µL droplets served as control. Cells were stained 1 h, 1 day, and 7 days post-printing.

3 Results and Discussion

3.1 Accessibility and Assembly of SVEn

The modification of the open-source FFF printer into a DIW printer is primarily intended for research laboratories. Therefore, the focus lies on biomaterial scientists, biotechnological engineering laboratories, and educational purposes for students and research groups that plan to enter bioprinting on an economical basis.

The low investment cost, reduced complexity of modifying the printer (no changes on the firmware, mainboard, or electrical wiring necessary), and the option to easily build the system back to the stock FFF printer shell increase the versatility of this project. The FreeCAD files, STL files, and SuperSlicer profile will be provided on a GitHub repository (<https://github.com/AnEn030/SVEn>).

3.2 Printing Different Substrates

Initial printing tests were conducted with mayonnaise, finely minced meat, and alginate solutions of different concentrations as substrates. A uniformity test was performed with an 18G nozzle to verify the machine's extrusion precision. The printing speed for DIW printing was drastically reduced compared to the 50 mm/s stock setting for FFF. Low-viscosity or sheer thinning printing substrates may display decreased print quality due to the faster movement of the print bed during y-axial motion. Hence, print speed was set to a maximum of 10 mm/s to decrease this possible negative impact. The decreased speed further aids in maintaining cell viability by reducing shear stress [22].

For the uniformity test, the average Line Width (LW) was analyzed, and the same g-code was used for all substrates. The 5% alginate resulted in an LW of 1.19 ± 0.04 mm. For the 10% and 15% alginate concentrations, LW of 0.98 ± 0.03 mm and 0.8 ± 0.04 mm, respectively, were measured. Pre-crosslinked 5% alginate performed similarly to non-pretreated alginate with a LW of 1.22 ± 0.02 mm. With mayonnaise, an average LW of 1.05 ± 0.07 mm was observed. During processing, we also observed that 15% alginate contained more air bubbles than the other alginate concentrations, which could be one factor for the uneven lines shown in Fig. 7. When printing with mayonnaise, the emulsion appeared to break when printing a one-layer line. However, when printing larger objects, this effect did not appear nor had a negative impact, as shown in Fig. 8, where we printed gummy bear structures out of mayonnaise (Fig. 8b) and minced meat (Fig. 8c).

3.3 Printing Cell-Laden Bioinks

Constructs containing C2C12 cells were bioprinted with 4% alginate and crosslinked by immersion in a 4% CaCl_2 solution. The viability of printed cells was monitored for 7 days post-printing and assessed by staining with PI/FDA. Figure 9 shows that high viability of cells is maintained immediately post-printing and throughout the observation period, with no apparent difference in viability to the non-printed control, demonstrating the ability of SVEn to process viable cells for the biofabrication of 3D tissue models. Cell viability following DIW is influenced by various parameters, such as print speed, nozzle diameter as well as the biological parameter (e.g. hydrogel viscosity, cell typ).

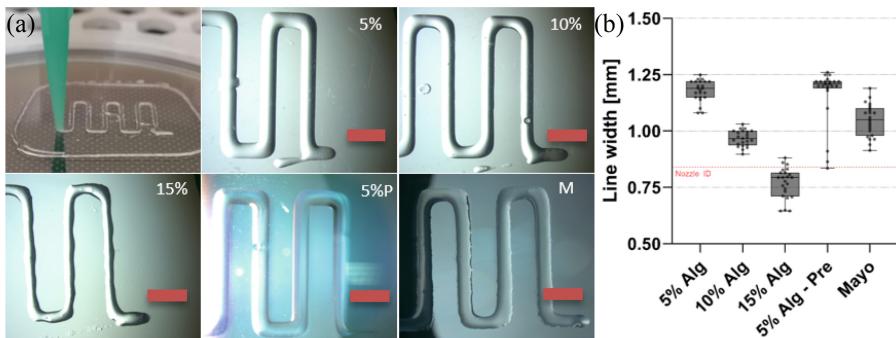


Fig. 7. Initial line width analysis for different substrates. (a) Image of alginate hydrogel printed with an 18G nozzle. Microscopic images of different print results: 5, 10, 15% alginate concentration, 5% alginate pre-crosslinked with CaCl_2 (5%), and mayonnaise (M). (b) Line width of extruded substrates. Plotted are the measured line widths at 15 points along the extruded line for each substrate. The dotted red line signifies the nozzle inner diameter (ID) of 0.84 mm. Red scale bar = 3 mm. (Color figure online)

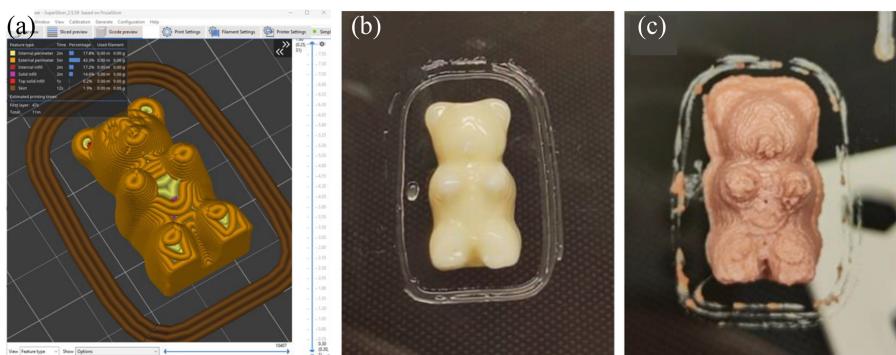


Fig. 8. Test prints made with SVEn and different substrates. (a) Utilized slicer software (Super-Slicer) displaying the printing pathway and additional information. Example prints of (b) mayonnaise and (c) finely minced meat to demonstrate the printability of pastes in the form of a gummy bear ($\sim 10 \times 20 \times 8$ mm).

Decreasing speed or increasing the nozzle diameter reduces shear stress exerted on extruded cells, thus offering options to fine-tune parameters to maximize viability [23]. Another option is coaxial extrusion, where a cell-laden core solution is extruded within a protective shell solution, protecting embedded cells from mechanical stress [24].

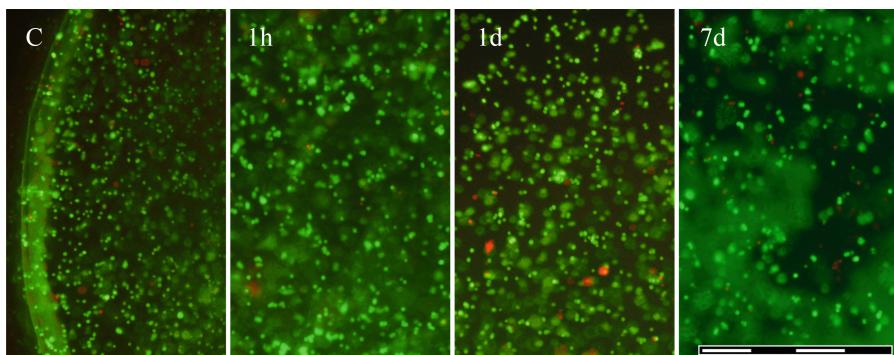


Fig. 9. Fluorescence microscopy image of viable (green) and dead (red) C2C12 cells encapsulated or bioprinted in 4% alginate and stained by PI/FDA. The control (C) was prepared by manual deposition and crosslinking of cell-laden alginate bioink. Bioprinted alginate constructs were examined 1 h, 1 day, and 7 days post-printing. Scale bar = 500 μ m. (Color figure online)

4 Conclusion

This printer modification for the highly community-supported, economical, open-source FFF printer Ender 3 V2 enables users to extrude a wide variety of viscous substrates. The modification does not interfere with the stock electronics, nor does the firmware need to be flashed, decreasing the risk of damage to machine or operator. This minimal interference with the hard- and firmware allows a quick build back to the stock configuration FFF printer. Several mounting points for M3 screws were designed onto various positions to allow the mounting of additional features (e.g., UV-LEDs, a temperature-controlled syringe cover, external vapor generators, or cameras for observation). Due to the open-source nature of this project and the freely available CAD files, additional components can be added by anyone to improve the process and add new features, such as coaxial extrusion, to enable more in-depth research in the bioengineering field.

Regarding the DIW extruder, we demonstrated the printability of alginate, a readily available and suitable entry-level hydrogel for bioprinting and biomaterial printing. Additionally, it was shown that SVEn can print cells encapsulated in 4% alginate, which were viable up to 7 days post-print. However, the mechanical movement of the print bed during y-axis movements may affect low viscosity or shear-thinning printing materials during the print. This effect can be mitigated by decreasing the overall print speed and acceleration rate at the cost of print time. Nevertheless, with ~ 55 €, a very commonly used and highly rated 3D printer can be converted into a DIW 3D printer suitable for bioprinting which can be operated in a laminar flow hood for aseptic processing of bioinks with standard lab ware.

Acknowledgments. This research study has been supported by the European Union's Horizon 2020 Research and Innovation Programme under grant No. 953134 (INKplant: Ink-based hybrid multimaterial fabrication of next generation implants).

20. Grzelak, K., Łaszcz, J., Polkowski, J., Mastalski, P., Kluczyński, J., Łuszczek, J., et al.: Additive manufacturing of plastics used for protection against COVID19—the influence of chemical disinfection by alcohol on the properties of ABS and PETG polymers. *Materials*. **14**(17), 4823 (2021)
21. After-sale CC: Service tutorial Ender - 3 V2 hotend kit replacement (2021). <https://www.youtube.com/watch?v=kHhSCwUON9k>. Accessed 18 Oct 2021
22. Boularaoui, S., Al Hussein, G., Khan, K.A., Christoforou, N., Stefanini, C.: An overview of extrusion-based bioprinting with a focus on induced shear stress and its effect on cell viability. *Bioprinting* **20**, e00093 (2020)
23. Chaji, S., Al-Saleh, J., Gomillion, C.T.: Bioprinted three-dimensional cell-laden hydrogels to evaluate adipocyte-breast cancer cell interactions. *Gels* **6**(1), 10 (2020)
24. Shahabipour, F., Tavafoghi, M., Aninwene, G.E., Bonakdar, S., Oskuee, R.K., Shokrgozar, M.A., et al.: Coaxial 3D bioprinting of tri-polymer scaffolds to improve the osteogenic and vasculogenic potential of cells in co-culture models. *J. Biomed. Mater. Res., Part A* **110**(5), 1077–1089 (2022)