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Hardware Article

Open source 3D-printed 1000 μL micropump

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ABSTRACT

Scientific innovation goes hand in hand with technological innovation, so scientific work depends to a great extent on the hardware available in the laboratory. The investment in developing countries is still far below that of OECD countries, which was about 2.4% of the gross domestic product (GDP) in 2015. In stark contrast, Brazil made the highest investment of Latin American countries at just 1.2%. Today, the "open-source revolution" appears more than ever to be a powerful ally for the promotion of development and the narrowing of the economic gap between developed and developing countries. In this context, this article presents the design of a 1000 μl 3D printed micropump. It is a practical and simple design inspired by pipette pumps. The present design was printed with a 3D printer and assembled very easily with common tools. Upon comparison of the micropump's performance, it exhibits a systematic error between 1.4 and 3.8% of the volume and a random error between 0.38 and 9.5% of the volumen.
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Specifications table

Hardware name	OPEN SOURCE 3D-PRINTED 1000 μL MICROPUMP
Subject area	• Chemistry and biochemistry • Medicine • Neuroscience • Biological sciences • Educational tools and open source alternatives to existing infrastructure
Hardware type	• Biological sample handling and preparation
Open source license	*CC BY*
Cost of hardware	US $43.45
Source file repository	https://3dprint.nih.gov/discover/3dpx-007460

1. Hardware in context

Developing countries have very low per-capita incomes and a small taxpayer base, and this predictably leads to low health and research spending [1]. In conjunction with minimal resources, the cost of consumables in developing countries

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can be two to five times higher than developed countries depending on the distance between the manufacturer and the consumer when compared to consumables in developed [1,2]. To a large extent scientific innovation depends on scientific hardware and the lack of access to technology delays scientific progress in developing countries. The access to scientific equipment is often limited by their high cost [2]. However, the open-source movement has given hope to many; this movement is based on licenses that allow free access to hardware designs and software source code for use, and, in a spirit of collaboration, modification for purposes of improvement [3,4]. This movement began in the field of software and has expanded to other areas such as hardware development. The success of open source hardware has been further enabled by the reduced cost of 3D printing and the creation of open-source microprocessors such as Arduino [5]. 3D printing has become a low-cost alternative to manufacturing consumables and equipment. An important example is the do-it-yourself (DIY) DNA lab designed by Peter Allen and colleagues at the University of Idaho, which, by using 3D printing, generates a cost savings of 50–90% in comparison to commercial equivalents [6]. As a result, throughout these decades, a large and enthusiastic community has developed a series of low-cost scientific instruments that includes: automated sensing arrays [7], biotechnological and chemical labware [8,9], micropipettes [10], colorimeters [11], DNA nanotechnology lab tools [6], a thermocycler for PCR [12], optics and optical system components [13,14], and a sample rotator mixer and shaker [15].

In this manuscript, I present a 3D printed micropump that uses commercial micropipette tips. The development of the 3D models was done with the Fusion 360 program (Autodesk Inc., USA). The models were printed with the DaVinci 1.0 printer (XYZ Printing Inc., USA). The performance of the micropump was compared to that of commercial micropipettes (Gilson Inc., USA and Eppendorf, Germany) and while the 3D printed micropumps were less precise than their commercial analogs, they exhibit a systematic error between 1.4 and 3.8% of the volume and a random error between 0.38 and 9.5% of the volume. This accuracy and precision is well within the necessary parameters for many research applications, such as Cell culture media preparation, cell perfusion solution for electrophysiology, titration, among others.

2. Hardware description

The design was made in order to produce a light and manual micropump that would function like a pipette pump. It consists of four parts: a body, a slide, a gear, and a nozzle (Fig. 1). The body accommodates the rest of the components, and on the lower front side has a cap that provides access to the interior and is attached with two screws (M5 × 25 mm)

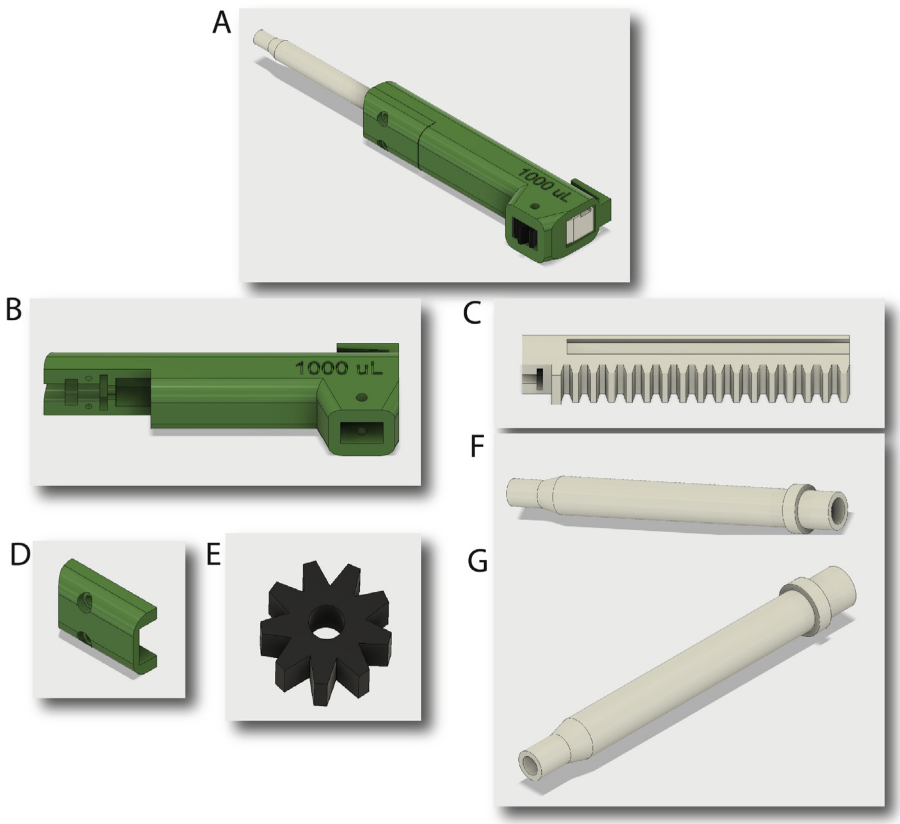

Fig. 1. Micropump components. The components of the micropump comprise five elements which are: (A) Assembled micropump, (B) Pump body, (C) Slider, (D) Body cover, (E) Gear, (G) Nozzle.

(Fig. 1B and D). On the upper part of the same side is the place where the gear is housed; the gear is fixed to the body by a headless screw (M5 × 25 mm). On the upper backside, there is a short arm so that the micropump can be hung thus preserving the sterility of the tip.

The gear has 9 coarse teeth so the thumb can move it easily. To be joined to the body, it has a central hole (Fig. 1E).

The slide runs along the interior of the body and on the front, it has the same teeth as the gear so that it can move when the gear is rotated. On the lower front side, it has a hole so that the top of a 1 ml (insulin) syringe plunger can be embedded. On the left side, there is a slit where the scale of the micropump is glued (Fig. 1C).

The key to the success of this micropump is the nozzle (Fig. 1F and G). It consists of a tube and at the top, it has an edge to fix the nozzle to the body of the micropump. At the bottom is where the commercial micropipette tips fit, so there is a reduction of the external diameter.

3. Design files

Design file summary

Design filename	File type	Open source license	Location of the file
Fig. 1	figure	Public domain	
Fig. 2	figure	Public domain	
Fig. 3	figure	Public domain	
Body.stl	STL	CC BY	doi: http://dx.doi.org/10.17632/jj65p3znnr.1and https://3dprint.nih.gov/discover/3dpx-007460
Cap.stl	STL	CC BY	doi:http://dx.doi.org/10.17632/jj65p3znnr.1 https://3dprint.nih.gov/discover/3dpx-007460
Gear.stl	STL	CC BY	doi: http://dx.doi.org/10.17632/jj65p3znnr.1 https://3dprint.nih.gov/discover/3dpx-007460
Nozzle.stl	STL	CC BY	doi: http://dx.doi.org/10.17632/jj65p3znnr.1 https://3dprint.nih.gov/discover/3dpx-007460
Slide.stl	STL	CC BY	doi: http://dx.doi.org/10.17632/jj65p3znnr.1 https://3dprint.nih.gov/discover/3dpx-007460

Fig. 1: Illustration of the parts of the micropump.
Fig. 2: Illustration of the method for assembly of the micropump.
Fig. 3: Illustration of the method for use and validation of the micropump.
STL files: Ready-to-print component files of the micropump.

4. Bill of materials

Bill of materials

Designator	Component	Number	Cost per unit - currency	Total cost - currency	Source of materials	Material type
Micropump	*1.76 mm Printer filament*	*64.19 gr*	*$0.043 USD(in Mexico)*	*$2.76 USD*	https://www.amazon.com/s/ref=nb_sb_ss_i_6_3?url=search-alias%3Daps&field-keywords=abs+filament+1.75mm&sprefix=ABS%2Caps%2C174&crid=3BIFNC36242OX	*ABS*
	1 ml syringe	1	$0.3 USD *(in Mexico)*	$0.3 USD	https://www.amazon.com/s/ref=nb_sb_ss_c_1_3?url=search-alias%3Daps&field-keywords=1ml+syringe&sprefix=1ml%2Caps%2C172&crid=3G9RV0ZASFEU1	plastic
	Screw (M2.5 × 6)	2	$0.52 USD*(in Mexico)*	$1.04 USD	https://www.amazon.com/s/ref=nb_sb_noss_2?url=search-alias%3Daps&field-keywords=(M2.5x6)+screw&rh=i%3Aaps%2Ck%3A(M2.5x6)+screw	Hard alloy steel
	Headless screw (M2.5 × 6)	1	$0.59 USD*(in Mexico)*	$0.59 USD	https://www.amazon.com/s/ref=nb_sb_noss?url=search-alias%3Daps&field-keywords=(M2.5x6)+headless+screw&rh=i%3Aaps%2Ck%3A(M2.5x6)+headless+screw	

5. Build instructions

The design was exported to STL (STereoLithography) files which were loaded into the printer software. Acrylonitrile butadiene styrene (ABS) plastic 1.75 mm in diameter was used. The printing parameters used were: fill density 50% (nozzle 90%), thick shells, layer height 0.2, slow print speed, extruder temperature 212 °C and platform temperature 90 °C. The printing takes 10 h to complete. The orientation of the parts when printing is illustrated in Fig. 1. The nozzle Is best printed by raising it and with supports.

Once the parts were printed, I proceeded to clean them from the internal and external supports that the printer software added in order to print without the walls of the parts collapsing. It is very important that the body cavities are not only cleaned from the supports but also polished with 400 grain sand paper, until the walls are smooth, in order for the gear and the slide to be able to move freely. The outer walls were sanded and polished to provide a more aesthetically-pleasing appearance.

To assemble the micropump, first the slide is placed inside the body (Fig. 2A) and then the gear is placed and affixed with the headless screw (Fig. 2B). It should be noted that the slide runs smoothly when the gear is moved and when the gear is released, the slide moves alone. The last tooth of the slide is a stop so that the slide does not become detached from the body (Fig. 1C).

Since printing is a layered plastic extrusion method, the process leaves grooves on the pieces. This is important to ensure the parts fit together tightly. The internal diameter of the nozzle is extremely important as the accuracy of the micropump depends on it. Therefore, the diameter must be uniform throughout and this is very difficult to achieve without a specialized tool, which would make the construction of the micropump expensive. Instead, the inner diameter was designed to allow the body of a 1 ml syringe to be housed therein (Fig. 2C). The syringe must be attached to the nozzle with silicone or epoxy glue in an airtight manner. Then the syringe plunger is placed and the entire assembly placed in the body of the micropump (Fig. 2D) and the cap is screwed to the body (Fig. 2E).

Finally, the scale of the micropump is printed with a laser printer on any type of paper. The scale should be printed vertically at a minimum of 600 DPI as the accuracy of the micropump also depends on the accuracy of the scale. It is cut and glued into the slit of the slide with the first line of the scale 2 mm from the upper edge of the slide (Fig. 2F).

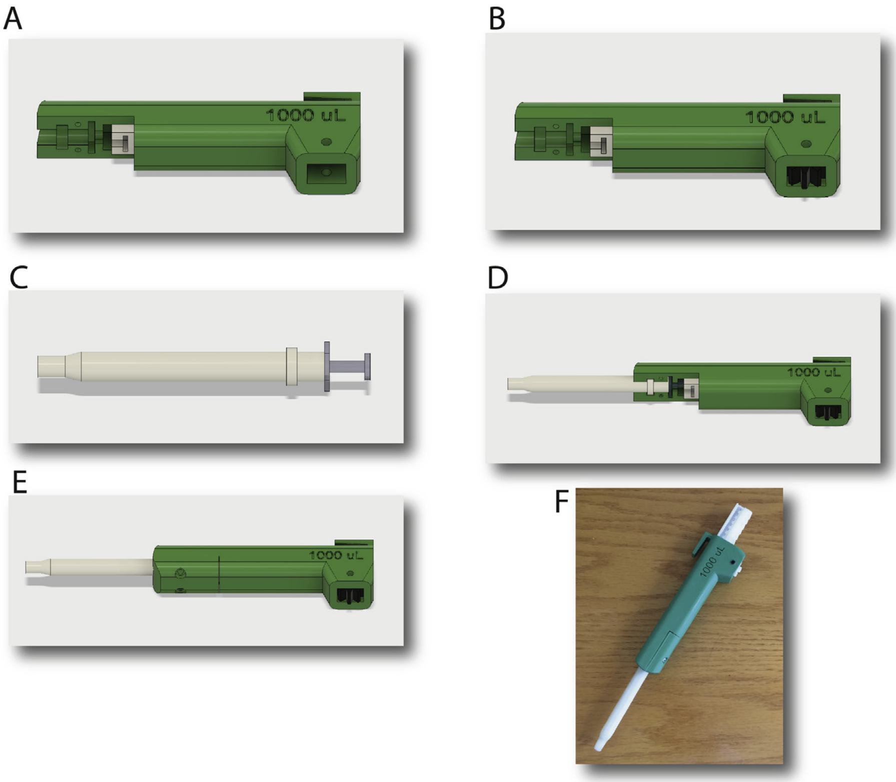

Fig. 2. Micropump assembly. Once the inside and outside of the components have been cleaned, the slide is placed inside the body (A). The gear is fitted and secured with the headless screw (B). The nozzle is prepared by placing the syringe inside the nozzle by sealing it with silicone or epoxy adhesive (C). The nozzle is placed with the syringe in the body (D) making sure that the plunger head of the syringe engages the slide as shown in the figure. Finally, the lid is placed and screwed into position. (F) The assembled micropump.

6. Operation instructions

In order to obtain accuracy, the micropump must be used properly. The recommended steps are as follows: the first step is to place the plastic tip on the end of the nozzle (Fig. 3A). Second, the gear must be moved so that the first line of the scale is located at the edge of the body (zero position, Fig. 3B). Subsequently the tip is immersed in the liquid to be loaded and the gear is moved to draw up the liquid until the scale shows the desired volume. The scale line representing the desired volume must be in the same position with respect to the body as the zero line (Fig. 3C). Finally, the liquid is discharged into the desired location.

7. Validation and characterization

To determine the accuracy of the 3D printed micropump, its performance was compared with two recently calibrated commercial micropipettes, the Pipetman P1000 model from Gilson and the Eppendorf Research 1000 µl. Twenty measurements of deionized water were taken for test volumes of 100, 500, and 1000 µl with the micropump and micropipettes and discharged onto a Sartorius/Basic analytical balance (Sartorius Lab Instruments GmbH & Co. KG, Göttingen, Germany) to determine the weight of the volume. Values are expressed as mean ± standard deviation. With these information, systematic and random errors where calculated, values are expressed in% of the test volume.

The performance of the three was as follows (Fig.3D):

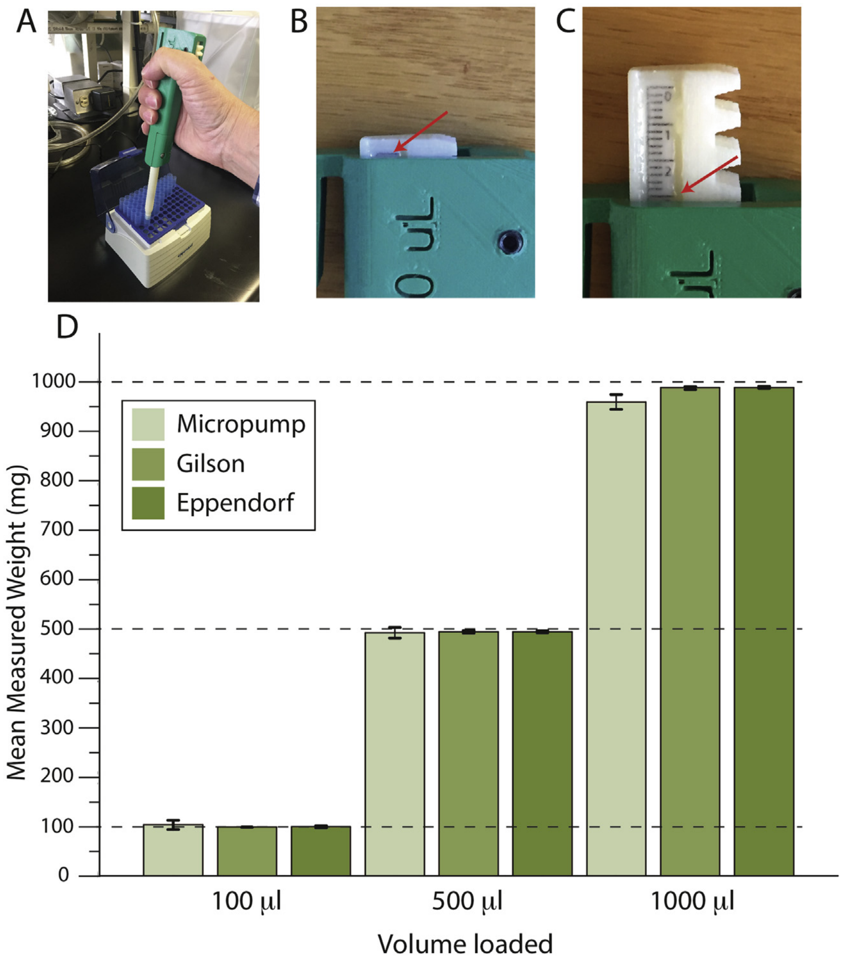

Fig. 3. Mode of operation and validation of the micropump. (A) Illustrates how the zero line is placed on the edge of the micropump body. (B) Illustrates how the stripe of the desired volume must be in the same position as the zero line with respect to the body of the micropump. (C) Graph of the average of measurements (mean ± SD, n = 20) vs each volume (100, 500, 1000 µl) with the manual micropump, the Gilson, and the Eppendorf. The averages are very similar but the variability of measurements is greater with the manual micropump.

Volume	3D printed	Gilson	Eppendorf
100 µl	01036g ± 0,00935	0,09936g ± 8,96103E−4	0,09952g ± 0,00231
500 µl	0,49286g ± 0,00192	04949g ± 0,00247	0,49516g ± 0,00189
1000 µl	0,96128g ± 0,00626	0,99078g ± 0,00742	09906g ± 0,00225

Performance of Micropump and Micropipettes

Volume		3D printed	Gilson	Eppendorf
100 µl	Systematic Error (%)	±3	±0,64	±0,48
	Random Error (%)	±9.5	±0,89	±2,31
500 µl	Systematic Error (%)	±1.44	±1,02	±0,96
	Random Error (%)	±0.38	±0,49	±0,37
1000 µl	Systematic Error (%)	±3.8	±0,92	±0,94
	Random Error (%)	±0.62	±0,74	±0,22

8. Discussion

This article presents the design of a 1000 µl 3D printed micropump, which is light, manually operated, and inspired by the use of pipette pumps. The design is very easy to print on any 3D printer. The cleaning of the pieces as well as the assembly of the micropump can be done with very simple available tools.

Comparing the 3D printed micropump with two commercial micropipettes, it was found that the average performance was sufficiently comparable to commercial micropipettes for inexact applications; the systematic error of the micropump falls within the limits that commercial manufacturers establish for their micropipettes (for Eppendorf is ±3.0%, [16]. The random error is beyond the error established by standard manufacturers (for Eppendorf is ±0.6%, [16]). I believe this parameter largely depends on the consistency of the operator micropump (Fig. 3D). In my hands, for 500 µl, the mean volume (±SD) was 0,49286 g ± 0,00192, n = 20 and for two other people was: 0,5 g ± 00024 and 0496 g ± 0003 (n = 20). Although our results show that the 3D printed micropump is not as accurate as its two tested commercial counterparts, it has shown sufficient precision for jobs like preparing cell culture media, perfusion solutions for electrophysiology, adjusting pH, etc. this micropump is not suitable for performing jobs that need very precise small volumes like PCR. The accuracy of this micropump depends on three factors: the construction, the scale, and the manner in which it is used. The printer must print each of the parts, in particular the nozzle, without defects. The nozzle must be printed with a density of 90% to avoid micro-holes whereby the negative pressure of the micropump is lost and the material is drained. The nozzle where the tips are placed should be polished very well (removing the stretch marks from the printed product) with 400grain sand paper until your fingers feel the surface smooth so that there is a tight connection between the nozzle and the tip. The scale must be printed in high resolution so that the distance between its lines is preserved. This is very important for the micropump to maintain its accuracy. Finally, the accuracy depends on the exactness with which the micropump is used. Before the liquid is drawn up, the micropump must be placed in the zero position. The operator must very carefully note the position of the zero line, load the desired volume, and then ensure that the volume line is in the same position as the zero line (Fig. 3A–C).

Conflicts of interest

None.

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