3D Printed Micro Check Valve for Biomedical Applications

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Abstract. This paper presents development of a novel three dimensional imprinted micro check valve for biomedical applications. Due to its rapid and cost effective fabrication techniques, micro check valve devices are widely used in several areas of the biomedical industry such as intravenous (I.V.) fluid transfusion. The fabrication method consists of SolidWorks modelling and 3D printing steps for prototyping. The micro check valve is a self-controlled valve that relies on pressure change for operation. In this particular design, a sphere was used to prevent any backward flow allowing the pressure change to only initiate a one-way flow. The tests showed that the check valve design allowed for zero backward flow while also allowing flow through the device in the proper direction at a rate of 98.6 μl/sec.

1. Introduction
Check valves have been used for the past 50 years and keep improving as technology advances. A check valve allows flow in one direction and prevents flow in the reverse direction. They can be designed with a spring mechanism that opens when flow goes through and closes when the flow stops. Check valves have been implemented in different areas of the biomedical engineering such as surgical procedures [1], in vitro tests [2-3], drug delivery [4-5] and microfluidic applications [6-13]. They have also been used to facilitate procedures to treat glaucoma [14-15]. Different materials such as silicon-on-insulator wafers [16], shape memory alloys [17], piezoelectric materials [18-19], graphene [20] and hydrogels [21] have been used in fabrication of micro check valves. One type of the check valves works based on spring loaded design and uses a plunger style stopper with a rubber grommet that stops backward flow by pressing the stopper against the housing walls. This type of check valve provides quick interruption of flow and positive sealing at a pressure below the cracking pressure of the valve. In another study, a polymeric micro check valve used springs to channel fluid on a wafer. The results showed that as flow increased through these check valves, the pressure increased [22]. This paper presents the design, fabrication and testing of a micro check valve used in I.V. fluid transfusion. The goal was to design a check valve that could be classified as a microsystem and be fully functional when being applied in an I.V. transfusion. The check valve has a free floating ball inside on tracks. When fluid is pushed through the valve, the ball will move to open the flow chamber, allowing fluid to pass. When the flow stops, the ball will slide down on the tracks to stop any backward flow. The check valve was modelled using SolidWorks and printed on a 3D printer.
2. Design

The check valve was required to be designed such that it could be applied for I.V. transfusions. The initial design of the valve included ball and socket parts. The ball would block the smaller channel from any possible backward flow and sit into a perforated socket to allow the fluid to pass. A redesign was created and involved bars that would contain the ball in the chamber and a cap-type bottom to cover the smaller inlet channel. The perforated socket containing the ring remained the same, and small tabs were added and connected to the bars to ensure that the ball would not rotate. In order to improve the valve performance, a three part valve was designed and included a perforated ring, a containing ring with bars and a ball with grooves cut into it, as shown in Figure 1. The ball still needed to contain the capped bottom to allow for proper backward flow prevention, while the bars needed to remain to contain the ball. When fluid comes from the inlet of the valve, the ball will be pushed up into the perforated ring, allowing for fluid to freely flow around the ball through the small holes in the ring. Once the fluid stops flowing, the back pressure on the outlet of the valve will push the ball flush against the inlet of the valve, ensuring that no fluid will be able to flow backwards (Figure 2). The cap on the bottom of the ball ensures that a tight seal is made on the inlet of the valve to completely prevent backward flow. While most designs have a spring loaded ball, the design in this paper is based entirely off of the laws of pressure flow.

![Figure 1. Exploded view of the check valve assembly.](image)

![Figure 2. Cross sectional view of the assembly in the forward flow position (a) and backward flow position (b), with the flow shown as red arrows.](image)

The ball itself has a diameter of 2mm where the valve inlet and outlet have diameters of 1.25 mm. The perforated ring has the same outer diameter of the valve outlet, but the inner diameter is 1.25 mm. This inner diameter needed to be smaller than the ball because the ball required to be contained within the flow chamber. The diameter of the cap on the bottom of the ball is 1.25 mm. The reason for this being larger than the valve inlet is to ensure that the ball can adequately cap the inlet. Further dimensions of the parts are presented in Table 1.
Table 1. Dimensions of the developed valve parts

| Part                              | Dimension (mm) |
|-----------------------------------|----------------|
| Ball diameter                     | 2              |
| Valve inlet diameter              | 1.25           |
| Valve outlet diameter             | 1.25           |
| Valve length                      | 4              |
| Perforated ring outside diameter  | 3              |
| Perforated ring inside diameter   | 1.25           |
| Perforated ring thickness         | 1              |
| Outlet holes                      | 0.875          |
| Ball smaller diameter             | 0.6            |
| Ball radii cut                    | 1.8            |
| Bar radii                         | 0.5            |
| Bar width                         | 1              |
| Overall length                    | 5              |

3. Fabrication

To fabricate the check valve, a Formlabs Form 2 3D printer was used to make parts with an ABS plastic resin material. This fabrication method was quick and simple, which facilitated the process. To use the 3D printer, the design was first modelled in SolidWorks. The check valve was printed in three parts: the ball, the valve inlet and the perforated ring outlet, which were all printed at the same time. This printer uses a laser that heats resin in a tank and solidifies the resin. The resin is attached to a base plate hanging above the resin tank. As it solidifies, the base plate moves upward pulling the already solidified layer out of the tank so the next layer can be solidified by the laser. It continues this process until the part is completed and entirely pulled out of the resin base. The 3D printer allowed a print resolution of 100 μm per layer which made for very clean and precise features in the parts. After the printing process, the parts were placed in isopropyl alcohol for 10 min, rinsed in water for 10 min, and dried in ultraviolet (UV) light. The mounts that the parts were printed on were then removed. The ball was placed into the cylinder after printing, and then the top part was installed on the valve inlet. The check valve must be coated with a thin layer of parylene in order to make it biocompatible and safe for use in the human body [23]. Figure 3 shows a photo of the fabricated check valve.

![Figure 3. 3D printed check valve.](image)

4. Testing

Several tests were conducted on the check valve to physically prove that the valve would prevent any backward flow and allow for a fluid to freely pass through it. The valve was fabricated in two different sizes, once at actual aforementioned size, and once at three times larger size. The larger valve was
used to visually represent what was occurring in the actual-sized valve, whereas the actual-sized valve was used to gather test results and data. Both valves were subject to the same experiments during the entire test process.

The first test conducted was simply to see if liquid would flow freely through the valve with very little pressure. The valve was secured to a wall and the inlet was placed upwards, whereas the outlet was placed downwards. Colored fluid was then placed in the valve by a syringe and it was observed that fluid was able to pass through the valve with no issues. This test proved that the valve would allow forward flow. Next, the valve was flipped so that the outlet was facing upwards. Fluid was then added in the same fashion, and it was observed that no fluid was able to pass through. This proved that, when not subjected to any additional pressure, the valve has a solid seal so that no fluid can flow backwards. The test results were conclusive that the valve design was functional enough to further the testing procedures.

The next test was to subject the valve to a certain pressure. These tests were conducted to prove that the valve would not fail and that the backward flow seal would not falter under certain pressures. The pressure that the valve had been subjected to is much greater than the pressure it would experience in the field, but the reasoning for this is to ensure that the valve would not fail under a normal operating pressure. Indeed, the valve would only be subject to pressures slightly greater than the atmospheric pressure, simply because the I.V. transfusion and similar applications that the valve will be used for is not a very high pressure application. The design on the valve allows for it to open when pressure at the inlet is greater than the outlet, which means that even the slightest difference in pressure will allow the valve to open or close, depending on which side of the valve has a higher pressure. Figure 4 shows the experimental setup and the aforementioned tests in forward and backward flow directions.

5. Results and Discussion

In order to quantify the results, several test trials were performed on the valve. The tests included placing the micro check valve in an IV and then placing one end of the IV in a graduated cylinder while pushing colored water through the other end of the IV. The amount of liquid in the syringe was measured before the valve testing. The amount of liquid in the graduated cylinder was then measured every 5 seconds for 30 seconds while pushing the colored water through with constant pressure. This test was repeated to test for both forward and backward flow through the valve. Figure 5 shows the volume of the fluid passing through the valve as a function of time in forward and backward flow directions. This test not only showed whether or not there could be backward flow but it also showed the rate at which liquids could flow through the valve. As shown in Figure 6, the check valve design allowed for zero backward flow while also allowing flow through the device in the proper direction at a rate of 98.6 μl/sec.
6. Conclusions
This work demonstrated the development of a novel micro check valve for biomedical applications, particularly I.V. transfusion. The design, fabrication and characterization of the check valve was discussed in this paper. In the check valve design, a movable ball was used to allow fluid flow in one direction while prevent any backward flow in the other direction. 3D printing was used to fabricate the valve prototype. The qualitative and quantitative tests were performed to check the performance of the check valve. The tests showed a successful design with a zero backward flow while a 98.6 μl/sec flow rate in the open direction.

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