Cost and time reduction of industrial mold design and manufacturing by implementing additive manufacturing for premature neonatal prong

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Research Article

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Abstract

Introduction: For a long time, molding was one of the most important methods of producing metal, ceramic, and polymer materials. The two essential factors in this method were always cost and time. Nowadays, with a computer and additive manufacturing technology, you can design in 3D. This article describes how to reduce the time and cost to get the final product using 3D-Printers. The design and production of molds for premature neonatal respiratory aid, called "Prong," were applied based on neonatologists' considerations.

Method: This study is performed in Alzahra hospital in Tabriz University on fifteen very low birth neonates from September 2017 till September 2019. In the first section, we described dental plaster material for molding. To use this material, select the printing material to control the parameters, including melting temperature and printer speed, so that the final sample results with acceptable quality. If the final three-dimensional design is suitable, various objects can be printed using CAD (Computer-Aided Design) software.

Results: By using additive manufacturing technology, we achieved a new design with a little creativity and trial and error, and we also solved bubble problems at a low cost. So, we designed some cavities in the new mold to ensure that silicon takes up all of the mold space and provides a way to exit the bubble in the silicon.

Conclusion: To achieve an optimal and final design for prong mold. Using 3D printers helps us reduce production costs and time and optimize the design. Finally, the CNC machine produced the ultimate mold made of aluminum. We tested the final product in Al-Zahra Hospital in Tabriz in Iran, and the results were satisfactory, and there were no reports of necrosis on the babies' noses.

1. Introduction

One of the most commonly used methods for molding small objects that require high precision is the molding method used in dentistry. One of the most used and purest materials in this method is alginate powder [1]. The main factors affecting the molding using this powder are the ratio of water to gypsum, time, the pressure applied to the plaster, and the amount of plaster expansion after mixing with water.

On the other hand, the ordinary plaster expands rapidly, which does not match the beautiful appearance of the final product, so we changed the molding plaster to reduce the problem of the high expansion of standard applications and produce a more smooth surface. Besides, the mold must be tightened so that the thin area can be well molded [2]. As a result, Heshmati introduced the High Strength Stone material in dentistry, which has a more excellent level of smoothness, greater strength, and less expansion than previous plaster [3].

However, around 1997–2000, many efforts were made to express the quality of the parameters in this molding. The research showed that the valid parameters for molding are more than can easily be controlled. Therefore, it is not easy to define an overall standard for a molding method with the desired specifications [4–6]. The most critical malfunctions of molding with these materials are a) In addition to the difficulty of mold production, the number of products to be produced by this method; b) industrial molding is very costly and cannot be used before reaching an optimal specimen [7].

In recent years, with the introduction of Additive Manufacturing Technology and the ability to implement it in medicine, they are widely used [8–10]. 3D printers have a variety of raw materials, each with its characteristics. To use this material, type the material to the printer to control the rest of the parameters, including melting temperature, melting speed, and printer speed, so that the final sample results are acceptable. If the final three-dimensional design is suitable, various objects can be printed using CAD (Computer-Aided Design) software and selecting the suitable material type [11].

One of the advantages of 3D printers is that design parameters are entirely in the user's hands. Therefore, the software can make changes before printing [12]. Hence, we can achieve a final optimum sample. Besides, its other advantage is the least cost compared to constructing molds using CNC machines [7, 13].

Babies born under 37 weeks gestational age are called premature [14]. Today, the highest number of neonatal intensive care unit admissions are preterm babies [15]. The most important cause of death in premature is respiratory distress syndrome. The establishment of regular respiratory status in neonates is the most important goal.

One of the most commonly used respiratory aids in the Treatment of respiratory distress is CPAP in preterm infants. Gregory et al. first introduced this less invasive method in 1971. CPAP results in the maintenance of alveoli in the Treatment of RDS [16]. Early use of CPAP before initiating RDS prevents lung damage and protects the baby's surfactant stores [17, 18]. CPAP provides positive pressure to premature by implementing silicone prongs.

Unfortunately, most of the silicone prongs on the market are unsuitable for Iranian babies' nose sizes. The prong should be such that it completely covers the nose and, at the same time, does not push the nose. An unsuitable shape of prongs causes serious problems such as nose necrosis. Removing a baby's nasal necrosis is one of the most critical issues, and many studies try to resolve it in different ways. As a result, nurses should be cautious about these conditions [19–21].

After examining the types of molding for objects with a precision of millimeters, we conclude that we need to use additive manufacturing technology to reduce the cost and time of the first molds. Using CAD software, variables can be easily changed to achieve a suitable design. In this way, we designed it economically feasible, and mass production is justifiable. Finally, after examining the disadvantages of each molding method, an optimal design is obtained with the help of additive manufacturing technology. From the optimal format with the aid of a three-dimensional printer, we arrived at an aluminum mold, with the final samples produced. The final product was tested in Tabriz's al-Zahra hospital on preterm infants in Iran, with satisfactory results.

2. Methods

This study is performed in Alzahra maternity hospital in Tabriz university on fifteen very low birth neonates from September 2017 till September 2019. In the first section, we described dental plaster material for molding. We discussed the disadvantages of this method in section 2.1. Section 2.2 explains how to create the desired template using additive manufacturing technology. How to solve the problems in the various types of molds are expressed in Section 2.3

2.1 Molding with dental plaster

First, we mold prongs available in the market with dental plaster. To achieve an optimal template, we make several templates in various ways to choose a cost-benefit method for the manufacturer. Figure 1 shows the plaster stuck inside the tubes, resulting in removing the original plaster from the mold. As a result, preparing the appropriate mold is a complicated process.

After producing several template samples, we will use them and make a better prong, as shown in Fig. 2. After removing the sample from the molds, we saw that the produced tubes did not form ultimately.

In a few cases where these tubes partially formed, they had torn off due to gypsum sticking when the product was removed from the mold. Besides, it was difficult to separate the two pieces of the molds (female and male), so sometimes we had to break the mold, resulting in extra time and cost.

After working with dental alginate to remove the issues mentioned above, we used *High Strength Stone* material for molding. The most important features of this type of plaster were: a) slight expansion, b) high resistance in the edges of the prong, and c) a super-smooth surface [22]. After molding the prong with this plaster, as shown in Fig. 3, the tubes were torn off again.

2.2 Prong mold design using additive manufacturing technology

Following the molding failure in the above methods, the most suitable way found for the molding was using three-dimensional printers with the required precision. As shown in Fig. 4, the initial design was based on a single mold piece. In the integrated design, the problem of Accuracy is not the size of the final template, and there is no change in the size of each piece of the template. In this way, the amount of filament material (raw material for 3D printers) was reduced. Therefore, each mold was cheaper, which was the most crucial goal in implementing this project.

After producing the mold using a 3D printer, we observed that the silicon material injected into the mold did not fully penetrate the middle of the mold to form the tube tubes, which is a fundamental problem of this method. Because the tubing will not be damaged due to the adhesion problem while removing the specimen from the shell. See Fig. 5. In Section 4, we will describe how to fix this problem.

2.3 Multilayer templates

Due to the problems in the mold of a piece mentioned in Section 3, we designed a multi-piece mold design. Figure 6 illustrates a sample of two-piece design molds. Creating the space between the lower and upper pieces of the template helps prevent the tearing of tubes during separation.

Although as shown in Fig. 6, there are a few bubbles (due to the splitting of two silicon materials) in the manufactured prongs' tubes. The second piece of the mold deforms by warming (the warming process is necessary to solidify the silicone material). Besides, the surface of the product did not have a uniform wall, and even in some areas, it was so thin that during utilization, it quickly turned.

To correct the issue, parts of the mold are individually designed; by inserting silicone into the mold, the pins of molds place individually in their location. As shown in Fig. 7, it is difficult to remove the pins, but the final sample is better than the previous one, and this superiority has been seen through a step-by-step design. As shown in Fig. 8, to remove the probe easily and without damage, the bottom part of the mold was designed to be two pieces, pins, and bars, attached to the top piece. Finally, we observed that tubes in the middle of the prong were removed, which was our goal, but the removal of the product from the mold tearing off was still the problem.

We did not separate the mold from the center to reduce the contact surface between silicone handles and the mold. We noticed that the product's appearance had an acceptable quality, but there was still a bubble in the silicone mixture. Bubbles are created during a mix of RTV2 silicone with substances' A' and 'B.' The final silicone is cooked and hardened with warmth. After mixing 'A' and 'B,' the mixed silicon has many bubbles that should come to the surface during warming.

In the design, there is a problem that there is not enough space to exit the bubble from the mold. These bubbles are eventually captured inside the template and damage the final product. In section A of Fig. 9, we see that bundles and tubes are well-produced, but in other parts of B, C, and D, we show the form of a model, the bubbles captivated in the silicon after being cooked.

By using additive manufacturing technology, we achieved a new design with a little creativity and trial and error, and we also solved bubble problems at a low cost. So, we designed some cavities in the new mold to ensure that silicon takes up all of the mold space and provides a way to exit the bubble in the silicon. To prevent bending of the pins and uniform formation of prongs in walls, we designed the mold's parts so accurately that the parts of the mold fit precisely. The specification of the 3D printer we have used is 20-micron layer resolution, 12-micron X.Y. precision, and 5micron Z precision.

3. Result

After producing several mold samples, we noticed that it is unnecessary to make the male part of the mold with two sections because debris on the final product makes it ugly. As a result, the molds of Fig. 10 were designed and printed as a final optimal mold. Also, for the release of silicone bubbles, we placed holes in the parts of the mold to come out. Another problem in the final sample was that the final product did not have a smooth surface because the 3D printer prints one layer on the other. This problem can be resolved by adjusting the device in terms of the type of filament material. Although we were able to implement the new idea using additive manufacturing technology, the problem of bubbles remained unresolved. These bubbles were tiny, so we tried to find another way to remove them. As shown in Fig. 10, the final product is correct, but sometimes the tiny remaining bubbles cause a breakdown in the product.

To resolve this problem and achieve the ultimate quality product, we produced the final mold made of aluminum which was expensive after trial and error. The cost of having a sample of mold using the CNC machine and aluminum as a material cost approximatly100 times more than a 3D printer, Fig. 11.

After producing several aluminum molds, despite the creation of holes in the female part of the mold, it was observed that the final products had tiny bubbles, as shown in Fig. 12. To overcome this problem, we implemented the method used in the cement mixture, and the Fig. 13shows the desired result.

4. Discussion

The most crucial goal of this study was to design and produce low-cost prong mold for premature infants in Iran. So we first created the mold with standard molding techniques used in dentistry for having high resolution. In this process, we examined whether these traditional methods can be appropriate or not. Finally, we found that standard molding techniques for delicate products would face a particular problem. On the other hand, the cost of producing molds is very high using a CNC.

Another problem was the lack of suitability of existing prongs on the market for Iranian babies' noses. After researching additive manufacturing technology, we concluded that the use of 3D printers is the cheapest method for producing high-precision molds. In 3D printer settings, we minimized the density of the mold and the thickness of the walls to reduce production costs by reducing the consumption of raw material for each mold. After designing the required templates in CAD software and many tests, we finally managed to reach the optimal and usable format. Using inappropriate prongs causes nasal necrosis and infections in the infant. In this research, with the help of additive manufacturing technology, we produce various samples.

5. Conclusion

To achieve an optimal and final design for prong mold. Using 3D printers helps us reduce production costs and time and optimize the design. Finally, the CNC machine produced the ultimate mold made of aluminum. We tested the final product in Al-Zahra Hospital in Tabriz in Iran, and the results were satisfactory, and there were no reports of necrosis on the babies' noses. Figure 14 shows a tested prong on a baby in Al-Zahra Hospital.

Declarations

Competing Interests: The authors declare no competing interests

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Figures

Figure 1

Problem with dental plaster molding

Figure 2

The prong produced by a dental plaster with the absence of forming the tubes

Figure 3

poor Quality Using *High Strength Stone* mold for producing prong

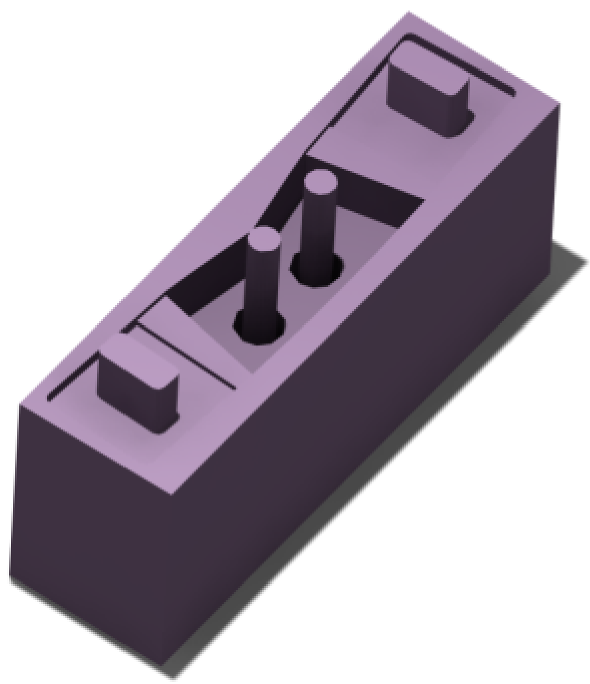

Figure 4

Single mold design

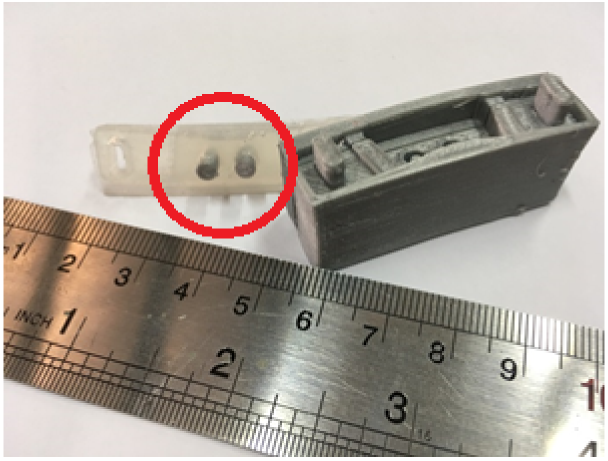

Figure 5

Pinching the pipe pins in the product and the difficulty of removing it without damaging the product

Figure 6

Multi-piece mold deformed and no proper fitting of tubing pipes

Figure 7

improper forming prong tubes in the new design

Figure 8

shows the standard removal of the hollow tubes and tearing off the handles

Figure 9

a) Successful formation of tubes and bunches of b, c, d) remaining silicone bubbles inside the product cause damage to the final product

Figure 10

the existence of a bubble in an optimized mold

Figure 11

The aluminum frame was designed and manufactured using a CNC, which is the model of the best format printed by the 3D printer

Figure 12

Samples of right product with bubbles

Figure 13

Samples of the product with the ultimate quality

Figure 14

final prong product tested on premature infants in Al-Zahra Hospital Tabriz-Iran