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ADDITIVE MANUFACTURING AND INJECTION MOLDING PROCESS FOR MASS-PRODUCTION OF FACE SHIELDS DURING COVID-19 PANDEMIC: A COMPARATIVE STUDY

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ABSTRACT

Face shield is an equipment required for healthcare professionals to decrease the risk of contamination during the COVID-19 pandemic. Fused deposition modeling (FDM) is the most applied process of additive manufacturing due to its usability and low-cost, the injection molding (IM) is the fastest process for mass industrial production. In this study a qualitative comparison of these processes was performed for mass-production and distribution of face shields. The FDM manufacturing of 35,000 face shields was carried out by a volunteer network using low-cost 3D printer and the IM manufacturing of 80,000 was carried out by partner companies. Through the FDM process was possible to make daily deliveries of small batches to local hospitals. A total of 80,000 face shields was produced in larger batches by the IM process and delivered to remote regions in Brazil. Considering the manufacturing resilience of the processes, quality, costs, and production time, both FDM and IM processes were suitable for mass production.The FDM process promotes a fast-daily production once a committed network of volunteers is formed in strategic regions. The IM process was the best option for large scale production of face shields and delivery to remote regions without the availability of 3D printers.

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INTRODUCTION

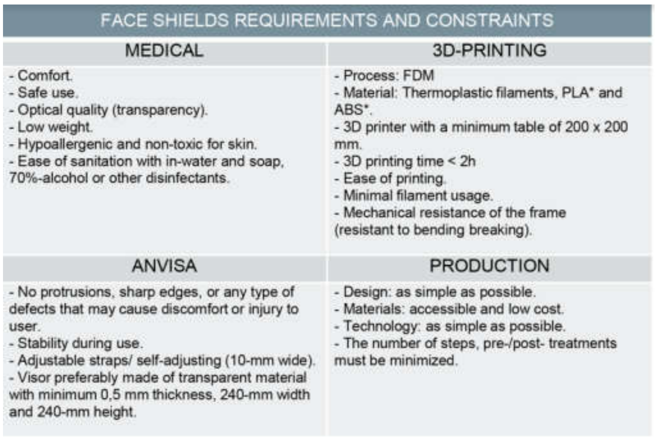
Coronavirus Disease 2019 (COVID-19) is a life-threatening disease caused by the novel coronavirus that has caused a large global outbreak [Gorbalenya, 2020]. The transmission of this disease occurs at human-to-human level, when droplets are generated close to the eyes, nose, or mouth and reach the respiratory system or through direct contact with contaminated surface followed by the touching of the eyes, nose, or mouth [Lai, 2020]. The most common symptoms are fever, pneumonia, and cough, but the severe cases progress to respiratory and death [Al Mamun, 2020; WHO, 2020]. The COVID-19 infection began in Wuhan, China, in December 2019, and it has rapidly spread across several other countries. In Brazil, the number of COVID-19 cases grew fast, and currently, Brazil was the second country with the highest number of infected individuals [Rodriguez-Morales, 2020]. Brazil has a hybrid health system. Every citizen has free access to the National Health System, but a private system offers services covered out of payments and insurance plans [Paim, 2011; Menezes Filho, 2019]. Public health policies and infection control measures were required to limit virus spread and decrease the damage associated with the COVID-19 outbreak [Lai, 2004; Biscayart, 2019]. In all countries affected by the new coronavirus, the increased number of cases is associated with an overwhelmed health system, resulting in shortages of personal protective equipment (PPE) such as gloves, face masks, goggles, face shields, N95 masks, and gowns [Livingston, 2020; Ranney, 2020; International Council of Nurses (ICN) 2020; National Nursing

Council. 2020]. Healthcare workers are at the front line of the COVID-19 outbreak, as they are submitted to hazards that put them at risk of high pathogen exposure. The use of barriers that block respiratory droplets seems to prevent COVID-19 transmission, among which face masks and shields are the two primary options [Perencevich, 2020]. Face shields are used for the protection of the facial area and mucous membranes (eyes, nose, mouth) from splashes, sprays, and body fluid spatter [Christensen, 1991; Roberge, 2016]. Face shields significantly reduce the amount of inhalation of the influenza virus, providing a transparent physical barrier that covers the face and can be used in conjunction with face masks and goggles [Ng, 2009; Rengasamy, 2010]. For optimal protection, the shield should cover the forehead, extend below the chin, and wrap around the side of the face, and there should be no exposed gap between the forehead and the shield frame [National Nursing Council. 2020; Roberge, 2016]. Non-use of face shields by nurses during high-risk aerosolizing procedures on patients withrespiratory infections resulted in greater than three-folds increased risk of infection. Face shields are efficient in reducing viral exposure by 97% on a contaminated surface [Lindsley, 2014]. The Brazilian Health Surveillance Agency (ANVISA) simplified the PPE product regulation process during the COVID-19 pandemic. The requirements for face shields production enabling the development of alternative models [ANVISA, 2020]. Some solutions have been created using additive manufacturing, popularly known for 3D printing [Gibson, 2014].

This technology allows the manufacture of physical models through the addition of materials in layers in a cost-effective and fast approach based on computer aided design (CAD). Fused Deposition Modelling (FDM) is the most accessible printing process in the medical field due to its usability, availability of low-cost 3D printers, and a broad range of thermoplastic material [Munhoz, 2016; Santos, 2018; Shahrubudin, 2019]. This process has been used to produce face shields using open-access models to supply the demand of hospitals in the COVID-19 pandemic [Ishack, 2020; Swennen, 2020; Tino, 2020]. Injection Moulding (IM) is a manufacturing process that transforms raw thermoplastic material into designed parts of a particular shape. It is the most important process for mass production through the melting and injection of plastic at high pressure into a mold [Kichukov, 2019].The production of face shields can be accomplished through the manufacturing processes FDM or IM [28-29]. However, which of the methods is the most suitable for mass production and rapid distribution of face shields in a pandemic situation? This studycarried out in Brazil during the COVID-19 pandemic, is the first one to compare theFDM and IM processes through the production of 115,000 face shields that were distributed to support the healthcare system.

MATERIAL AND METHODS

Design and prototyping cycles of the Higia face shield: The process of the Higia face shield design, development, testing, and improvement was carried out in 3 prototyping cyclesinspired by the open-source model of the face shield Prusa RC1[30]. The face shield consists of a frame, produced by 3D-printing in polymeric material, a visor and a rubber band. The Prusa RC1 face shield model requires long 3D-printing time (about 5 hours) and the use of a considerable amount of material. In the Higia model, some features of the Prusa RC1 model were adaptedto suit a list of requirements that was created considering medical needs, 3D printing, ANVISA standards and production logistics[19](Fig. 1). The first version of the Higia frame was created with Fusion 360® 3D modeling software (Autodesk, USA) and saved in an STL file (standard tessellation) for additive manufacturing. In the prototyping cycles, the STL file was converted into a G-code file using Simplify3D® slicing software (Simplify3D, USA). The polylactic acid (PLA) filament (Material 3D, China) was used to manufacture the frame in a 3D printer Stella 2 (Boa Impressão 3D, Brazil) with the FDM process.



FACE SHIELDS REQUIREMENTS AND CONSTRAINTS	
MEDICAL	3D-PRINTING
- Comfort. - Safe use. - Optical quality (transparency). - Low weight. - Hypoallergenic and non-toxic for skin. - Ease of sanitation with in-water and soap, 70%-alcohol or other disinfectants.	- Process: FDM - Material: Thermoplastic filaments, PLA* and ABS*. - 3D printer with a minimum table of 200 x 200 mm. - 3D printing time < 2h - Ease of printing. - Minimal filament usage. - Mechanical resistance of the frame (resistant to bending breaking).
ANVISA	PRODUCTION
- No protrusions, sharp edges, or any type of defects that may cause discomfort or injury to user. - Stability during use. - Adjustable straps/ self-adjusting (10-mm wide). - Visor preferably made of transparent material with minimum 0,5 mm thickness, 240-mm width and 240-mm height.	- Design: as simple as possible. - Materials: accessible and low cost. - Technology: as simple as possible. - The number of steps, pre-/post- treatments must be minimized.

Figure 1. Face shield requirements defined to meet medical needs, 3D printing, ANVISA standards and production logistic. (ABS: Acrylonitrile butadiene styrene; PLA: Polylactic acid, and ANVISA: Brazilian Health Surveillance Agency)

Manufacturing of the Higia face shield using the fused deposition modeling (FDM) and the injection molding (IM) processes: To produce the Higia face shields using the additive manufacturing process, an FDM type 3D printer was required, with a minimum printing area of 200 x 200 mm, filament (PLA), acrylonitrile butadiene styrene (ABS) or similar, transparent Polyethylene Terephthalate (PET) sheet or similar with a thickness between 0.3 and 0.5 mm, and elastic bands. The 3D printing parameters were 5% full honeycomb infill, 0.3 mm layer height, 3 top solid layers, 3 bottom solid layers, 3 outline/perimeter shells, and 50 mm/s printing speed. The metal mold of the frame produced for the IM process was based on the same design, but the frame design was changed to allow the melted polypropylene to flow during the injection process in the mold. The mold is a structure of two parts: the cavity and the ejector the mold. The melted material enters through a feed channel in the mold's cavity half and then it is hard-pressed, flowing through the machined ducts (guides) in cavity and ejector molds halves to form the desired part. After forming, the two parts of the molds are separated, the frame is attached to the second mold and ejected from there, falling freely inside a collecting container in the machine. The qualitative comparison of both face shield production processes FDM and IM was based on Franchetti and Kress [Franchetti, 2017].

Mass-production and distribution: The Higia project website was created to recruit volunteers Makers to print the face shields on your 3D printers, to make available the open-source model of the Hígia face shield, and to receive requests of face shields donations from hospitals all over Brazil using the application Google form (Google, USA). Additionally, an account was created on Instagram (Facebook, USA) to provide training videos for the volunteers and to disclose information regarding the face shield donation progress. A crowdfunding campaign was created to raise funds for financial support for material purchase for FDM and IM processing and logistics. The mass production of face shields was launched in two phases. The first one was carried out using FDM process, and in the second phase relied on the IM process. The first phase accounted on a network of volunteers grouped into 3D printing production hubs all over the country remotely coordinated by the central hub in the city of São Paulo due to the quarantine lockdown. A logistics system was created aiming at material delivery, to coordinate the distribution of the 3D-printed frames, assembling of face shields, and supplying to hospitals according to the demand. The second phase was carried out by a partner company, and deliveries in remote regions were made by sea and air transportation.

RESULTS

The first version of the Higia frame has the shape of two arcs attached by their ends and united in a single piece with four anterior square pins for visor fitting, and two posterior round pins for the fixing of the frame to the head using a rubber band (Fig.2). Several changes were implemented in this version during three prototyping cycles (Fig.3). First, two strips were modeled to adjust the frame on the user's head (1); the angles formed by the union of the two bands were smoothed to facilitate cleaning (2), and the name "Higia" was imprinted (3) (Fig. 3A). However, the strips were fragile and broke during testing with users. In the second prototyping cycle (Fig. 3B), the shape of the anterior pin was changed into a hook to avoid detachment of the transparent sheet during face shield use (1); the distance between the pins was adjusted to ensure fixing and adjustment of the transparent sheet (2); The strips were remodeled for strength (3); The imprinted name "Higia" was removed to make cleaning easier and replaced by a triangle to indicate the position of use (4); the frame thickness was changed from 15 to 10 mm (5), and the frame type was changed from square to round (6). However, through the FDM process using PLA, the strips were not strong enough and were replaced by two elastic bands. In the last prototyping cycles, the distance between the two ends of the frame was increased from 101 to 128 mm, and the pin for the elastic band was changed for safety (Fig. 3C).

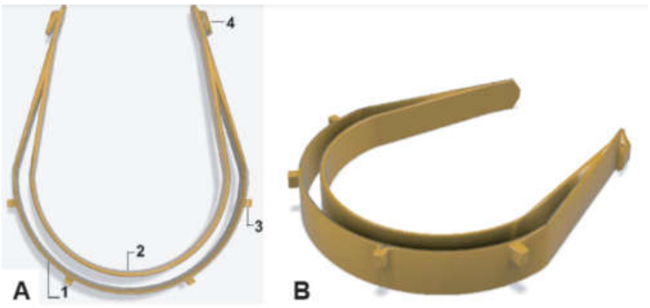


Figure 2. 3D model of the first version of the Higia frame, superior (A) and lateral (B) views. The main parts are: 1. The first arc, 2. The second arc, 3. Anterior square pins, 4. Posterior round pins

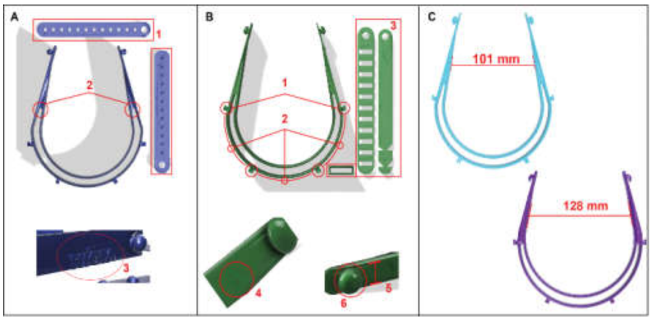


Figure 3. Details of the 3 prototyping cycles (A, B and C) performed during the 3D modeling of the Higia face shield frame. A) Two strips were modeled to adjust the frame on the user's head (1); the angles formed by the union of the two bands were smoothed to facilitate cleaning (2), and the name "Higia" was imprinted (3). B) The shape of the anterior pin was changed into a hook to avoid detachment of the transparent sheet during face shield use (1); the distance between the pins was adjusted to ensure fixing and adjustment of the transparent sheet (2); The strips were remodeled for strength (3); The imprinted name "Higia" was removed to make cleaning easier and replaced by a triangle to indicate the position of use (4); the frame thickness was changed from 15 to 10 mm (5), and the frame type was changed from square to round (6). C) The distance between the two ends of the frame were increased from 101 to 128 mm, and the pin for the elastic band was changed for safety.

In the additive manufacturing FDM process, the frame printing time was about 90 minutes (Fig.4A, B). For the face shield assembling, the transparent sheet was cut and perforated with a conventional sheet hole puncher according to a layout (Fig. 4C). Each hole was fitted into the anterior frame pin and an elastic band was used to attach the head protector (Fig. 4D). The assembled face shield Higia has a full-face length with outer edges reaching the tip of the ear, including chin and forehead protection. It is low-cost (U$ 0.75), light (frame 16 g, assembled 43 g), flexible and resistant, one size fits all, comfortable, disinfectable, and it allows repeated reuse several times (Fig. 4E, F). Higia's open-source model of was available on the internet with a guideline for production and use [Higia Project Website, 2020].

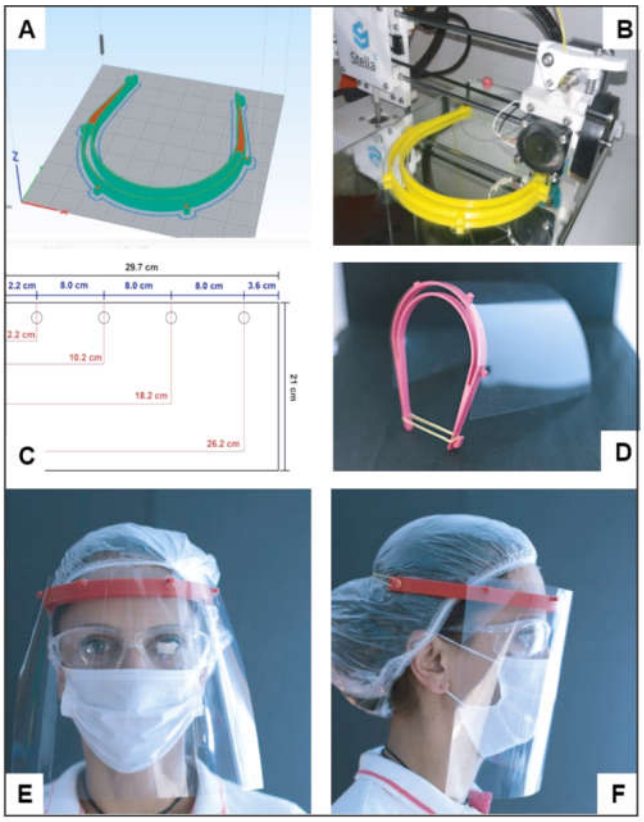


Figure 4. Higia face shield production through the Fused Deposition Modeling (FDM) process. A) 3D model of the frame. B) 3D printing process of the frame. C) The layout of the transparent sheet. D) Assembled face shield (frame, transparent sheet, and elastic band). Frontal (E) and lateral (F) views of a user with the Higia face shield

In the IM process, the injection time of each frame was 25 s (Fig. 5A, B). The stripes of the original Higia 3D printed model were reincorporated in the IM model resulting in one flexible strip of good mechanical resistance (Fig. 5C). A transparent plastic sheet of Polyethylene Terephthalate Glycol (PETG) with 0.5 mm of thickness was used as a visor (Fig. 5D). The Hígia face shield manufactured under the IM process is easy to assemble and transport, low-cost (U$ 0.47), light (frame 29 g, assembled face shield 56 g), flexibility and resistance, one size fits all with adjustable band, comfortable and reusable (Fig. 5E, F). The qualitative comparison of both processes, is summarized in Figure 6. In the first 11 days of the Higia project, almost 80% of the face shields orders were placed by the state of São Paulo, the initial epicenter of the pandemic in Brazil. In the second month, orders from other states started increasing, as the coronavirus had spread over south and southeast states also infecting Brazil's northern and northeastern states. In total, 61.6% of orders were placed by the state of São Paulo, and the remainder was distributed among the other 26 Brazilian states. Apart from São Paulo, the northern and northeastern states, such as Amazonas, had the highest percentage of orders. The logistic system created is presented in Fig.7.

About 2,000Makers volunteered, and 20 Brazilian 3D printing companies signed up for 3D printing and about 500 kg of filament donation. Through the crowdfunding campaign it was possible to pay for filament, transparent sheets, IM material, transportation, and other expenses. With the collaboration of Makers, 35,000 Higia face shields were produced through the FDM process, and the IM process resulted in the production of another 80,000 face shields by partner industries (Fig. 8). The face shields were donated and distributed to public hospitals for emergency rooms, surgical units, oncology units, and intensive care unitsof all states in Brazil. These distributions reached even the indigenous population in remote regions of the state of Amazonas.

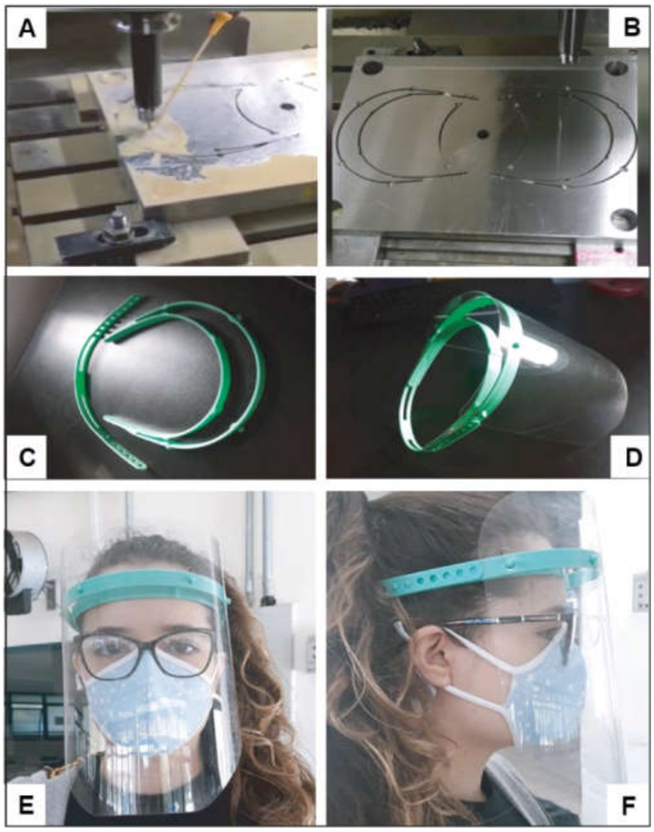
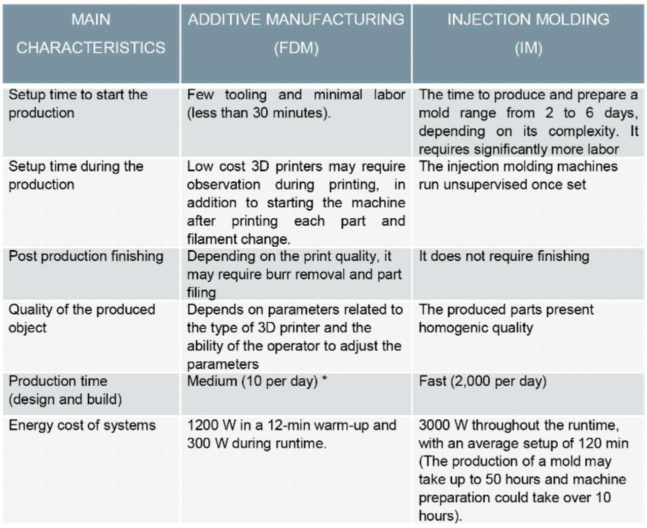


Figure 5. Higia face shield production through the injection molding process (IM). A) Metal mold production (Coral Dent company, Brazil). B) Metal mold. C) Face shield frame. D) Assembled face shield. Frontal (E) and lateral (F) views of a user with the face shield.



MAIN CHARACTERISTICS	ADDITIVE MANUFACTURING (FDM)	INJECTION MOLDING (IM)
Setup time to start the production	Few tooling and minimal labor (less than 30 minutes).	The time to produce and prepare a mold range from 2 to 6 days, depending on its complexity. It requires significantly more labor
Setup time during the production	Low cost 3D printers may require observation during printing, in addition to starting the machine after printing each part and filament change.	The injection molding machines run unsupervised once set
Post production finishing	Depending on the print quality, it may require burr removal and part filing	It does not require finishing
Quality of the produced object	Depends on parameters related to the type of 3D printer and the ability of the operator to adjust the parameters	The produced parts present homogenic quality
Production time (design and build)	Medium (10 per day) *	Fast (2,000 per day)
Energy cost of systems	1200 W in a 12-min warm-up and 300 W during runtime.	3000 W throughout the runtime, with an average setup of 120 min (The production of a mold may take up to 50 hours and machine preparation could take over 10 hours).

Figure 6. Qualitative comparison of the main characteristics of the manufacturing processes Fused Deposition Modeling (FDM) and Injection Molding (IM)

About 2,000 Makers volunteered, and 20 Brazilian 3D printing companies signed up for 3D printing and about 500 kg of filament donation. Through the crowdfunding campaign, it was possible to pay for filament, transparent sheets, IM material, transportation, and other expenses. With the collaboration of Makers, 35,000 Higia face shields were produced through the FDM process, and the IM process resulted in the production of another 80,000 face shields by partner industries (Fig. 8). The face shields were donated and distributed to public hospitals for emergency rooms, surgical units, oncology units, and intensive care unitsof all states in Brazil. These distributions reached even the indigenous population in remote regions of the state of Amazonas.

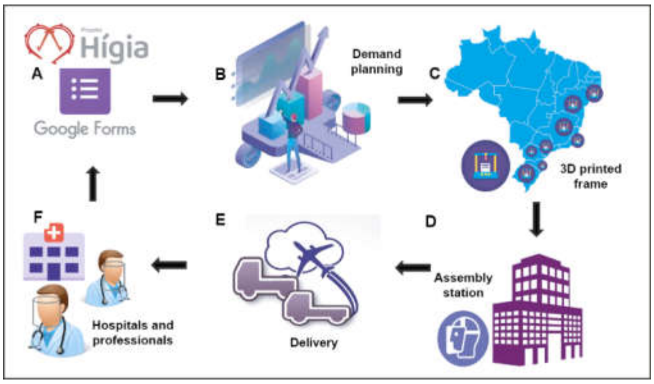


Figure 7. Scheme of the logistics system developed for Higia face shield production using 3d printing FDM process. A) The analysis of face shield requests; B) Definition of required demand of face shields by the planning sector, use of the resources acquired for purchase and transportation of transparent plastic sheets and rubber bands to the assembling hub; C) Request and collection of 3D printed frames from the Makers and delivery to the assembling hub; D) Assembling of the Higia set: a 3D-printed frame, a transparent plastic sheet, two rubber bands and an instructions manual on assembling the face shield; (E) Transportation of the Higia set by partners transportation companies; (F) Delivery of the Higia set to the public health institutions.

Figure 8. Scheme of the Distribution of 115,000 face shields in Brazil: 35,000 produced through the Fused Deposition Modeling (FDM) process, and 80,000 produced through the Injection Molding (IM) process. The distribution point was the city of São Paulo, and all regions were served by land, sea, and air transportation. *Brazil is the fifth largest country in the world, with roughly 4,350 km from north to south and from east to west

DISCUSSION

The high demand for PPE during the COVID-19 pandemic left millions of healthcare workers unprotected, endangering the functioning of the healthcare system. Most of Brazil's public healthcare institutions did not have enough PPE, and few of them had face shields, which were used only in high-risk areas. The Higia project was created on 20 March 2020 when the period of community transmission of the new coronavirus had started over the entire Brazilian territory, the number of confirmed cases of COVID-19 had reached 904 with 11 deaths. Ten days later, the Higia project was distributing their first volunteers-produced 3D-printed face shields to hospitals, while Brazil's updated numbers were showing 4,309 confirmed cases with 139 deaths. After 13 days of production, more than 10,000 3D-printed face shields had already been delivered. Such data showed great potential for rapid device production using additive manufacturing in an emergency. Many 3D printer owners, small business owners, startups, and university students took their 3D printers home to have around 1,000 face shields printed daily in production hubs in different cities. Due to the application of a design for the face shield frame as simple as possible the 3D printing of the frame was carried by volunteers without difficulties. The greatest challenge was the materials acquisition for production, as since the stores and shops were closed and the volunteers were under a lockdown or social distancing measures, sometimes unable to leave their houses. The logistics for production and delivery of face shields mass production during the confinement period in a country with continental dimensions like Brazil was a big challenge. An important factor was the possibility of delivery of 3D-printed face shields for hospitals rapidly and continuously despite the lower number produced.

This problem was solved with simple delivery logistics trying to access the volunteer closer to the requesting hospital. The IM face shields production allowed an increase in the number of manufactured frames by 100 times, each day. However, this high production volume was accumulated in a single location, and the logistics of delivery from a single spot became a challenge. Many countries around the world have used the FDM process to produce cost-effective medical face shields [Shokrani, 2020; Amin, 2020; Mostaghimi, 2020; Neijhoft, 2020; Sapoval, 2020; Wesemann, 2020]. Some 3D-printed face shields are as good as commercial standard-models [Kalyaev, 2020]. However, due to the process' heterogeneity, some devices have been produced with no standardized procedure or medical approval. Face shields were adapted for oral and maxillofacial surgeons [Amin, 2020] and the radiology sector [37] with a design that makes cleaning a difficult activity. Face shields with very thin frames are more fragile, they can break during transportation or use, and are less comfortable and reliable.It is possible to define the practicality, and clinical suitability of 3D-printed face shields related to weight, printing time, and if it required assembling tools to find an ideal dataset to be used for printing, scalability, and economic efficiency [Wesemann, 2020]. The Higia face shield designed in this study meets general requirements and specific ANVISA standards to reduce the potential for autoinoculation by preventing the user from touching their face [ANVISA, 2020].

The main features of the face shield are space for safe air ventilation and comfortable and low weight head fixation that does not limit the user's movements. Despite the recommendation that the face shield should avoid an open area between the first and second arc of the frame (Fig. 2), a consensus was established to reduce this distance and leave the area open, reducing the 3D printing time from 5 to 1.5 hours. This design ensures adequate space for the use of additional equipment such as surgical masks, respirators, eyewear, among others. In this study, the level of protection offered by the use of the face shield it was not accessed, but it is known that this device protects to reduce transmissibility below a critical threshold [18]. The acetate and PETg used in the visors are transparent with high optical clarity, providing a good physical barrier to respiratory droplets. Acetate provides the best clarity and is more scratch-resistant against chemical splash protection, and PETg offers chemical splash protection at a lower cost.

The Higia face shield is reusable, a replacement transparent sheet can be found in office supply stores. For disinfection, cleaning the face shield with soap and water or another type of disinfectant approved by the hospital infection control service is sufficient. Sterilization of the face shield using high temperatures or abrasive materials is not possible, due to the low melting point of the filament used in the FDM process. The main advantage of additive manufacturing is the design freedom that may be applied at any point in the process. The FDM is the most commonly used 3D printing processwith thermoplastics materials, with ease of handling, rapid processing, simplicity, and cost-efficiency [Shahrubudin, 2019]. The final cost of the FDM process is reduced due to the machine and material low cost, but the process shows some limitations [Clifton, 2020], as filaments such as PLA and ABS vary in material composition, porosity, and environmental stability. Although in this study, no mechanical test was performed with the 3D printed face shields, it is known that mechanical properties such as tensile strength, Young's modulus, elongation at break, and impact strength are lower in an object manufactured under FDM process compared with the ones under the IM process [Lay, 2019]. However, the mechanical stress that a face shield receives during use is extremely low, and although the face shield produced by IM has better quality, both have a comparable functionality level. Even though some authors claim that the FDM is a slow process and not suitable for mass production of face shields [Shokrani, 2020; Mostaghimi, 2020; Wesemann, 2020], the IM process, in contrast, requires skilled operators and relatively costly materials and equipment to be carried out. None of the additive manufacturing technologies is yet able to practically replace IM for medium- and high production volumes [Achillas, 2017]. However, this study showed that low-volume production of a network on volunteers using the FDM process may offer an alternative for short lead times and a decreased overall production cost. While IM allows producing a large number of parts in a short period time, the distribution through a continental country like Brazil takes a long time, making it difficult to fulfill large orders quickly, regardless of production method. Despite not being as fast as IM processes, the FDM method allows the at-home, on-demand manufacture of face shields by a broad spectrum of users [38]. It is possible also to have multiple frames printed at the same time to decrease production time using stacked frames. In this study, it was not possible to calculate the effective cost of FDM process production, as different 3D printers and filaments were used. Aneffective analysis should be based on cost regarding the purchase of the manufacturing equipment, material, labor, and other costs.

This study showed the viability of using the FDM process in low cost 3D printers for rapid modeling and the production of small batches of face shields by volunteers with a simple process that can be organized for larger-scale production. Due to the support provided by 3D printing, the delivery of face shields started first, whereas the IM mold was still being produced, which the allowed for large-scale production. The FDM process allowed daily deliveries while the IM process allowed the production of large quantities in a short period time and it may be the best option for the production of a large quantity for remote areas that do not have access to 3D printers. This research shows how the FDM process allows small scale decentralized production of consumer goods at a pandemic situation as a response from civil society, allowing assistance to hospitals in need [Smith, 2017]. The results highlight the role of the ''maker'' or ''citizen supply chain'' community across the world, with collaborators from industrial and academic institutions, in a network, in a short period, to donate face shields to healthcare professionals [36]. This mobilization happens mainly due to the commotion and the sense of unity that is ongoing during the pandemic.

Since the STL file of the Higia face shield was made available on the internet, many people in other countries such as Israel, Portugal, Jordan, Poland, Germany, the USA, and China have also produced face shields. It comes to show the accessibility and possibilities of integration and collaboration that 3D printing can promote. In this study, a qualitative comparison between FDM and IM manufacturing processes in a case of large-scale production and rapid distribution of face shield was performed.Considering the manufacturing resilience of the processes (quality, costs, and production time), in a situation such as the current COVID-19 pandemic with disturbances and uncertainties, both FDM and IM processes are suitable for mass production of face shields. Once a committed network of volunteers is formed in strategic regions, the FDM process allows for fast daily production of face shields. On the other hand, the IM process is proven to be the best option for large scale production and delivery to remote areas that have reduced access to 3D printers. The 115,000 produced face shields were donated and distributed to support the healthcare system during the COVID-19 pandemic in Brazil.

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REFERENCES

Achillas C, Tzetzis D, Raimondo MA. Alternative production strategies based on the comparison of additive and traditional manufacturing Technologies. International Journal of Production Research. 2017.

Al Mamun M, Mannoor K, Shirin T, Flora MS, Qadri F, Ren L, et al. A snapshot on COVID-19: A review. 2020

Amin D, Nguyen N, Roser SM, Abramowicz S. 3D printing of face shields [34] during covid-19 pandemic: a technical note, Journal of Oral and Maxillofacial Surgery. 2020:doi: https://doi.org/10.1016/j.joms.2020.04.040.

ANVISA. Agência Nacional de Vigilância Sanitária – ANVISA. RDC 356. http://portal.anvisa.gov.br/legislacao?p_ p_id=56_ INSTANCE_qAFOGUoZCUzJ&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-2&p_p_col_count=2#/visualizar/416315 Accessed 05 Jul 2020.

Biscayart C, Angeleri P, Lloveras S, Chaves T, Schlagenhauf P, Rodriguez- Morales AJ. The next big threat to global health? 2019 novel coronavirus (2019-nCoV): What advice can we give to travelers? Interim recommendations 2020, Travel Med Infect Dis. 2020;doi:10.1016/j.tmaid.2020.101567.

Christensen RP, Robison RA, Robinson DF, Ploeger BJ, Leavitt RW. Efficiency of 42 brands of face masks and 2 face shields in preventing inhalation of airborne debris. Gen. Dent. 1991;39:414–21.

Clifton W, Damon A, Martin AK. Considerations and Cautions for Three-Dimensional-Printed Personal Protective Equipment in the COVID-19 Crisis. 3D Printing and Additive Manufacturing, 2020.

Franchetti M, Kress C. An economic analysis comparing the cost feasibility of replacing injection molding processes with emerging additive manufacturing techniques. The International Journal of Advanced Manufacturing Technology. 2017:88(9-12), 2573-79.

Gibson I, Rosen DW, Stucker B. Additive manufacturing technologies. New York: Springer; 2014.

Gorbalenya AE, Baker SC, Baric RS, de Groot RJ, Drosten C, Gulyaeva AA, et al. Severe acute respiratory syndrome-related coronavirus: the species and its viruses - a statement of the Coronavirus Study Group. 2020.

Higia Project Website. https://www.projetohigia.com.br/english. Accessed 05 Jul 2020.

International Council of Nurses (ICN) 2020. 90,000 healthcare workers infected with COVID-19: ICN. https://www.aa.com.tr/en/europe/90-000-healthcare-workers-infected-with-covid-19-icn/1831765. Accessed 05 Jul 2020.

Ishack S, Lipner SR. Applications of 3D Printing Technology to Address COVID-19 Related Supply Shortages. The American Journal of Medicine.2020.

Kalyaev V, Salimon AI, Korsunsky AM. Fast mass-production of medical safety shields under COVID-19 quarantine optimizing the use of University fabrication facilities and volunteer labor. International Journal of Environmental Research and Public Health. 2020:17(10),3418.

Kichukov II, Atanasov AL. Some of the inovationsapproches in plastic injection moulding technology. Machines. Technologies. Materials. 2019:13(3),118-20.

Lai CC, Shih TP, Ko WC, Tang HJ, Hsueh PR. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and coronavirus disease-2019 (COVID-19): the epidemic and the challenges. International journal of antimicrobial agents, 2020.105924.

Lay M, Thajudin NLN, Hamid ZAA, Rusli A, Abdullah MK, Shuib RK. Comparison of physical and mechanical properties of PLA, ABS and nylon 6 fabricated using fused deposition modeling and injection molding. Composites Part B: Engineering. 2019;176,107341.

Lindsley WG, Noti JD, Blachere FM, Szalajda JV, Beezhold DH. Efficacy of face shields against cough aerosol droplets from a cough simulator. J OccupEnvironHyg. 2014;11(8):509-18.

Livingston E, Desai A, Berkwits M. Sourcing personal protective equipment during the COVID-19 pandemic. JAMA. 2020; 323(19):1912-14.

Menezes Filho N, Kirschbaum C. Education and Inequality in Brazil. In: Arretche M, ed. 239 Paths of Inequality in Brazil: A Half-Century of Changes. Cham: Springer International 240 Publishing; 2019: 69-88.

Mostaghimi A, Antonini MJ, Plana D, Anderson PD, Beller B, Boyer EW, et al. Rapid prototyping and clinical testing of a reusable face shield for health care workers responding to the COVID-19 pandemic. medRxiv, 2020.

Munhoz R, Moraes CADC, Tanaka H, Kunkel ME. A digital approach for design and fabrication by rapid prototyping of orthosis for developmental dysplasia of the hip. Research on Biomedical Engineering. 2016;32(1),63-73.

National NursingCouncil. 2020. Cofen registra 10 mil casos de COVID-19 entre profissionais de Enfermagem. http://www.cofen.gov.br/cofen-publica-observatorio-diario-da-covid-19-entre-profissionais-de-enfermagem_79551.html Accessed 05 Jul 2020.

Neijhoft J, Viertmann T, Meier S, Söhling N, Wicker S, Henrich D, Marzi I. Manufacturing and supply of face shields in hospital operation in case of unclear and confirmed COVID-19 infection status of patients. European Journal of Trauma and Emergency Surgery. 2020.1.

Ng TC, Lee N, Hui S-H D, Lai R, Ip M: Preventing healthcare workers from acquiring influenza. Inf. Control Hosp. Epidem. 2009;30:292–5.

Paim J, Travassos C, Almeida C, Bahia L, Macinko J. The Brazilian health system: 237 history, advances, and challenges. The Lancet. 2011;377(9779):1778-97.

Perencevich EN, Diekema DJ, Edmond MB. Moving Personal Protective Equipment into the Community: Face Shields and Containment of COVID-19. JAMA. 2020.

Prusa Protective Face Shield - RC2.https://www.prusaprinters.org/prints/25857-protective-face-shield-rc1. Accessed 05 Jul 2020.

Ranney ML, Griffeth V, Jha AK. Critical Supply Shortages - The Need for Ventilators and Personal Protective Equipment during the Covid-19 Pandemic. NEJM. 2020;doi:10.1056/NEJMp2006141.

Rengasamy S, Eimer B, Shaffer RE. Simple respiratory protection: evaluation of the filtration performance of cloth masks and common fabric materials against 20-1000 nm size particles. Ann OccupHyg. 2010;doi:10.1093/annhyg/meq044.

Roberge RJ. Face shields for infection control: A review. Journal of occupational and environmental hygiene. 2016;13(4),235-42.

Rodriguez-Morales AJ, Gallego V, Escalera-Antezana JP, Mendez CA, Zambrano LI, Franco-Paredes C, et al. COVID-19 in Latin America: the implications of the first confirmed case in Brazil. Travel medicine and infectious disease. 2020.

Santos NA, Artioli BO, Goiano E, Gonçalves M, Kunkel ME. (2019). A Parametrization Approach for 3D Modeling of an Innovative Abduction Brace for Treatment of Developmental Hip Dysplasia. In World Congress on Medical Physics and Biomedical Engineering 2018 (pp. 227-231). Springer, Singapore.

Sapoval M, Gaultier AL, Del Giudice C, Pellerin O, Kassis-Chikhani N, Lemarteleur V, et al. 3D-printed face protective shield in interventional radiology: evaluation of an immediate solution in the era of COVID-19 pandemic. Diagnostic and Interventional Imaging. 2020.

Shahrubudin N, Leea TC, Ramlan R. An overview on 3D printing technology: Technological, materials, and applications. Procedia Manufacturing. 2019;35:1286–96.

Shokrani A, Loukaides EG, Elias E, Lunt AJ. Exploration of alternative supply chains and distributed manufacturing in response to COVID-19; a case study of medical face shields. Materials & Design. 2020:108749.

Smith P, Mortati M. Commons people: additive manufacturing enabled collaborative commons production (by design). International Journal of Rapid Manufacturing. 2017;6(2-3):197-213.

Swennen GRJ, Pottel L, Haers PE. Custom-made 3D-printed face masks in case of pandemic crisis situations with a lack of commercially available FFP2/3 masks. Int J Oral MaxillofacSurg. 2020.

Tino R, Moore R, Antoline S. Ravi P, Wake N, Ionita CN, et al. COVID-19 and the role of 3D printing in medicine. 3D Printing in Medicine. 2020:1-8.

Wesemann C, Pieralli S, Fretwurst T, Nold J, Nelson K, Schmelzeisen R., et al. 3-D Printed Protective Equipment During COVID-19 Pandemic. Materials. 2020;13,1997.

WHO. World Health Organization 2020. Coronavirus disease 2019 (COVID-19) Situation Report–66. March 26, 2020. https://www.who.int/docs/default-source/coronaviruse/ situationreports/20200326-sitrep-66-covid-19.pdf. Accessed 05 Jul 2020.

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