

Future of Natural Disaster Medication Relief: How 3D Printing can Enable a Future of Quick and Efficient Medicine Distribution
Word Count: 3311

Executive Summary

Power outages. Blocked roads. Lack of medication. The life-changing effects of a natural disaster – such as Hurricane Ian and the 2022 Montana Flood – affect everyone, but these issues become direr to those who rely on a daily dose of over-the-counter medications. If consumers cannot get the medications needed, the consequences can be life-threatening. Right now, places rely on pharmacies to provide emergency doses of medications during the aftermath of a disaster, but a study done by Healthcare Ready found that only 29% of pharmacies were ready to serve during a natural disaster (Centers for Disease...). This puts overwhelming pressure on citizens to make sure a pharmacy is open and the only way to know if a pharmacy is open is to check a website that is extremely unreliable in itself (Rx Open FAQs). In a nutshell, the current infrastructure is too inconsistent and relies too much on chance.

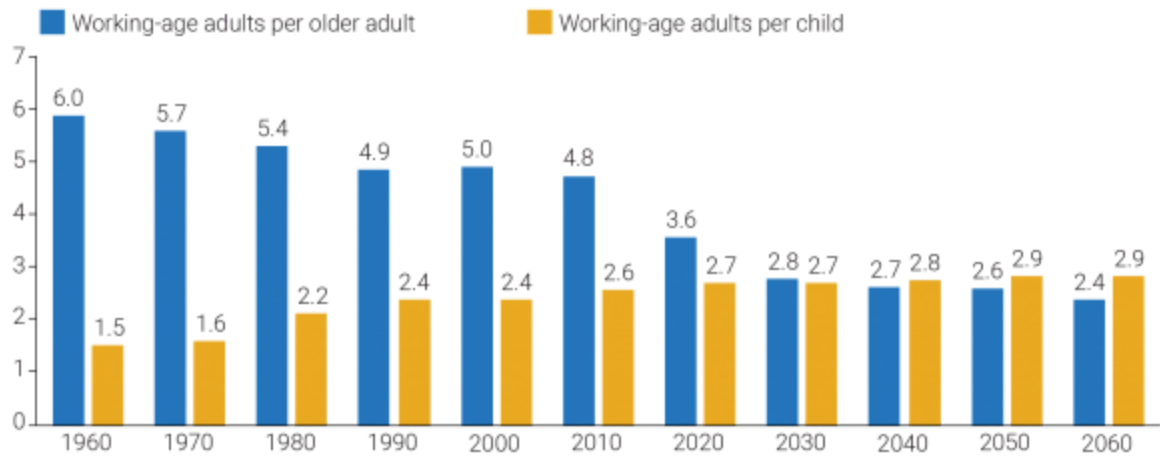
This study proposes a solution to this issue through existing technology and infrastructure to help individuals get the medical supplies needed in a timely yet economic method. Ibuprofen will be the example provided, however, any medication can be printed if the right ingredients are there. The proposed solution is to use a 3D printer to print out the medications needed during a natural disaster. Specifically, using the technique of fused deposition modeling (FDM) to print out the medication. There are two different ways to achieve this drug incorporation – mixing the drug in a pharmaceutical grade excipient polymer and using traditional fuse printing technology, and manufacturing a shell and adding a drug filling. These methods are both more efficient and economic than the current method of compressing the materials together and can be applied to more than just natural disaster recovery medication. Indeed, the future of having 3D printed pills is coming sooner than we thought as the FDA has approved Spritam, a medicine that can treat children because of its release control, and more are expected to come soon (Spritam).

Industry Overview

Current Deficiency

The current deficiency in the natural disaster infrastructure is extremely present. Specifically, the lack of proper infrastructure in providing individuals with the medications needed after a disaster. The U.S. Food and Drug Administration (FDA) recommends citizens intricately track their medications before an incident/disaster (Center for Drugs...). However, studies have shown that over two-thirds of Americans do not feel properly prepared for their needs during a natural disaster (Davis). So, individuals who need medication currently rely on pharmacies to remain open after a natural disaster and be prepared to operate and serve customers and individuals. However, a new issue arises as the current infrastructure relies on a website to alert people if a pharmacy is opened. A study shows that once a storm makes landfall, there is a 43% chance that all power is lost, and it could take around four days for power to be restored (Perkins). In more extreme cases, a storm could take out 95.6% of all power lines and telecom towers, as seen in Puerto Rico (Centers for Disease...). Therefore, the reliance on individuals to check a website to see if a pharmacy is open is extremely unreliable and relies on an infrastructure that has too many faults.

The need to implement a disaster-proof medication method is dire, especially considering the current age distribution trend: a growing skew towards the right as seen from Figure 1, and seniors are more vulnerable during disasters and need additional support. This is particularly true in Florida, which has the 5th most natural disasters and the 2nd highest population over 65 or over 4 million individuals (NBCUniversal; Which U.S. states...).



(Figure 1: Graph showing population skewing towards an older population) (Mather and Kilduff)

In events where natural disasters block off roads to outside civilization and where help is quickly needed, the benefits of an on-site medication solution are needed. Rather than the current method of relying on pharmacies being open and hoping they have the medication desired available, the proposed method, utilizing a three-dimensional (3D) printing approach, relies more on distribution centers in places that shelter those in need such as schools, arenas, or churches.

Timeline

Therefore, the timeline in which healthcare workers have to act is extremely limited. Before a natural disaster, it is important to make sure individuals know where they can get their medications from, which in this case are common shelters like schools, churches, and other large buildings (Naval). This can be done through mass communication methods like radios, television, posters, etc. The next concern is getting pharmaceutical powders and excipients to places in need. Fortunately, most pharmacies carry the powders used to make the pills, reducing the need to have them transported from an outside place therefore also reducing the transport time too. However, in cases where pharmacies are running low on a certain item, a system should be created to see which powders are needed. Then, the local and federal governments can send

the items down to the location in the strike zone of a natural disaster. Lastly, the common shelters would set up printing machines and powders and serve individuals in need.

Benefits in Time and Money

Currently, it takes an average of 55 seconds to make each pill (Tarn et al.). 3D printers can print a pill in around 7 seconds, meaning 3D printed pills are 7.86 times more efficient than conventional methods, even without considering potential shipping times to get the pills and excess labor that conventional pill making entails (Healthnews).

Although solid money figures for 3D-printed pills have not been released, several medical experts have expressed ways that 3D printing could save money. For example, the hardware needed costs less as well as the modularity of 3D printed pills. In other words, the cost reduction comes in the form of flexibility and the reusability of modules (Macdonald).

Design, Functionality, and Durability

Features and Functions

The function is simply to serve people the required doses of pills quickly, efficiently, and on demand. The 3D printer merely serves as an enabler in doing this by printing out the correct medication in a round or ovular shape.

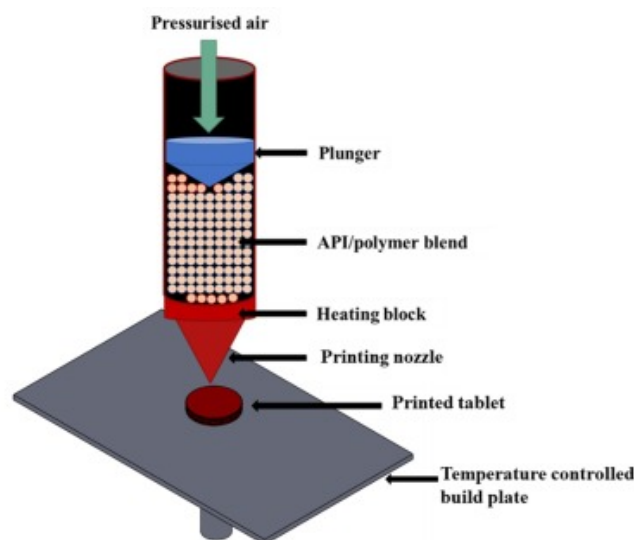
Additionally, the method of 3D printing is also very important. Using a method that has been widely used in the field of biomedicine and is used to manufacture oral drugs, called fused deposition modeling (FDM) 3D printing, the printing of pills can become more efficient and simpler. Compared with other legacy methods -- stereolithography (SLA), selective laser sintering (SLS), and ink jetting --FDM is more economical and simpler to implement (Lan et al.). As such, the amount of FDM research has increased tenfold, beating every legacy method. Startups dedicated to the research of FDM technology in oral technology have also started to pop

up: for example, FabRx, GlaxoSmithKline, Takeda GmBH, etc (All3DP). The cooperation between commercial enterprises and university research teams also shows the value and future commercial prosperity of FDM in the field of drug manufacturing.

Drug Incorporation

There are two methods of applying FDM to drug printing. The first method is drug incorporation which mixes the drug in a pharmaceutical-grade excipient polymer -- like polyvinyl alcohol -- and then traditional fuse printing technology to achieve drug curing as shown in Figure 2. This keeps the price of fuse printing low and can be mass-produced without secondary development if the polymer diameter is the same (Tagami et al.). Thus, for custom drug manufacturing, mixed drug fuse printing is a promising approach.

However, there are some downsides to this method too. For instance, the polymer filaments may dissolve and not return to their original state after drying, and then liquid drugs cannot be fused (Shaour et al.). So, the technique is less efficient for loading. Fortunately, many institutions are attacking this issue and significant progress has been made (Kukkonen).



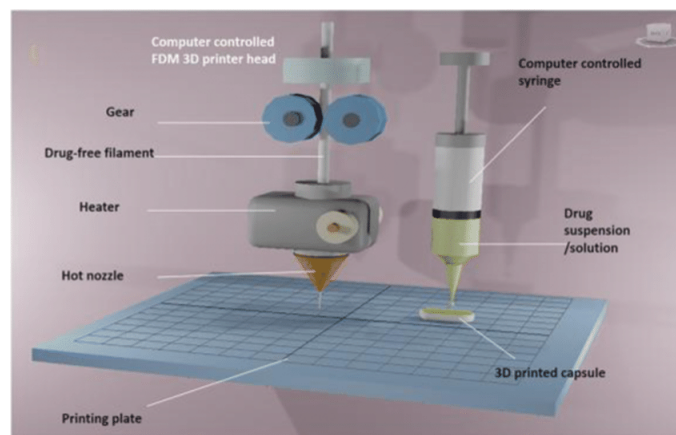
(Figure 2: Graph showing how drug incorporation works) (Tabriz et al.)

Manufacturing a Shell and Adding a Drug Filling

The second method is manufacturing a shell and then adding a drug filling, or when an empty shell drug structure is printed and the drug is injected into the shell with a dropper to be sealed together. This technology would mainly be used with liquid capsule medicines (soft shell and liquid core) (Smith et al.).

The biggest problem with this method is sealing the medication, so the structural design of the drug's shell is very important. A standard solution to this issue is to add plasticizers to the shell material, changing the thickness and material of the outside shell also provides the opportunity for an improved drug release property (Lan et al.).

A dual-nozzle FDM 3D printer prints the drug shell using FMD and then uses the liquid dispenser with the injection function to dispense the solution (Lan et al.). This will be easier to implement as MakerBot Industries has optimized this technology. In the figure below (Figure 3), the nozzle on the left is an FDM nozzle and the nozzle on the right is a direct-ink-writing syringe (Researchgate).



(Figure 3: An optimized FDM 3D printer demonstrating how the shell and drug filling method works) (Lan et al.)

The second method has good drug retention when compared with other methods and can be altered to achieve the desired profile of drug release.

For ibuprofen, it would usually be printed with the drug incorporation method (first method), but the shell-filling method (second method) is also applicable for people who cannot digest a solid pill.

Health

The health benefits of 3D-printed pills after a natural disaster are endless. Specifically, ibuprofen is a common drug used during the aftermath of a disaster and can help numb mild to moderate pain, decrease inflammation, and can relieve pain from a cold or flu (NHS). Certainly, drugs other than ibuprofen can be printed as well during disasters. In addition, the resulting health benefits of on-demand drug printing are endless and can be altered to fit the needs of each individual for a precise dosage. For instance, if someone cannot digest a solid pill, a liquid pill can be 3D printed for that individual.

Safety Concerns

For drug printing users, some of the safety concerns of using a 3D printer include breathing in potentially harmful materials, the heat of the extruder, and getting hazardous materials on the skin (Centers for Disease...). To mitigate this issue, it is important to wear a face mask and proper protective equipment. The consumption of the pills has minimal safety concerns other than wrong dosage or choking. Ibuprofen can cause nausea and other digestive issues and can damage the liver if the wrong doses are taken (NHS). Certainly, these all can be prevented from human care.

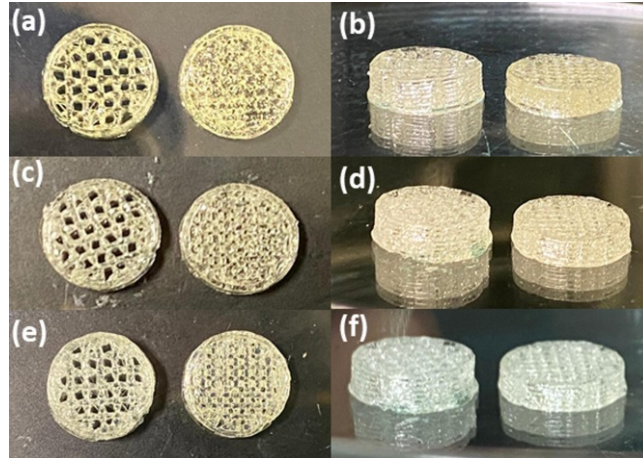
Quality

Quality assurance is extremely important for over-the-counter medication. Therefore, the quality of 3D-printed pills must maintain the same quality as conventional methods. For gel-based pills, the thickness of the outside shell must remain around 1.6mm so that it can evenly distribute the medicine and avoid leaking (Lan et al.). As well as other manufacturing and design considerations when making drugs incorporating 3D printing. The intricate dimensions required are a small drawback, however, other than those limitations, studies have found that the quality control solutions for conventional tablets are the same as 3D printed ones (Goh et al.). This means that the quality control of 3D-printed pills can be done through the same methods as they are done for conventional pills.

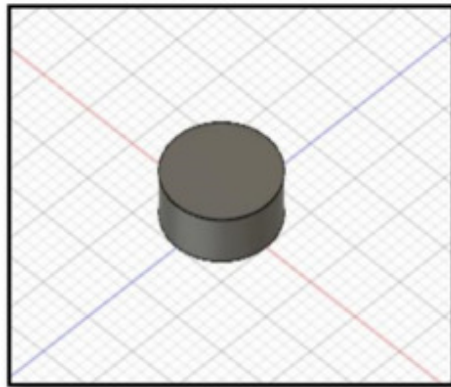
Additionally, controlling the pill-to-pill dosage may be a struggle for those who are not experienced in doing so, dimensions and viscosity are also important considerations as clogging in the nozzle is very probable. Lastly, a lot of printers are needed which means the upfront costs will be relatively expensive.

Dimensions of the Printed Pill

The dimensions of a printed pill can vary to fit the needs of an individual. In Figure 4, several samples from a paper by Tabriz et al. show small holes created from layering the powder to form a lattice to help with digestion. Figure 5 shows a similar design to Figure 4 except for its solid format. Both pills use similar dimensions, or 10 layers each 100 μm in layer thickness, and exposure duration of 800 s.



(Figure 4: Pills printed using FDM printing) (Tabriz et al.)



(a)



(b)

(Figure 5: 3D printing program and FDM printed pills) (O'Neal)

Anticipated Lifetime

The anticipated lifetime of a typical printer such as the Cellink Bio-X 3D printer is around 10 years, but it can last a long time depending on usage cases. The Cellink Bio-X printer has been reported to have a lifespan of up to 15 years with proper maintenance (Cellink). The key performance indicators the 3D printed pills need to achieve are straightforward: be able to provide access to pills to people in need and reduce the time and other restraints present in the current medication-providing method during disasters. Further creature comforts aspects are also

present such as being able to dissolve faster and the ability to add personalized flavorings (New Atlas).

Design Integration and utilization of DDM materials and processes

This design approach integrates fairly well with traditional medication methods while improving the faulty aspects of the current method. The fastest way to replicate pharmacies during the aftermath of a natural disaster is to use a 3D printer. Traditional aspects are present in the infrastructure and the sourcing. For instance, the powders would still primarily be provided by the pharmacies and the primary locations where the medication would be distributed are the traditional shelters.

Multiple different materials can be used, but each of them requires a binder – which in this case, is a polymer. The binder could be a pharmaceutical-grade excipient polymer like Soluplus, VA 64, Eudragit, or any other binder (Agrawal et al.). For instance, if someone wants to print ibuprofen, the main component would be ibuprofen, and the excipient would be added to serve as the vehicle or medium and help control the release rate of ibuprofen.

Additionally, in a study using FDM to print ibuprofen as shown in Figure 6, they found that in each trial, the pill was consistently printed and kept a consistent drug load. This study used Soluplus as the excipient polymer (O’Neal).

Formulation	Weight (mg)	Diameter (mm)	Thickness (mm)	Hardness (N)	Drug Load (mg)
F1	387.00 ± 45.20	11.13 ± 0.62	3.00 ± 0.00	47.33 ± 3.21	24.11 ± 2.51
F2	378.00 ± 29.00	10.86 ± 0.31	3.09 ± 0.20	32.00 ± 17.00	23.00 ± 1.58
F3	323.40 ± 21.60	10.81 ± 0.31	3.00 ± 0.00	108.33 ± 23.71	15.00 ± 1.00
F4	296.70 ± 4.50	10.17 ± 0.26	3.02 ± 0.04	92.33 ± 29.02	14.40 ± 0.22
F5	354.40 ± 21.10	10.55 ± 0.38	3.00 ± 0.00	33.00 ± 4.58	22.30 ± 0.13
F6	278.90 ± 11.50	10.04 ± 0.09	3.00 ± 0.00	132.33 ± 18.88	18.30 ± 0.75
F7	345.10 ± 32.70	10.52 ± 0.32	2.99 ± 0.02	n.d. ¹	21.70 ± 2.05
F8	400.10 ± 42.90	12.40 ± 0.55	2.97 ± 0.23	29.67 ± 3.51	27.10 ± 2.91
F9	340.50 ± 19.50	10.60 ± 0.17	2.94 ± 0.13	19.00 ± 8.66	23.00 ± 1.13
F10	375.00 ± 28.70	11.53 ± 0.43	2.92 ± 0.11	37.00 ± 16.52	25.80 ± 1.98
F11	377.50 ± 37.30	11.40 ± 0.47	2.99 ± 0.12	35.00 ± 24.25	25.50 ± 2.53

(Figure 6: Chart showing 11 samples of ibuprofen and the respective dimensions of each)

(O’Neal)

The reasoning behind choosing 3D printing as the method/process of making pills is that 3D printing is very affordable and efficient. These two aspects are crucial during the aftermath of a natural disaster. 3D printing is also largely automated by computers, lowering the chance of human error and speeding up the process of creating medications.

Digital and physical infrastructure: Systems integration, utilization, value chain leverage, agility, lean and continuous improvement

For this plan to become a reality, the dissemination among large corporations and hobbyists must run smoothly. In terms of large corporations, many pharmacies have outside sources where they get the raw ingredients to make the pills – for instance, McKesson is the distributor for CVS – and they would help with providing the ingredients for the medication (McKesson), such as isobutyl benzene and acetic anhydride for ibuprofen (Drugs.com). Large institutions should have raw powders, and local/chain pharmacies too. Before a natural disaster, the government should collaborate with pharmacies to see which components are available and which ingredients are needed. Moving forward, an increase in funding for FDM 3D drug printing

to institutions is needed, so the increase in recent years can continue to increase exponentially. Collaborations with local media will also be beneficial in improving the viability of the proposed drug printing method. In addition, natural competition will also improve this technology as many companies invest in these technologies and the market becomes more saturated with competitors; with this, the printing price will go down further making it an ideal solution.

Hobbyists, such as volunteers and 3D printer enthusiasts, can play a crucial role too; the 3D printing community is one of the largest communities of many enthusiast sites such as Discord and Reddit. Particularly, an FDM 3D printer is a relatively simple piece of technology to manage, master, and maintain, so with minimal training, volunteers can run the machine very well.

Cost Benefit/Value Analysis

Although specific numbers have not been released because of how new this technology is, past numbers suggest that 3D printing can save around 40 to 60 percent compared to conventional medical methods (Rathi). Furthermore, the value added is tremendous as shown in the following:

Social

3D-printed pills would be very cost-effective and help poorer people and third-world countries get the medications needed as well as people after a natural disaster (Stephan).

Environmental

The production of 3D-printed pills is very environmentally friendly. During the process of manufacturing tablets, the 3D printer creates no pollutants in the air, and the ability to create small batches not only leads to financial savings but also less waste if a batch does go wrong (Dvoretzkaya).

Additionally, since most of the powders would come locally, it reduces fuel costs and other environmental strains that the transportation of traditional pills leads to.

Health

Flexibility is one of the most important aspects of medication after a natural disaster: each person is different and requires different dosages and components. Therefore, the health benefits of 3D-printed pills in comparison to the current methods are very significant. 3D-printed pills can be any shape and size, be built with a custom dosage, regulate the number of active substances, and alter the composition of a tablet by removing or replacing components (Dvoretzkaya; Stephan).

Ibuprofen serves the purpose of easing pain and inflammation caused by conditions that affect joints, bones, and muscles (Ibuprofen uses and...). This is an extremely important medication to have after a natural disaster.

Safety

Many safety benefits are brought by 3D-printed pills. For instance, the ability of 3D printed pills to be altered to the wants and needs of an individual allows them to fit the health or digestive restrictions of an individual (Stephan)

Regulatory Compliance

The regulatory compliance of 3D printed pills follows similar guidelines to current medications. Recent developments in 3D printing medication technology have allowed medications like Spritam, a medication used to treat seizures, to become FDA-approved (Spritam). However, there is still a gray area as the FDA thinks of how to deal with the materials 3D printers create (Journal of Science...).

Conclusions

To conclude, the viability of 3D drug printing as a solution to the current lack of infrastructure for over-the-counter medication during and after disasters is very plausible. Not only does 3D printing create more flexibility and customizability, but it also is easier to control and manage. The enabling method is fused deposition modeling (FDM) 3D drug printing; specifically, FDM through drug incorporation or printing out the shell and filling it with the drug. Both of these methods are more efficient and cost-effective than the current method and can make a pill in around 7 seconds, nearly 8 times faster than the current compression method. Thus making 3D printing the optimal technology during the aftermath of a natural disaster. An example of this method in action is ibuprofen: mixing ibuprofen powder with a polymer to stabilize and act as a base for printing. Other than the incorporation of 3D printers – like the Cellink Bio-X 3D printer – in natural disaster recovery and pre-planning powder collection, no other major infrastructure changes are needed – schools, churches, and other shelters would host individuals and provide them with both shelter and medication.

This design stands out because there are no current alternatives to the inefficient drug distribution issue during and after disasters. The future benefits of this design would allow more people to get medication help with specialized pills. Furthermore, a typical FDM 3D printer is the most affordable and efficient way of doing this without sacrificing other aspects of what traditional pressed pills offer. Based on this plan, the mind-boggling stress involved in getting medication can become something of the past.

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