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3d-Printed Medical Aids For Hemorrhage Control In Battlefield Conditions

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Abstract: Additive manufacturing, also known as 3D printing, is a way through which we bring our ideas to life. Instead of using traditional cutting tools, it is a way of manufacturing an object layer by layer directly from digital designs. This cutting-edge technology enables innovators to create intricate components for industries like healthcare, automotive, and aerospace with enhanced speed, precision, and cost efficiency. It fosters endless advancement, sustainability, and flexibility on demand for customization which was witnessed during the COVID-19 pandemic.

War fatalities result from combat injuries (i.e., Penetrating Injuries, Blast Injuries, Gunshot Wounds, Burns, Crush Injuries, Traumatic Amputations, etc.). Though mortality rates due to combat injuries have decreased significantly over the past few decades globally, Hemorrhage remains a leading cause of combat casualties. It is caused due to Gunshot Wounds (GSW), Explosive Injuries (IEDs, Bombs, Mines), Sharp Weapon Injuries, and Crush Injuries (Collapsed Buildings, Heavy Equipment Accidents). This underscores the critical importance of effective bleeding control measures in combat situations. Today, many organizations are stepping up to provide military-grade medical solutions to help treat trauma and emergencies when it matters most.

3D printing is playing a key role in prosthetics, implants, and surgical advancements. Its potential in trauma care, especially in combat settings, is immense. Our study focuses on developing personalised 3D-printed medical aids for gunshot wounds (GSW) and similar injuries that provide effective solutions for hemorrhage control, injury stabilization, and increased survival chances in battlefield conditions. Rapid production of customized, biocompatible wound care materials enhances adaptability in emergency situations.

***Index Terms* -** 3D printing, hemorrhage, gunshot wounds (GSW), medical aid.

I. Introduction

The advancements in additive manufacturing have led to revolutionary changes in the healthcare sector, particularly in trauma care. 3D printing allows for the rapid production of customized medical aids, reducing dependency on conventional supply chains. The ability to create patient-specific solutions provides enhanced medical outcomes, particularly in emergency combat situations.The integration of this technology with conventional trauma care methods, such as tourniquets and hemostatic dressings, further enhances its effectiveness in managing battlefield injuries.Technology is being used to reduce complexity concerning the design prospects of these complex components, thereby avoiding assembly requirements in whole. This offers an added advantage of being a tool-less process significantly.

- **EXISTING 3D PRINTING TECHNIQUES**
- **IMPACT OF 3D PRINTERS IN HEALTHCARE INDUSTRY**

3D printing, which is an Additive manufacturing process, is a technology that develops objects layer by layer from a digital 3D design, which eliminates cutting, drilling, or molding materials. 3D printing deposits material very precisely as defined by the model, which in turn reduces the waste and promises to yield a high-quality product.

Commonly used 3D printing technologies:

1) Stereolithography (SLA).
2) Fused deposition modeling (FDM)
3) Selective Laser Sintering (SLS)
4) Laminated object manufacturing (LOM)
5) Digital Light Processing (DLP)

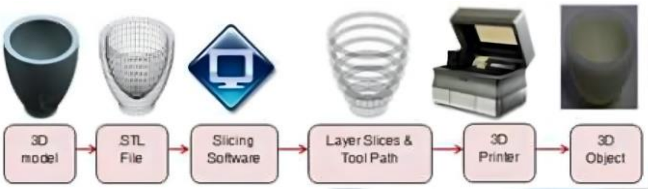

Figure 1 - 3D printing process (Adapted from [1])

The product development process begins with the creation of a digital 3D design. This digital model is then converted into a standard tessellation language (STL) file, which serves as the blueprint for the printing process. Specialized slicing software processes the STL file and generates a G-code—a set of machine instructions that the 3D printer can interpret to fabricate the object layer by layer. The 3D printer, functioning as a mechanical system, follows these instructions to precisely deposit material and gradually construct the final form. This layer-by-layer manufacturing approach enables the transformation of innovative ideas into tangible products with high accuracy and efficiency. The culmination of these steps results in a functional, well-formed product that aligns with the intended design specifications.

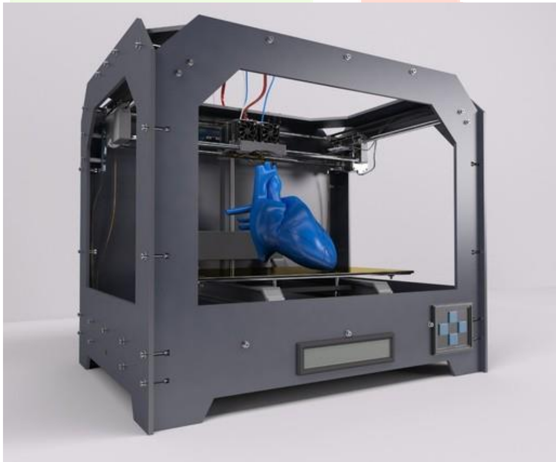
Figure 1.1 - Fused Deposition Modeling (FDM) Printer (Adapted from pixabay.com)

1. Eliminates Assembly Needs – Produces complex medical components as a single unit, reducing weak points and assembly errors.[2]
2. On-Demand Battlefield Manufacturing – Enables real-time production of medical aids in combat zones, miSing logistical challenges.[3]
3. Rapid Customization – Facilitates patient- specific wound care, implants, and prosthetics for improved medical outcomes.[3]
4. Lightweight & Durable Designs – Develops strong yet lightweight medical devices, enhancing mobility and comfort for soldiers.[3]
5. Enhanced Hemorrhage Control – Integrates with tourniquets, hemostatic agents, and pressure bandages for more effective bleeding management. [3]
6. Cost-Effective & Reduced Waste – Uses precise material deposition, minimizing waste and significantly lowering production costs.[3]

7. Biocompatible & Infection-Resistant Materials – Employs bioresorbable polymers and antimicrobial coatings which reduces infection risks.[3]
8. Advanced Surgical & Prosthetic Applications – Supports customized implants, prosthetics, and skeletal reconstruction for trauma patients.
9. Scalability & Efficiency – Adaptable for mass production while maintaining flexibility for highly specialised medical needs.[3]

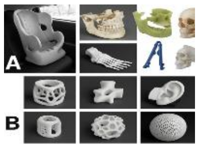

Figure 1.2 - 3D printing in health care (Image by chatgpt.com)

Overview of Hemorrhage

Hemorrhage occurs when excessive bleeding is caused by trauma or rupture of blood vessels. It can be categorized into two types:

1) Internal Haemorrhage: Is the consequence of bleeding within the body, compromising organs or tissues. eg - brain hemorrhage,gastrointestinal hemorrhage etc.
2) External Haemorrhage:Is the effect of blood loss due to an open wound , deep cuts , incisions and similar injuries . eg - gunshot Wounds (GSW), Deep cut wounds and Burns, etc.

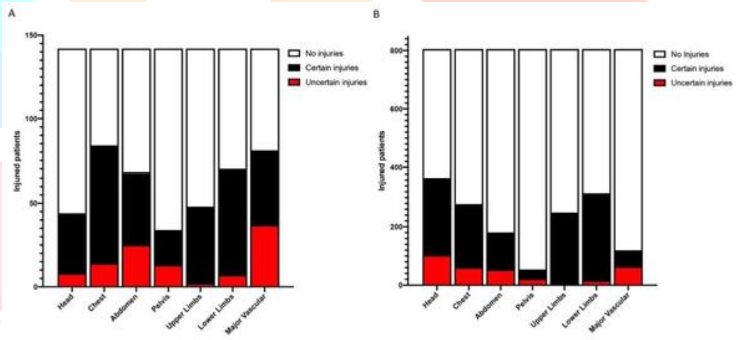

Figure 2 - (Adapted from[4])

Proportion of clinician diagnostic uncertainty of injuries (by Abbreviated Injury Scale category) in (A) patients diagnosed prehospital with major hemorrhage (n=142) and(B) patients not diagnosed prehospital with major hemorrhage (n=805).[4]

Causes of Hemorrhage in Warfields

Although mortality rates worldwide from combat injuries have been diminishing considerably in the past few decades, Hemorrhage remains one of the prominent causes of fatal outcomes.

Vital causes of hemorrhage on battlefield:

1. Gunshot wounds (GSW)
2. Blast injuries (Explosion and fragmentation injuries)
3. Weapon-inflicted wounds

A. Stab and puncture wounds
B. Burns and chemical warfare
C. Landmine and improvised-explosive devices(IED’s) injuries

On the combat field, GSW’s are a prominent contributor to hemorrhagic demises, as bullets with extreme velocities cause severe damage to tissues and also causes vascular ruptures. These impairments can be penetrative (i.e, Bullet is inside the body) or perforative (with exit wounds) this leads to excessive bleeding hemorrhagic- shocks.Approach of trauma and Fatalities Across 75th Ranger Regiment Casualties (N=419, 2001–2010)

Mechanism	All (%)	Fatal (%)
Explosive (non-IED)	43	9
Explosive (IED)	24	31
GSW	24	50
Blunt Trauma	6	9
GSW + Expl.(non-IED)	3	—

Table 1 - (Adapted from [5])

- **Present Methodologies Used to Control Hemorrhage**

  There are wide-range of haemorrhage control tactics which have been devised to elevate the survival rates. These include equipment-based interventions, Hemostatic agents and surgical solutions.

1. Tourniquets: It acts as a primary response to limb hemorrhage, Effective control of arterial bleeding could be achieved utilizing these in battlefield circumstances.
2. Hemostatic dressings: High-tech dressing methods involve the use of Celox, QuickClot and ChitoGauze etc. Which contain entities that stimulate rapid clotting.

   Non-compressible wound can be effectively treated both in civilian military scenarios.
3. Pressure-Bandages & Wound-Packing: Direct pressure exerted by the elastic bandage helps in stabilizing the bleeding. Hemostatic gauze will be crucial for treating deep injuries by wound packing.
4. TXA :Antifibrinolytic drug -TXA helps in preventing severe blood loss by supporting the clot formation.
5. Surgical haemorrhage control (Damage Control Surgery, DCS): Immediate surgical measures like vessel ligation, Clamping or wound structuring is necessary in some cases.

- **Benefits of Using 3D Printing Techniques**

1. Personalized and patient-specific solutions: Additive manufacturing enables manufacturing, Which targets unique needs of each patient.
2. Cost-effective and Faster medical device production of medical : Standard manufacturing equipments are cumbersome and expensive with the help of 3D-printing it can be significantly reduced.
3. On-Demand medical-aids: 3D-printing plays a significant role when the supply chains are minimal. In battlefields, disaster scenarios and remote areas.
4. Regenerative medicine and Bioprinting : 3D bioprinting has enabled to create skin grafts, Tissue creation based on patient specific needs.

Our Work

Materials and Methodology

Our study focuses on building a silicon strap embedding a dome packed with hemostatic sponges. This strap serves as a primary care in treating the wounded soldiers in the battlefield.It's a wearable device which could be used on the wounds located on limbs. The hemostatic sponges pushed into the wound cavity plays a vital role in controlling hemorrhage caused due to GSW's and similar combat injuries.

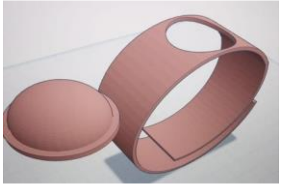

Figure 3 - Strap Design

The figure 3 is a design of our product which can be customized for the patient specific needs. Leveraging the 3D printing technology we are able to get a Cost effective precise medical grade equipment.

Figure 3.1 - Mass production of domes

The development of the medical strap began with detailed 3D modeling using computer-aided design (CAD) tools, followed by fabrication through Fused Depo Modeling (FDM). A silicone-compatible filament was selected for its mechanical strength, flexibility, and skin-friendly properties—making it well-suited for emergency medical applications. The design included built-in dome cavities intended to hold hemostatic sponges, which assist in controlling severe bleeding. STL files generated from the models were processed using finely tuned slicing parameters to maintain consistency and print precision. After fabrication, each dome was manually filled with sponge inserts and sealed to enhance product lifespan. These components were then integrated with reusable silicone straps to allow fast, efficient use in high-pressure environments.

Silicone's resistance to moisture, temperature changes, and chemical interactions makes it ideal for harsh conditions, while its insulating nature allows for potential future enhancements, such as incorporating electronic sensors for wound monitoring or real-time data collection.

Figure 3.2 - Preserved domes

The hemostatic sponge-filled domes can be preserved as they have a longer shelf life which is an added advantage for mass production. These domes can be used with a reusable silicon straps.This strap can be effectively used by the wounded battalions which addresses the primary care until they are evacuated to a hospital which will significantly reduce the mortality rate.

Future Outlook in Health Care Industry

Wound Monitoring Incorporating Tweezers and Antiseptics

Biosensors can be used to monitor the wounds, regulate the bleeding rate, avoid infection.

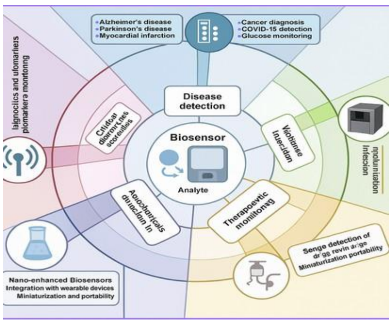

Figure 4 - Biosensor (Image by chatgpt.com)

Advanced Hemostatic Sponges

The drug-induced homeostatic sponges help in rapid clotting of the blood ensuring instant relief.

Figure 4.1 - Hemostatic sponge (Image by chatgpt.com)

Integrating different medical equipments within the strap to help pre-treat the wound before fastening the strap.

Figure 4.2 - (Image by Freepik.com)

Figure 4.3 - (Image by chatgpt.com)

Improved Sustainable Features

Use of biodegradable materials addresses environmental concerns .

Conclusion

This research highlights the viability of applying additive manufacturing to enhance medical support on the battlefield, particularly for hemorrhage management. We introduced a customizable, wearable device - a silicon strap integrated with hemostatic sponge-filled domes designed to offer immediate, frontline intervention for traumatic injuries such as gunshot wounds. The proposed system stands out for its reusability, biocompatibility, and long shelf life, making it both practical for mass deployment and effective in critical conditions.

Leveraging 3D printing technology, the solution aims to accelerate emergency response, reduce the reliance on manual procedures, and improve survival rates prior to clinical evacuation. Overall, the findings support the deployment of tailored, on-demand medical interventions to significantly lower preventable fatalities in combat zones.

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