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Research Report

From Printer to Patient:
Assessing the Feasibility of Implementing 3D-Printed Prostheses in
Conflict Zones Across the Middle East and North Africa Region

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Disclaimer

This paper is entirely my work, and I claim all possible biases as my own. This work does not represent the perspectives of any individual or institution involved, including my research supervisor, the Laidlaw Foundation, or the University of Toronto.

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Introduction

In the past two decades, nations across the Middle East and North Africa (MENA) regions have experienced higher rates of military conflict as civil wars and genocides spark across the region.¹ In 2011, protests against President Assad's regime in Syria escalated to a civil war, leading to persisting instability in the region today. In 2014, the Houthis, an armed rebel group, invaded Yemen's capital city Sanaa, resulting in a civil war that, similarly, still reigns today. And in 2023, Hamas, an armed political organization, attacked Israel, and the conflict that followed afterward is what the UN has classified as a genocide upon the Palestinian people.² Escalations of these existing conflicts has resulted in extreme military conflict in the region, including airstrikes and bombs, which destroy hospitals, kill medical aid personnel, and directly harm civilians, often resulting in amputations. As military conflict increases across the MENA region, amputee populations climb concerningly high. In 2025, the United Nations released a statement stating that Gaza was officially home to the largest population of child amputees in modern history.³

Amplifying this crisis are the collapsing healthcare systems in these conflict zones.⁴ With import restrictions, equipment and staff shortages, and interruptions from military conflict, amputees are left unable to access prosthetic care.⁵ Scarce healthcare resources struggle to meet the needs of emergency trauma; as a result, amputee needs and prosthetic rehabilitation are routinely deprioritized, widening this crisis significantly.⁶

¹ International Institute for Strategic Studies, "The Armed Conflict Survey 2025: Middle East and North Africa," IISS, 2025, <https://www.iiss.org/publications/armed-conflict-survey/2025/armed-conflict-survey-2025/regional-sections-middle-east-and-north-africa/>.

² UN Human Rights Council, "Legal Analysis of the Conduct of Israel in Gaza Pursuant to the Convention on the Prevention and Punishment of the Crime of Genocide," in *A/HRC/60/CRP.3* (2025), <https://www.ohchr.org/sites/default/files/documents/hrbodies/hrcouncil/sessions-regular/session60/advance-version/a-hrc-60-crp-3.pdf>.

³ Philippe Lazzarini, "UNRWA Commissioner-General on Gaza: Gaza Now Hosts the Largest Group of Child Amputees in Modern History - Question of Palestine," Question of Palestine, December 9, 2025, <https://www.un.org/unispal/document/unrwa-statement-5dec25/>.

⁴ Deema Al Bakri et al., "The War on Gaza and Its Impact on Public Health: Challenges and Pathways to Recovery," *Frontiers in Public Health* 13 (October 2025), <https://doi.org/10.3389/fpubh.2025.1664850>.

⁵ WHO Admin, "WHO EMRO - WHO Calls for Urgent Support to Rebuild Syria's Health System," Who.Int, 2025, <https://www.emro.who.int/afg/who-calls-for-urgent-support-to-rebuild-syrias-health-system.html>.

⁶ Humanity and Inclusion Org, "Amputation Crisis in Conflict Zones: Report Reveals Urgent Need for Rehabilitation Services in Gaza, Syria and Ukraine," Humanity-Inclusion.Org.Uk, 2025, <https://www.humanity-inclusion.org.uk/en/amputation-crisis-in-conflict-zones-report-reveals-urgent-need-for-rehabilitation-services-in-gaza-syria-and-ukraine>.

With faster production times, lower production costs, and low-maintenance needs, 3D-printed prostheses can provide support for amputees in conflict zones with unstable healthcare systems. 3D printed prosthetics have been deployed across both developed and developing nations to meet the needs of amputees living in low-resource settings with limited access to hospital care, thus demonstrating their capability to successfully assist amputees in the absence of stable healthcare systems. Ishengoma et al. find that 3D-printing has the potential to reduce operational and equipment costs and increase accessibility in the healthcare systems of developing nations, but that a lack of availability of 3D-printing experts in the region and the feasibility of attaining large 3D-printers may impact this potential, concluding that more research and innovation in the area is required to further explore 3D-printing in healthcare.⁷ Abbady et al. conclude that aesthetic appearance, and personalized fittings, and low material costs make 3D-printed prostheses a feasible solution for amputee patients, but, similarly, the study finds that the lack of data and published research on the topic necessitates further exploration.⁸

However, in conflict zones, infrastructural damage and institutional collapse have impacted data collection, resulting in a deficit of data that typically enables researchers to analyze and assess the feasibility of implementing healthcare initiatives. Subsequently, despite conflict zones harbouring some of the largest amputee populations in the world, little research exists regarding the deployment of 3D-printed prostheses in conflict zones specifically.⁹

This study fills this gap by utilizing qualitative analysis to identify the obstacles that may prevent the implementation of 3D-printed prostheses in conflict zones and determine the capacity that 3D-printed prostheses have to address rising amputee populations in warzones that lack medical infrastructure. By analyzing existing literature on 3D-printed prostheses, studying existing government policies and NGO reports, and gathering firsthand experiences of individuals

⁷ Fredrick R Ishengoma and Adam B Mtaho, “3D Printing: Developing Countries Perspectives,” 1410.5349v1, October 20, 2014, arXiv (1410.5349v1), <https://doi.org/10.5120/18249-9329>.

⁸ Hnady E. M. A. Abbady et al., “3D-Printed Prostheses in Developing Countries: A Systematic Review,” *Prosthetics and Orthotics International* 46, no. 1 (2022): 19–30, <https://doi.org/10.1097/PXR.000000000000057>.

⁹ Cornelia Anne Barth et al., “Retrospective Observational Study of Characteristics of Persons with Amputations Accessing International Committee of the Red Cross (ICRC) Rehabilitation Centres in Five Conflict and Postconflict Countries,” *BMJ Open* 11, no. 12 (2021): e049533, <https://doi.org/10.1136/bmjopen-2021-049533>.

operating in conflict zones, this study maps potential barriers and successes in 3D-printed prosthetic implementation across four key areas:

- 1) Engineering and manufacturing challenges
- 2) Policies that may restrict medical care and the imports of medical equipment
- 3) Scalability of 3D printed prosthetics to the MENA region
- 4) Practical conditions that may impact the effectiveness of implementation

Methodology

This study uses qualitative analysis to map obstacles to 3D-printed prosthetic implementation in conflict zones in the MENA region across a policy analysis, a comparative case study analysis, and semi-structured interviews with industry experts. A concept indicator framework was developed and used to conduct a thematic analysis across collected data.

Policy Analysis

Conflict zones across the MENA region are unique, with competing government and political bodies that make mapping policy and maintaining compliance a complex process. To grasp an understanding of the current existing policy landscape in certain conflict zones across the MENA region, policy analyses were conducted for three nations: Yemen, Syria, and Gaza and the West Bank. This policy analysis included official policy documents from recognized government bodies and military groups, along with media and NGO reports regarding informal authority from non-state political actors.

Comparative Case Study Analysis

Two published cases of attempted 3D-printed prosthetic implementation in low-resource settings were analyzed to identify challenges, successes, and outcomes. These case studies provided insights into how anticipated obstacles, specifically within engineering and policy themes, translate to real-world experiences.

Semi-structured Interviews

Six interviews were conducted with individuals who possessed expertise related to an aspect of the research study. Four participants had professional backgrounds in biomechanical engineering, including a registered prosthetic technician and two biomechanical engineers with previous experience deploying medical aid in low-resource settings. One participant leads an incubator for healthcare start-ups in the MENA region. The remaining participant leads a 3D-printed assistive device company operating in the MENA region. This work was approved by the University of Toronto Health Sciences Research Ethics Board, and all participants provided informed consent before the interviews commenced.

Concept Indicator Framework

A concept-indicator framework was developed for four concepts: policy, engineering, scalability, and practicality. This framework was applied to the analysis of case studies, policies, and interview transcripts. As subthemes arose throughout the analysis, data was recoded to include analysis of subthemes.

Policy

This study defines policy as the existing governments, militaries and non-state political actors present in conflict zones, and their policies that may serve as potential barriers to implementing 3D-printed prostheses. Indicators include references to “dual-use” policies, import restrictions, aid delivery permits, military checkpoints, and gaps in policy surrounding medical imports.

Engineering

This study defines engineering as the production challenges for manufacturing durable, low-cost prosthetics designed for conflict zones. Indicators for this concept include the durability and longevity of 3D-printing materials and the potential to automate production processes.

Scalability

This study defines scalability as the capacity to scale 3D-printed prosthetic implementation initiatives across the MENA region. Indicators for this concept included growing research and development in 3D-printing markets in the MENA region, availability of funding, and supply chain stability.

Practicality

This study defines practicality as the physical, environmental, and infrastructural conditions impacting the administration of 3D-printed prostheses. Indicators include weather conditions, such as heat and rain, and environmental conditions, such as dust and sand, and how military conflict impacts medical facilities and power supply.

Results and Discussion

Policy

Syria, Yemen, and Gaza and the West Bank are conflict zones in the MENA region operating under “fragmented authority”, meaning a variety of government bodies, military presences, and non-state political actors control different territories within the region.¹⁰ By analyzing official and unofficial policy documents and media and NGO reports, this study summarizes the policies and presences that may impact the ability to import medical equipment and/or provide accessible services to implement 3D-printed prostheses in conflict zones in Syria, Yemen, and Gaza and the West Bank.

This study finds that the main obstacles existing within this theme are fragmented authority structures, attacks by political actors, and counterterrorism policies. Fragmented authority structures in conflict zones in the MENA region create competing bodies and policies that make it difficult for NGOs to gain permits, visas, and import approvals necessary to conduct humanitarian aid. Political actors also often engage in intimidation attacks, targeting humanitarian aid workers to diminish their presence and deter their operations in the region. NGOs conducting aid must also comply with their nation’s counterterrorism policies, and as a result, may be unable to operate in areas under certain jurisdictions if those jurisdictions are designated as terrorist organizations. These obstacles are crucial to the implementation of 3D-printed prostheses, as NGOs must navigate compliance with several policy structures as they import 3D-printed prosthetic aid into conflict zones in the MENA region.

¹⁰ ACAPS, *HUMANITARIAN ACCESS OVERVIEW Spotlight on Fragmented Contexts: Lebanon, Palestine, Syria and Yemen* (2025), https://www.acaps.org/fileadmin/Data_Product/Main_media/20260210_ACAPS_Humanitarian_Access_Overview_December_2025.pdf.

Syria

Syria's territory is divided between the Syrian Transitional Government, which controls approximately 70% of its territory, and various opposition governments and political actors.¹¹ This includes the opposing military bodies of the Syrian National Army (SNA) and the Syrian Democratic Forces (SDF), the latter of which retains control over many Iraqi-Syrian border crossings, and the Kurdish Autonomous Administration, which exercises authority across Syria's Northeastern region.¹² These competing bodies each establish and enforce different policies and institutions to gain legitimacy in Syria, creating a complex government structure of inconsistent and sometimes contradictory policies, procedures, rules and authorities. As a result, humanitarian aid organizations seeking to operate in Syria must navigate this complex structure.

On an international scale, Syrian borders and the territory surrounding them have developed economies dependent on trade, bribery, corruption, and smuggling.¹³ Informal taxation on imports and interference by different governing bodies leaves civilians and NGOs vulnerable to extortion and corruption, unable to anticipate or ensure smooth import processes or aid delivery. Most aid imports enter Syria through the Bab al-Hawa border crossing between Syria and Turkey; while aid imports are often monitored to reduce corruption, as Syria's only UN-approved border crossing aid route, the border experiences higher volumes of traffic, and thus attracts bribery and corruption.¹⁴

On a national scale, the Syrian Ministry of Health under Syria's Transitional Government outlines that primary healthcare services are free of charge at public health centers, and NGO-run health centers also offer health services at flat rates.¹⁵ However, if medical supplies or medical devices are needed, there is often an additional cost for the patient. If 3D-printed prostheses were to be implemented in local public hospitals or NGO hospitals, the recipient would thus incur the extra cost for the prosthetic device, which would likely deter patients from seeking prosthetic

¹¹ PeaceRep: The Peace and Conflict Resolution Evidence Platform, *Humanitarian Aid, Borders and Conflict Lines in Syria* (2025), <https://peacerep.org/wp-content/uploads/2023/07/Navigating-Fragmentation-Humanitarian-Aid.pdf>.

¹² European Union Agency for Asylum, "3. Actors of Persecution or Serious Harm," in *Country Guidance: Syria* (2025).

¹³ The Brookings Institution, "Syria's Dissolving Line between State and Nonstate Actors," Brookings, January 27, 2023, <https://www.brookings.edu/articles/syrias-dissolving-line-between-state-and-nonstate-actors/>.

¹⁴ Counter Extremism Project, "Houthi Diversion of Humanitarian Assistance in Yemen," Counter Extremism Project, June 2024, <https://www.counterextremism.com/content/houthi-diversion-humanitarian-assistance-yemen>.

¹⁵ "Healthcare - Syria Is Home," Syria Is Home, February 9, 2026, <https://syriaishome.org/en/healthcare/>.

care. Furthermore, no legal documents are required to receive basic healthcare services, equalizing accessibility to healthcare services for civilians who do not possess legal identification. However, “if specialized or medicine services are provided”, ID must be provided. Assuming prosthetic care is classified as a specialized service, the requirement for legal ID may deter or prevent potential patients from seeking prosthetic care at local hospitals. The Ministry of Health has also built a digital health portal that allows Syrian civilians to book appointments, keep track of medical services, and use digital health tools through the mobile app and website.¹⁶ This app could increase the feasibility of implementing 3D-printed prostheses in Syria by digitizing follow-up appointments, answering trouble-shooting questions, and facilitating overall prosthetic care. However, it is important to note that one case study used in the analysis conducted a 3D-printed prosthesis healthcare initiative in Syria, and experienced limited capacity of operation due to policy and political obstacles in the nation.¹⁷ This suggests that, despite efforts to increase accessibility within Syria’s healthcare system, NGOs still face significant barriers when implementing aid in the region.

Yemen

Yemen’s territory is divided between several actors, including formal authority from the Presidential Leadership Council (PLC), Yemen’s internationally recognized government backed by Saudi Arabia, along with its former ally the Southern Transitional Council (STC), a force backed by the United Arab Emirates.¹⁸ Both recognized governing bodies were previously allied together against the Houthi rebels, a non-state political group retaining control along the Northwestern regions of Yemen, including its capital city Sanaa. In early 2026, the STC was dissolved entirely due to disagreements with the PLC, weakening the anti-Houthi movement and further heightening complexities at the border with territorial and import control.

¹⁶ “Digital Health Portal App | Ministry of Health | Syrian Arab Republic, Ministry of Health | Syrian Arab Republic,” 2026, الجمهورية العربية السورية | وزارة الصحة, <https://www.moh.gov.sy/about-app>.

¹⁷ Jérôme CANICAVE and Danielle TAN, *RS 05 Pilot Testing of 3D Printing Technology for Transtibial Prosthesis in Complex Contexts (Togo, Madagascar and Syria) Research and Studies Scientific Summary Operations and Technical Resources Division* (2017), https://www.hi-us.org/sn_uploads/document/3D_Printing_Pilot_Test_May2017.pdf.

¹⁸ Alia Chughtai and Mohamed A Hussein, “Mapping Who Controls What in Yemen In 2026,” Al Jazeera, January 14, 2026, <https://www.aljazeera.com/news/2026/1/14/mapping-who-controls-what-in-yemen-in-2026>.

On an international scale, the Houthis have historically deterred NGOs from operating in Yemen. Houthis have a history of targeting humanitarian aid workers, including raids of UN offices and staff homes, interfering in the aid import process by diverting supplies and changing beneficiary lists, and sentencing Yemenis involved in humanitarian aid to prison or death.¹⁹ As a result, many NGOs, including the UN and the World Food Programme, have ceased operations in Houthi-controlled territory, instead relocating to Aden or the PLC-controlled southern Yemen, or even ceasing operations altogether.²⁰ In February 2025, the UN Secretary-General instructed NGOs to pause all activities in the Saada governorate of Yemen, citing the Houthi's detainment of dozens of NGO staff for several years.²¹ Given that prosthetic aid requires on-site practitioners to properly measure and fit the device, the inability to safely operate within Yemen's highly populated regions highlights a significant barrier to 3D-printed prosthetic implementation. Furthermore, shifts in the USA's counterterrorism policy have impacted the operating capacities of NGOs in Yemen; the Houthis have been designated, undesignated, and redesignated as a Foreign Terrorist Organization (FTO) across the span of four years.²² This designation complicates the ability for NGOs to operate in Yemen, since according to the USA's FTO policy, providing "material support" to terrorist groups is not allowed. Fearing non-compliance, many NGOs choose to refrain from operating in territories with designated FTOs. However, with 70% of Yemeni citizens living in Houthi-controlled areas, the constant changes of designation have only complicated most NGOs' abilities to provide aid to citizens that need it.

On a national scale, in January 2025, the Obour app was introduced to organize traffic and entry at the Al-Wadea border, a key border crossing between Yemen and Saudi Arabia serving as the only route of entry for humanitarian aid into Yemen.²³ While the app aimed to dismantle corruption at the border by standardizing import costs and decreasing wait times, glitches in the

¹⁹ Casey Coombs Ned Whalley, "Houthi Detentions Leave Stark Choices for Aid Sector," *Sana'a Center for Strategic Studies*, February 5, 2025, <https://sanaacenter.org/publications/policy-research/24213>.

²⁰ Philip Loft, "Yemen in 2025: Changing Balance of Power in the South," House of Commons Library, December 28, 2025, <https://commonslibrary.parliament.uk/research-briefings/cbp-10427/>.

²¹ United Nations, "World News in Brief: Aid Activities Suspended in Yemeni Governorate, Gaza Humanitarian Update, UN Welcomes Summit on DR Congo Crisis," UN News, February 10, 2025, <https://news.un.org/en/story/2025/02/1159981>.

²² Sritharan et al., "When Security Meets Survival: The Impact of the Houthi Terrorist Designation on Aid to Yemen," *Policy Brief*, 2025.

²³ Daifallah Al-Soufi et al., "Al-Wadea Crossing: A Critical Corridor in Disarray," *The Yemen Review*, nos. Oct-Dec 2025 (February 2026), <https://sanaacenter.org/the-yemen-review/oct-dec-2025/26148>.

app reduced its effectiveness. Persistent bribery, corruption, and wait times lasting as long as one week have created barriers for NGOs attempting to import aid at the border, presenting a major obstacle to 3D-printed prosthetic implementation.

Gaza and the West Bank

Gaza and the West Bank operate under competing governance between the Palestinian Authority, the Israeli government, and the military group Hamas.²⁴ Geographically, Gaza and the West Bank are both partially surrounded by Israel, and aid imports must have approval from Israeli authorities before entering Palestine. Israel's military, the Israel Defence Forces (IDF), is active at border crossings and within the occupied Palestinian territories.

On an international scale, several recent policies enforced by Israel have complicated the import process for humanitarian aid. On December 29th, 2025, a law was passed by the Israeli Knesset declaring the immediate expiration of a 1967 provisional agreement involving the United Nations Relief and Works Agency for Palestine Refugees in the Near East (UNRWA).²⁵ The UNRWA, which is a crucial NGO responsible for managing 65 healthcare facilities across Palestine, became banned from all operations on Israeli territory, unable to obtain visas or permits for their staff to enter the occupied Palestinian territory to provide aid.²⁶ While this ban has significantly constrained UNRWA operations, they are still present across the occupied Palestinian territories. Furthermore, as of April 2025, the Israeli military's Coordinator of Government Activities in the Territories (COGAT) updated their guidelines for criteria that NGOs must satisfy to operate in the occupied Palestinian territories.²⁷ This process examines commodities delivered by NGOs, which must be "humanitarian", "impartial", "complement the efforts of Israel", and "prevent... Hamas and other terrorist organizations to make definite advantage out of them". The vague wording of the conditions for COGAT's approval of NGOs

²⁴ ANERA, "What Are Area A, Area B, and Area C in the West Bank?," Anera, accessed August 30, 2026, <https://www.anera.org/what-are-area-a-area-b-and-area-c-in-the-west-bank/>.

²⁵ Ruth Levush, "Israel: Law to Cease UNRWA Activities Amended," The Library of Congress, 2026, <https://www.loc.gov/item/global-legal-monitor/2026-01-29/israel-law-to-cease-unrwa-activities-amended/>.

²⁶ UNRWA, "UNRWA Situation Report #203 on the Humanitarian Crisis in the Gaza Strip and the Occupied West Bank, Including East Jerusalem," January 7, 2026, https://www.unrwa.org/sites/default/files/content/resources/unrwa_gaza_sitrep_202_jan_2026_eng.pdf.

²⁷ State of Israel, *State of Israel Ministry of Defense Coordination of Government Activities in the Territories (Cogat)* (2025), <https://gaza-aid-data.gov.il/media/ffbbihlf/coagt-guidelines-for-examination-process.pdf>.

leaves this policy up to interpretation, enabling COGAT to use these vague grounds as justification for denying an NGO from operating in the Gaza Strip.²⁸ Furthermore, the policy requires that NGOs provide the names and personal details of their employees, including their passport numbers, identification numbers, marital status, and passport numbers of their spouses and children.²⁹ Given that Israeli authorities have killed more than 500 foreign aid workers, these new policies are a major deterrent for NGOs seeking to operate in Palestine.³⁰

On a national scale, COGAT has published a list of goods they classify as “dual-use”, meaning the good has potential to be used by an armed group as a weapon and must undergo additional security screening before entering Palestine. COGAT does not fully translate its dual-use list into Arabic or English, creating barriers for Palestinians and NGO staff to fully understand how to comply with dual-use policies as they import medical equipment. An English version of the dual-use policy translated by an NGO was used for analysis.³¹ This list was cross-referenced with a list of necessary materials used in 3D-printing and prosthetic manufacturing to identify which materials may be difficult to import; analysis found eleven materials necessary for 3D-printing and prosthetic manufacturing were designated as “dual-use” (see Appendix B). This represents a clear barrier to implementation, as NGOs may face additional security screenings and potential denials at border crossings with 3D-printing and prosthetic equipment. Additionally, Section 20 of Israel’s Defense Export Control Law (5767-2007) outlines that dual-use equipment must not be transferred into areas under Palestinian civil control unless a license is obtained for the transfer from COGAT.³² Any attempt to do so without a license will result in a fine equivalent to

²⁸ Riley Sparks, “How Israel’s New NGO Registration Rules Seek to Divide the International Aid Response,” *The New Humanitarian*, August 25, 2025, <https://www.thenewhumanitarian.org/analysis/2025/08/25/how-israel-new-ngo-registration-rules-divide-international-aid-response>.

²⁹ State of Israel, “International Non-Governmental Organizations Primarily Engaged in Activities with Palestinian Residents for the Purpose of Humanitarian Aid,” *The Ministry for Diaspora Affairs and Combating Antisemitism*, September 3, 2025, https://www.gov.il/en/pages/interministerial_team_registration_humanitarian_organizations_foreign_employees.

³⁰ OCHA, “Humanitarian Situation Update #311 | Gaza Strip | United Nations Office for the Coordination of Humanitarian Affairs - Occupied Palestinian Territory,” *United Nations Office for the Coordination of Humanitarian Affairs - Occupied Palestinian Territory*, August 6, 2025, <https://www.ochaopt.org/content/humanitarian-situation-update-311-gaza-strip>.

³¹ Gisha – Legal Center for Freedom of Movement, *Controlled Dual-Use Items -In English* (2008), https://gisha.org/UserFiles/File/LegalDocuments/procedures/merchandise/170_2_EN.pdf.

³² Gisha – Legal Center for Freedom of Movement, “Coordination of Government Activities in the Territories: Procedure for the Imposition of Fines on Unlawful Transfers of Dual-Use Good to the Gaza Strip,” September 2016, https://www.gisha.org/UserFiles/File/LegalDocuments/procedures/merchandise/190_EN.pdf.

approximately \$478 000 CAD, a large fine that may deter NGOs from attempting to import 3D-printed prosthetic equipment.

Engineering

This section analyzes how certain engineering obstacles and opportunities may impact the ability to manufacture and fit 3D-printed prostheses in conflict regions. Four sub-themes were identified during engineering analysis. Findings show that there is potential to automate certain processes of prosthetic production and fitting, which increases the chance of successful implementation as it reduces the reliance that 3D-printed prostheses have on hospital care, on-site medical practitioners, and other scarce healthcare resources. However, risks associated with pressure sores, alignment, and stability indicate that some sort of expertise is still required throughout the process to ensure the prostheses will not cause harm to the recipient. Additionally, making a professional available for online consultation via video-call or group-chat may partially satisfy the need for an on-site expert, further reducing the reliance that 3D-printed prosthetics have on medical practitioners, and increasing local development and sustainability.

Automation Potential

Four participants discussed the potential to automate certain procedures involved in the manufacturing and fitting process. One biomechanical engineer mentioned that computerized programs can conduct pressure mapping digitally, removing the need for on-site expertise for pressure-mapping. Each participant cited that, while there was some potential to automate scanning and measuring procedures, the fitting process of attaching the prosthetic device to the amputee's body requires on-site expertise to avoid pressure sores and ensure the socket fits comfortably and is functional. Additionally, one case study utilized a handheld 3D scanner to record and scan an amputated limb, requiring minimal equipment and expertise, making it ideal for low-resource areas such as conflict zones.³³

³³ Merel van der Stelt et al., "Improving Lives in Three Dimensions: The Feasibility of 3D Printing for Creating Personalized Medical Aids in a Rural Area of Sierra Leone," *The American Journal of Tropical Medicine and Hygiene* (United States) 102, no. 4 (2020): 905–9, PubMed, <https://doi.org/10.4269/ajtmh.19-0359>.

Potential, or lack thereof, to automate prosthetic fitting processes has implications for the ability to administer 3D printed prosthetics in conflict zones. Conflict zones in the MENA region have minimal healthcare infrastructure and NGO medical staff have limited operational capacities; military presences in conflict zones have repeatedly targeted NGO staff, resulting in NGOs withdrawing their operations from the region. As a result, automated processes are ideal to maximize accessibility to 3D-printed prosthetics and ensure their implementation is feasible and less vulnerable to military conflict and instability. However, the repeated emphasis of the need for on-site medical practitioners and experts to safely implement prosthetic devices suggests that, while perhaps some parts of the prosthetic production and manufacturing process can be automated, it cannot feasibly and safely be automated in its entirety.

Pressure Sores, Alignment, and Stability

Participants classified as biomechanical engineers were asked what concerns and points of weakness they identify within 3D-printed prosthetic implementation in low-resource conflict zones. Three out of four biomechanical engineer participants cited pressure sores as an area of concern. One biomedical engineer participant, whose occupation is a prosthetic technician, extended this concern further to alignment and stability, stating that a misaligned socket may also lead to pressure sores or instability, making the prosthetic unusable. In connection with pressure sores, when asked which parts of a 3D-printed prosthetic were most prone to mistakes during production and susceptible to cause harm to recipients, the same three out of four participants also identified the socket as a key area of concern, given its direct contact with the recipient's skin and body.

One case study found that participants judged 3D-printed sockets to be more comfortable than traditional sockets, and required fewer visits to the clinic, which increased convenience.³⁴ Furthermore, this prosthetic was fitted by a physiotherapist while a prosthetist provided remote assistance via an online video conference. This suggests that concerns regarding pressure sores, alignment and stability can be addressed via 3D-printed sockets.

³⁴ Jérôme CANICAVE and Danielle TAN, *RS 05 Pilot Testing of 3D Printing Technology for Transtibial Prosthesis in Complex Contexts (Togo, Madagascar and Syria) Research and Studies Scientific Summary Operations and Technical Resources Division* (2017), https://www.hi-us.org/sn_uploads/document/3D_Printing_Pilot_Test_May2017.pdf.

Escalation Pathway

Two engineers also mentioned the existence of escalation pathways to seek support online, either through group chats or web calls, from trained professionals regarding concerns about prosthetic production and manufacturing. This notion of an escalation pathway was reflected in one case study included in the analysis, in which a European prosthetic professional was available online for support via phone call as 3D-printed prostheses were provided to amputees in a low-resource setting with limited healthcare professionals.³⁵ Furthermore, one interview participant created a Whatsapp group chat for the local rehabilitation teams in a developing nation to connect them with American specialists and encouraged them to reach out if they had questions about patients or an area their expertise did not cover. The engineer mentioned that the team rarely reaches out, pointing to busy schedules and time zone differences as possible barriers. The engineer further mentioned that, given the lower scope of knowledge of the local rehabilitation team due to a lack of, or shorter, educational programs, the team was not aware of alternative ways to address certain prosthetic issues, and thus did not reach out to explore other options.

While further research is required to examine the barriers that may prevent local aid recipients from utilizing online escalation pathways to seek advice from experts, the application of an escalation pathway during 3D-printed prosthetic implementation may alleviate the barriers that patients and local teams face as they provide follow-up care, troubleshoot potential issues with the prosthetic device, or require consultations with experts that may not be available on-site.

Scalability

This section analyzes how certain scalability obstacles and opportunities may impact the ability to produce 3D-printed prostheses in conflict regions. Findings suggest that there is available funding in the MENA region from GCC nations, and that increased demand for prosthetic devices further fuels interest from these nations. However, prostheses must be customized to each specific recipient based on their individual needs, eliminating the possibility of rapidly

³⁵ Merel van der Stelt et al., “Improving Lives in Three Dimensions: The Feasibility of 3D Printing for Creating Personalized Medical Aids in a Rural Area of Sierra Leone,” *The American Journal of Tropical Medicine and Hygiene* (United States) 102, no. 4 (2020): 905–9, PubMed, <https://doi.org/10.4269/ajtmh.19-0359>.

mass-producing prostheses and instead reinforcing the need for onsite experts to assist in the customized fitting process. Additionally, findings show that establishing local manufacturing and utilizing local talent increases the longevity and sustainability of 3D-printed prostheses as a solution in conflict zones.

Funding and Pricing

Participants recognize that finding funding for these initiatives is a time-consuming obstacle, but they also claim that funding does exist and is available for most humanitarian healthcare aid projects. Participants do note that relying on third party funding does tend to strain resources, reduce the capacity of operation, and limit the number of patients they can help and devices they can produce. One participant also noted that it is easier to source funding for devices than it is to source funding for a population, as devices are more itemized, whereas patients have various needs and thus are less cost predictable. Two participants operating in healthcare-adjacent fields in the MENA region expressed their observations regarding the 3D-printing industry and the healthcare industry in the MENA region. Both participants mentioned that nations within the GCC are interested in funding healthcare initiatives. Furthermore, both participants acknowledged the growth in demand for accessible prosthetic devices in the MENA region given the recent rise in military conflict in the area; participants observed that nations in the GCC were willing to fund initiatives to meet that demand.

This observation has implications for the scalability of 3D-printed prosthetics in the MENA region. With available funding and high demand in nations bordering conflict zones in the MENA region, there is an opportunity to establish 3D-printed prosthetic initiatives operating in these nations, and import prosthetic materials, equipment, and healthcare practitioners across the border. With shorter travel distances and local manufacturing, aid imports would have stronger supply chains and lower production costs, increasing the feasibility of scaling these initiatives and having a wider impact in conflict zones.

Case-by-case Basis

Five out of six participants mentioned the importance of having consultations with patients, emphasizing how varying individual needs of different patients change the manufacturing and fitting process of a prosthetic (see Appendix A, Table A2).

This emphasis on the uniqueness of each prosthetic for its corresponding recipient has implications for the ability to scale 3D-printed prosthetics. Each amputee has different needs and requirements for their prosthetics, and thus mass-producing a one-size-fits-all prosthetic device is unfeasible. However, one case study found that scan-to-print technology made it easier to produce multiple sockets for the same patient.³⁶ So, 3D-scanning and printing technology may make it easier to produce prosthetic devices customized to patient needs without drastically increasing production times or costs.

Sustainable Development

Three participants mentioned the importance of sustainable development in this project, emphasizing that investing in local talent and local production can increase the longevity and sustainability of using 3D-printed prosthetics in conflict zones. One biomechanical engineer cited educational investments as a source of sustainability, funding local experts to obtain higher education in nations that offer specialized degrees, before returning to the setting with expertise on par with NGO staff and foreign specialists. This engineer questioned the feasibility of this solution given its long-term and expensive nature. Another participant had built prosthetics in a low-resource setting by using easily accessible and available items to form the device, so that in the case of breakage, individuals were able to source materials to fix the prosthetic with little difficulty. This engineer utilized household items such as Velcro, screws, and fishing rod components. Additionally, one case study used in the comparative analysis also emphasized the

³⁶ Jérôme CANICAVE and Danielle TAN, *RS 05 Pilot Testing of 3D Printing Technology for Transtibial Prosthesis in Complex Contexts (Togo, Madagascar and Syria) Research and Studies Scientific Summary Operations and Technical Resources Division* (2017), https://www.hi-us.org/sn_uploads/document/3D_Printing_Pilot_Test_May2017.pdf.

importance of sustainable development by training local collaborators to use simple 3D-printing and prosthetic design software.³⁷

Sustainable development is crucial to ensuring 3D-printed prosthetics have a long-lasting positive impact on amputees living in conflict zones. By investing in local manufacturing and educating local talent in the manufacturing and fitting process, 3D-printed prosthetic initiatives may become less reliant on foreign aid and foreign talent, and as a result, can be sustainably produced in local communities even when foreign aid is unable to provide support.

Practicality

This section analyzes how certain practicality obstacles and opportunities may impact the ability to produce 3D-printed prosthetics in conflict regions. Operating in a conflict zone presents a unique set of practical challenges as 3D-printed prostheses endure sand, heat, dust, and military conflict. Results indicate that follow-up with patients significantly increases the impact of the prosthetic device, but funding, military conflict, and disabilities may reduce a patient's accessibility to follow-up appointments. Additionally, the moral implications of operating in a conflict zone and working with vulnerable populations suggest that ethical considerations must remain central to the 3D-printed prosthesis initiative by continuously consulting patients and prioritizing patient needs throughout the process.

Follow-up

Two participants cited follow-up as a major component of the prosthetic manufacturing and fitting process. Follow-up care is crucial to ensure that the prosthetic continues to fulfill the patient's needs, does not cause discomfort or harm to the patient, and address wear-and-tear or damage to the device. These participants outlined that follow-up is difficult in low-resource areas due to practical conditions and lack of funding. One participant described that since prosthetic patients lived with physical disabilities that made travelling difficult, if the patient lived far away from the clinic, they were less likely to return to the clinic for follow-up appointments. As a result, healthcare practitioners sometimes instead went to patient homes to conduct follow-up

³⁷ Merel van der Stelt et al., "Improving Lives in Three Dimensions: The Feasibility of 3D Printing for Creating Personalized Medical Aids in a Rural Area of Sierra Leone," *The American Journal of Tropical Medicine and Hygiene* (United States) 102, no. 4 (2020): 905–9, PubMed, <https://doi.org/10.4269/ajtmh.19-0359>.

sessions. One case study mentioned that 3D-printing technology required minimal infrastructure and portable equipment, allowing the service to move geographically closer to the populations requiring aid, and reducing the distance that these populations had to travel to receive care, thus suggesting that 3D-printed prostheses are more accessible to conflict zone amputees than conventional prostheses.³⁸ An interview participant also described that follow-up appointments had extra costs, and NGOs sometimes only covered the costs of initial consultations or one-time appointments. If those costs were not covered, patients were far less likely to return for follow-up appointments. Lastly, the participant said that patients were more likely to return for follow-up if they endured another physical injury, or if their medical device was broken and no longer functional.

This suggests that, to ensure safe 3D-printed prosthetic implementation, NGOs should attempt to source funding for follow-up appointments. Furthermore, given that conflict zones have scarcer healthcare clinics, NGOs should not only offer appointments at clinics, but also offer to travel closer to patients to increase healthcare accessibility.

Ethical Considerations

Every participant made reference to the ethical implications that must be considered when operating in a conflict zone with a vulnerable population (see Appendix A, Table A3). One participant who worked in a low-resource setting mentioned that general stigma against disability does tend to exist across all cultures, and that cultural nuance and differences between Western NGO aid staff and local populations must be considered. One participant also mentioned the prioritization of healthcare in conflict zones, citing that amputees requiring prosthetics are often second-priority compared to individuals requiring urgent medical attention; and that, due to limited medical resources, are often overlooked. Three participants emphasized the moral importance of consulting the patient to understand their needs. Two of these three participants also emphasized that a large part of providing aid to local populations as a foreigner involves making decisions on behalf of the local population, which may also lead to making assumptions

³⁸ Jérôme CANICAVE and Danielle TAN, *RS 05 Pilot Testing of 3D Printing Technology for Transtibial Prosthesis in Complex Contexts (Togo, Madagascar and Syria) Research and Studies Scientific Summary Operations and Technical Resources Division* (2017), https://www.hi-us.org/sn_uploads/document/3D_Printing_Pilot_Test_May2017.pdf.

about the patients' needs. Thus, participants say that consulting patients is very necessary throughout this process.

An integral part of this research project is understanding the moral implications of working to develop global solutions for vulnerable populations. As amputees and civilians living in conflict, the recipients of 3D-printed prosthetics in conflict zones face barriers to accessibility, communication, and as a result, barriers to advocating for their needs. As a result, continued communication with patient needs is crucial for ethical implementation of 3D-printed prostheses.

Key Findings

- Conflict zones in the MENA region are governed by fragmented authorities, meaning competing governments, militaries, and political presences complicate import policies and aid access. Furthermore, many of these militaries are hostile toward NGO workers, and intimidation attacks may prevent the implementation of 3D-printed prostheses on the ground in these conflict zones. Lastly, counterterrorism policies create compliance risks for NGOs, further deterring their operations in conflict zones specifically.
- There is potential to automate certain production and fitting processes, which would strengthen the feasibility of implementing 3D-printed prostheses by reducing their reliance on scarce healthcare equipment and resources, but on-site expertise is still needed to fit prosthetics onto patient limbs, given concerns regarding alignment, stability, and pressure sores. Additional expertise can be made available through an online platform in which locals are able to consult experts through a group chat or video call.
- 3D-prosthetics cannot be scaled through mass-production, given the individual nature of prosthetic care. However, modifying the measurements of existing digital 3D-printing models may be a feasible and scalable production route that requires less expertise and is thus more accessible.
- Available funding from nations in the MENA region coupled with increased demand for prosthetic care and 3D-printed medical devices suggests potential for 3D-printed prosthetic healthcare initiatives to scale.
- Sustainable development must be prioritized if the aim is for 3D-printed prostheses to be implemented as a long-lasting, continuous solution for amputees. Sustainable

development involves sourcing local materials, investing in local talent, and prioritizing local manufacturing.

- Similarly, follow-up appointments must also be a priority. Given their expensive costs, finding funding for follow-up appointments is crucial to the longevity of 3D-printed prostheses as a sustainable solution in conflict zones.
- Ethical considerations must remain at the forefront of global development and 3D-printed prosthetic initiatives. Consultations to understand patient needs is key, and aid workers must be cognisant of cultural nuances, social norms, and the barriers to accessibility that civilians living in MENA conflict zones experience.

Conclusion

This study aimed to contribute to addressing a research gap in understanding how 3D-printed prosthetic devices can be used to address the needs of amputee populations living in conflict zones in the MENA region. Through a qualitative analysis of existing policies, media and NGO reports, and semi-structured interviews with industry experts, this study identified potential obstacles across four key themes: policy, engineering, scalability, and practicality. Key obstacles include: fragmented authorities, intimidation attacks, anti-aid policies, engineering risks, funding gaps reducing follow-up appointments, and partial reliance on on-site expertise. Key opportunities include: available interest and funding in the MENA region, the potential to automate certain production and fitting processes, a lack of reliance on stable healthcare systems (which reinforces operability amidst public health crises), and the implementation of local manufacturing to strengthen the longevity of the solution.

This study takes a holistic approach to address the research gap by examining how the 3D-printed prosthesis initiative interacts with a variety of intersectional factors to wholly assess its feasibility. A successful healthcare initiative, especially in the context of a conflict zone, spans beyond just successful technology; it also includes feasible implementation, which can only be determined by analyzing the external factors which impact it. Thus, by taking this holistic approach to research, this study contributes to the wider body of research on 3D-printed prosthetic initiatives. Furthermore, by identifying these specific obstacles, this research encourages further analysis of these obstacles and strategies to dismantle them to strengthen the

3D-printed prosthetic initiative in the MENA region, providing accessible support to the amputee populations that need it most.

Appendix A

Relevant Quotes from Interview Transcript

Tables A1, A2, and A3 organize relevant quotes from the interview transcript based on the theme and subthemes they were coded under. These quotes may provide insight and relevance into how conclusions were drawn from data.

Table A1: Engineering

Sub-Theme	Quote
Automation Potential	“Everybody who [has] a long-term [disability], becomes a second priority in conflict zone. So, if you are less reliant on hospitals, on healthcare professionals that are dealing with more urgent—I'm not saying more important, [but instead] more urgent —needs of the population, the better.”
Automation Potential	“If somebody was to fabricate or design prosthetic limbs, ... whether it's over... not necessarily in person, but [maybe] remote, but...I think there would definitely need to be some level of expertise”
Automation Potential	“Some level of expertise would be needed somewhere in the process, whether it's in person or over a telehealth thing...Some expertise is needed, definitely needed somewhere”
Automation Potential	“Are there digital systems that could be trained ... analyze the interface and map the pressure distribution, and flag points where the pressure distribution was unacceptable? That is something that we can afford to have trained professionals do here... But we know that in health systems, where typically due to conflict, they have lost a vast number of their trained healthcare professionals.”
Automation Potential	“Is the prosthetic complicated enough that the user can operate it without a third person, like, I don't need to be there to teach them how to use it every single time. They don't need to have a physiotherapist putting... helping them put on the prosthetic every time.”
Automation Potential	“We cannot remove the profession. It's mandatory... We are using AI mobile to just automate 90% of the process. But at the end, we need a review from a physiotherapist or occupational therapist, which is a professional specialist in seating.”
Pressure Sores, Alignment, and Stability	“While it has potential, I feel like that kind of thing has to...rolled out carefully, so you don't have people who are...getting a pressure sore from an ill-fitting prosthesis”
Pressure Sores, Alignment, and Stability	“I think the socket would definitely be a source of concern that you would need expertise, because if it doesn't fit properly, and you don't catch that, the person could end up with a pressure sore”.
Pressure Sores, Alignment, and Stability	“One of my concerns, I guess, around it is...Managing the socket...The interface with the human is at...the socket.”
Escalation Pathway	“There are times when...the work definitely needs to be done locally, and there are times when there can be some troubleshooting support off-site. And that is

	one of the cases where you can get... well-meaning people in highly resourced environments who can provide additional analysis support, right? Additional commentary, additional practice with other materials, and they'll learn together.”
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Table A2: Scalability

Sub-Theme	Quote
Case-by-case Basis	“Prosthetic care is successful when the user is actively engaged... if the assistive devices do not fit with other people’s lives and people’s workflow, then they will be abandoned”
Case-by-case Basis	“Everything could be the same, the design process, even the design could be the same thing, but at the end of the day, they’re not going to be used by the same people. And that changes a lot”
Case-by-case Basis	“It’s not like one size fits all..”
Case-by-case Basis	“It’s also according to the application, the state, the feasibility, where it will be used, the degree of fitting, the degree of amputation... it’s very customized”
Funding and Pricing	“Healthcare is going through...systematic change. Countries... in the GCC...are starting to have enough appreciation of the importance of having a strong and high-quality healthcare. And hence, this is attracting a lot of funding.”
Funding and Pricing	“As long as the demand is there, and there is a proof of concept of the technology that it works, superior to what's existing today, then there will always be interest in on money to flow after.”
Funding and Pricing	“Most of the...the capable countries, they are capable to pay for this. They want the technology. But it's all about the know-how. For now, I'm talking about Saudi Arabia, and... the United Emirates. Maybe Qatar. That's the GCC area...We have the funds, but it's all about the know-how and the technology. You just... and there is a big demand.”
Sustainable Development	“The CAD software is not that hard to learn. And it's easier to maintain a local expert at a local machine to help people with, like, adaptation as they grow.”
Sustainable Development	“Coming together to form the device, we used things like...regular screws you could find in any store, like a bicycle store. We used fishing rods, nylon rods. We used Velcros... So if someone is using it and let's say a Velcro falls off, they don't freak out. Oh my God, how am I going to get this Velcro?... They just need to walk to the nearest store....to get a replacement, right?”

Table A3: Practicality

Sub-Theme	Quote
Follow-Up	“[It may be] difficult to...get follow-up, right?...If it's, like, hard to get to the clinic for whatever reason, follow up with patients might be difficult.”
Follow-Up	“Partly because the distance...There's only a few centers where you can get this kind of [care], and so people are traveling a long way, and if you already have a disability, that can be challenging”

Follow-Up	“It depended how far away they lived. If they lived in town, then it wasn't so hard to come back. If they live far away, then they might not get follow-up. And part of what I did when I lived there was actually going out to people's homes and seeing how they did”
Follow-Up	“[An NGO] had funded and significantly developed the prosthetic department for war victims...Because there was funding for those things, the patients would come back and check how it's working, you know? So again, that's a real barrier. But if you have funding, you're gonna get a lot more people to come back.”
Ethical Considerations	“The patient population might be a little bit different as well in a conflict zone...People are having more of those traumatic injuries...So you might be working with, like, a different population in a conflict zone.”
Ethical Considerations	“The ethical and moral side... that ought to be really centered in our decision-making. Bit also ties to end user priorities and end user choice.”
Ethical Considerations	“Yes, it is just 3D printing, but it is more than just 3D printing in a way that you are designing for people with already existing discomfort. You don't want to add another discomfort to their lives. Your work is to be able to improve their quality of life.”

Appendix B

IDF Dual-Use List

The Israel Defense Forces has a published list of “dual-use” goods, which are goods that are classified as having the potential to be misused as weapons by terrorist or political forces. In order to import these goods into the Occupied Palestinian Territories, importers must possess permits from COGAT by submitting an application. Furthermore, importers may face additional security screenings at the border when crossing with these goods. The following items listed on the dual-use list are also relevant to the manufacturing of 3D-printed prosthetics, and as a result, NGOs may face obstacles during the import process.

Item	Description and Relevance to 3D-printing
Scanners, including X-ray machines	3D scanners are used during 3D-printing to measure the amputated limb and map pressure distribution.
CNC milling machines	CNC milling machines are used during 3D-printing to rapidly cut and shape the final 3D-printed product.
Epoxy resin	Epoxy resin is typically mixed with epoxy hardener and used as an adhesive coating to strengthen the durability of 3D-printed products.
Epoxy hardener	Epoxy hardener is typically mixed with epoxy resin and used as an adhesive coating to strengthen the durability of 3D-printed products.
Carbon fiber	Carbon fiber is typically mixed with polymers to create a durable material used in 3D-printers.
Glass fiber	Carbon fiber is typically mixed with polymers to create a durable material used in 3D-printers.
Graphite powder	Graphite powder is sometimes used after 3D-printing to enhance the appearance of a 3D-printed product, or used as an additive by mixing it with plastics or resins.
Aluminum rods	Aluminum rods are often used alongside 3D-printed products, including prostheses, to provide structural support.
Metal pipes	Metal pipes are often used alongside 3D-printed products, including prostheses, to provide structural support.
Physical or chemical analysis equipment	Chemical analysis equipment is used during the 3D-printing process when mixing resins, polymers and fibers to create a material that the 3D-printer can use to create the product.
Uninterrupted power supply parts	Uninterrupted power supply (UPS) parts are integral to 3D-printing, as 3D-printing machines rely on UPS to properly function.

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