# 3D technology and telemedicine in humanitarian settings

Worldwide, sizeable populations are living with disabling and disfiguring injuries and are unable to access rehabilitation services.[1,2] In 2017, the Médecins Sans Frontières (MSF) Foundation initiated a pilot project with the MSF Reconstructive Surgery Program (RSP; established in 2006) in Amman, Jordan, to help to provide comprehensive rehabilitation services for patients with facial burns and upper limb differences. A multidisciplinary team, spanning specialists with expertise in prosthetics and orthotics, physical and occupational therapy, rehabilitation medicine, surgery, and biomedical engineering, collaborated on development of personalised prosthetic and orthotic devices using 3D technologies and telemedicine (appendix).

Facial burns and upper limb differences are often difficult to address in humanitarian contexts. A well fitting transparent facial orthosis is needed to provide effective pressure therapy for deep facial burns, and to reduce hypertrophic scarring, improve appearance, and reduce the psychosocial impact of facial burns.[3-7] However, the time and specialised skill needed to create these devices are often scarce in humanitarian contexts. The conventional approach requires creating a plaster mould over the patient's face, which can cause discomfort to the patient. Similar challenges stand before the provision of limb prostheses in humanitarian settings. Problems include the lack of prosthetists and prohibitive costs of prosthetic components and materials. These factors have driven an interest in implementing a digital approach, whereby 3D technologies enable the generation of 3D models of patient anatomy without touching the patient (ie, 3D scanning) and the local manufacture of low-cost, lightweight, patient-specific devices without the need for expensive machines and moulds that are required for conventionally manufacturing plastic parts. Integrating telemedicine also enables remote digital design and expert clinical and technical support. However, few clinical data are available for factors such as the devices' utility, durability, comfort, and impact on quality of life, as well as the cost and time associated with using digital tools.[8-10]

Development and provision of a prosthesis or transparent facial orthosis also requires a patient-centred approach applied by a multidisciplinary team that can provide comprehensive care, perform long-term assessments, and maintain communication with patients indefinitely to provide replacement components when needed. User needs and preferences around cosmetic outcomes and overall function—namely, ability to achieve activities of daily living—should all be assessed initially. The patient should be encouraged to provide as much feedback as possible throughout an iterative design optimisation process. It is also crucial that patients be monitored for as long as possible, even if only through remote communication. This helps to evaluate factors influencing long-term adoption of the device, including durability and comfort, as well as enabling long-term challenges to be addressed, such as providing replacement components to a growing paediatric patient. This patient-centred approach might also help patients to come to terms with their conditions, as they work with the field team to establish realistic goals, by understanding their options and device limitations.

See Online for appendix

Since 2017, the project has provided transparent facial orthoses for 24 patients and upper limb prostheses for 29 patients. The patient population for the project comprised of two groups: the MSF RSP patient population and the local paediatric population. The MSF RSP patient population was composed of paediatric and adult patients primarily from Iraq, Syria, and Yemen who were admitted for complex surgical treatment—specifically orthopaedic, maxillofacial, and plastic surgery—not available in their home countries; rehabilitation care, including physiotherapy, occupational therapy, and psychosocial care, was also provided by RSP. The local paediatric patient population were patients younger than 18 years with upper limb difference who were residing in Jordan without access to prostheses. Patients who received a transparent facial orthosis were all initially admitted by MSF RSP (18 paediatric patients and six adult patients, from Yemen [n=8], Iraq [n=7], Syria [n=5], Jordan [n=2], and Palestine [n=2]). Patients were encouraged to wear the transparent facial orthosis for as many hours as possible every day for 4–6 months; sometimes this was extended to up to 1 year if the skin continued to improve after the initial period. Of the 29 patients with upper limb differences (17 paediatric patients and 12 adult patients, 17 of whom were RSP patients, from Yemen [n=8], Jordan [n=7], Syria [n=5],

Palestine [n=4], Iraq [n=4], and Egypt [n=1]), 23 patients had below-elbow limb difference, three had above-elbow limb difference, and three patients had partial hands. The clinical team planned to administer surveys and assessments (Orthotics & Prosthetics User Survey [OPUS], Child Amputee Prosthetic Project Functional Status Inventory, Unilateral Below Elbow Test, and Individually Prioritized Problem Assessment) at 2 weeks, 3 months, and 1 year if the patient was available for follow-up. After the 1-year assessment, patients were encouraged to provide updates remotely.

Although early outcomes from the first 2 years of the project were promising, we encountered many technical challenges. Patients with upper limb differences reported more than 90% mean patient satisfaction (as determined by the OPUS satisfaction survey) and more than 5 h mean wear time per day after receiving their prostheses. However, we experienced several technical challenges including print failures—particularly with flexible materials—and mechanical failure of flexible prosthetic hand components—specifically, delamination between printed layers at high-stress regions. The 3D-printed wrist connectors experienced mechanical wear and loosening after heavy use, but were easily replaced (<1 h print time and <US$1 per connector). We learned that it is essential to provide spare parts, especially to patients returning to their home countries. Two upper limb prosthesis options—the passive above-elbow and body-powered below-elbow options—were discontinued because five patients did not adopt these prostheses and these options required considerably more design, manufacturing, and clinical time, as well as more frequent maintenance and more materials, compared with the simple, passive below-elbow prosthesis with interchangeable terminal devices.

The project required many resources to establish and sustain. Raw materials costs were relatively low (<$50 per upper-limb prosthesis including trial components, <$20 per transparent facial orthosis), but abundant human and technical resources were required (appendix). We were fortunate enough to pilot our 3D project in collaboration with the well established MSF RSP. Although the cost of human resources in Jordan is generally less than in high-income countries, the multidisciplinary team includes part-time coordinators and advisors from outside Jordan, including burn specialists from Hôpital Léon Bérard (Hyères, France). We also partnered with a local Fab Lab (Luminus Shamal Start; Irbid, Jordan), which enabled launch with little initial investment in hardware, workspace, and technical staff. LimbForge (now part of Victoria Hand Project, Victoria, BC, Canada) also provided technical assistance to adapt their designs for our project. Both 3D printers that we used were open-source, desktop 3D printers. Although low-cost 3D printers helped to democratise production, design and 3D printing parameter optimisation required countless hours from our technical team.

Despite the many challenges, our experience suggests that 3D technologies and telemedicine can serve as useful tools for increasing access to comprehensive rehabilitation care in certain humanitarian contexts. However, more objective measures and longer-term follow-up are needed to determine the efficacy and effectiveness of implementing this technology to deliver prosthetics and orthotics. Well designed randomised control trials are needed to determine whether the digital approach can improve clinical outcomes or reduce cost without compromising the quality of care. Also, patients living in low-resource settings often require more durable devices that can withstand difficult conditions with minimal maintenance. Lastly, implementing a programme that focuses entirely on delivering devices and neglects the need for comprehensive rehabilitation care would probably result in rejection of the devices and inadequate patient care.

We report no competing interests. This project was entirely financed by Médecins Sans Frontières (MSF) Foundation, in collaboration with MSF routine programmes, both of which are financed by donations from individuals (entirely in the case of the MSF Foundation, 99% in the case of MSF routine programmes). We acknowledge MSF Foundation and its donors, MSF Reconstructive Surgery Project (Amman, Jordan), and all MSF patients. We are grateful for the remote clinical support provided by Hôpital Léon Bérard, the technical support provided by Fab Lab Irbid and LimbForge, and the 3D scanners and software loaned to the project by Rodin4D. Emma Veitch, freelance medical editor for MSF, provided editorial assistance and her work was funded by MSF USA.



*Pierre Moreau, Samar Ismael, Hatim Masadeh, Esraa Al Katib, Laetitia Viaud, Clara Nordon, *Safa Herfat*
**safa.herfat@paris.msf.org**

MSF Foundation, 75011 Paris, France (PM, LV, CN, SH); Médecins Sans Frontières, Paris, France (SI, EAK); Medical Engineering for Orthopaedic Equipment, Amman, Jordan (HM); University of California San Francisco, San Francisco, USA (SH)

1 WHO. World report on disability 2011. Geneva: World Health Organization, 2011.
2 Bright T, Wallace S, Kuper H. A systematic review of access to rehabilitation for people with disabilities in low- and middle-income countries. *Int J Environ Res Public Health* 2018; **15:** E2165.
3 Stokes MAR, Johnson WD. Burns in the Third World: an unmet need. *Ann Burns Fire Disasters* 2017; **30:** 243–46.

4 ISBI Practice Guidelines Committee. Practice guidelines for burn care. *Burns* 2016; **42:** 953–1021.

5 Finnerty CC, Jeschke MG, Branski LK, Barret JP, Dziewulski P, Herndon DN. Hypertrophic scarring: the greatest unmet challenge after burn injury. *Lancet* 2016; **388:** 1427–36.

6 Kant SB, Colla C, van den Kerckhove E, Piatkowski de Grzymala A. Clinical effects of transparent facial pressure masks: a literature review. *Prosthet Orthot Int* 2019; **43:** 349–55.

7 Bloemen MC, van der Veer WM, Ulrich MM, van Zuijlen PP, Niessen FB, Middelkoop E. Prevention and curative management of hypertrophic scar formation. *Burns* 2009; **35:** 463–75.

8 Diment LE, Thompson MS, Bergmann JH. Three-dimensional printed upper-limb prostheses lack randomised controlled trials: a systematic review. *Prosthet Orthot Int* 2018; **42:** 7–13.

9 Ten Kate J, Smit G, Breedveld P. 3D-printed upper limb prostheses: a review. *Disabil Rehabil Assist Technol* 2017; **12:** 300–14.

10 Manero A, Smith P, Sparkman J, et al. Implementation of 3D printing technology in the field of prosthetics: past, present, and future. *Int J Environ Res Public Health* 2019; **16:** 1641.