2021 43rd Annual International Conference of the
IEEE Engineering in Medicine & Biology Society (EMBC)
Oct 31 - Nov 4, 2021. Virtual Conference

# Remote creation of clinical-standard myoelectric trans-radial bypass sockets during COVID-19

Jennifer Olsen[1], John Head[2], Lee Willan[2], Sigrid Dupan[3] and Matthew Dyson[1]

***Abstract*— To enable the progression of research during the COVID-19 lockdown, a novel remote method of creating clinical standard trans-radial bypass sockets was devised as a collaboration between an engineering team and a clinical research group. The engineering team recruited two able-bodied participants, marked areas of interest on the participant's limb and captured limb geometry and electrode sites with a high definition optical scanner. The resulting 3D scan was modified to make electrode sites and areas of interest recessed and tactile. Models were 3D printed to scale and posted to the clinical team to manufacture the sockets. A modified lamination process was used, comprising plaster casting and rectifiying the model by hand. The recessed areas of the 3D printed model were used to guide the process. The bypass sockets were returned to the engineering team for testing. A simple electromyography (EMG) tracking task was performed using clinical electrodes to validate the skin-electrode contact and alignment. This paper demonstrates a validated method for remotely creating trans-radial bypass sockets. There is potential to extrapolate this method to standard socket fittings with further research.**

## I. INTRODUCTION

Upper-limb prosthetics research typically depends on able-bodied participants, often due to a lack of amputee volunteers, or when volunteers are required with no prior prosthesis experience [1]. When studying prosthesis control, a common approach is to have able-bodied volunteers wear a 'bypass socket' [2]. Bypass sockets aim to simulate wearing a prosthesis in limb-intact participants, allowing them to wear and control a terminal device, such as a prosthetic hand [2]. Many bypass sockets designs are present in literature [2], some may be used with various limb sizes [3], [4], [5], [6], [7], [8], [9], [10] and others are participant specific [11], [12]. Participant-specific bypass sockets, such as those used by Sobuh et al. [11], typically require a visit to a specialist clinic and intervention from trained prosthetics and orthotics professionals to create form-fitting bypass sockets which resemble clinical-standard sockets. Developing prosthetics without a local clinical team is difficult, and has been increasingly challenging during the COVID-19 lockdown. Attending a clinic to be fitted with bypass sockets would require time, clinical expertise and travel. During the pandemic, existing procedures had to be adapted to comply with social distancing and travel restrictions. Remote-fitting procedures for prosthetics described in literature do not currently include socket-fitting [13]. This paper describes a novel method of creating clinical-standard trans-radial bypass sockets by combining digital methods; such as optical scanning, modification in CAD (Computer-Aided Design) and 3D printing, with traditional methods such as plaster casting, hand sculpting and lamination. The project was a collaboration between an engineering team physically based at Newcastle University, UK and a clinical prosthetics team based at the University of Salford, UK.

## II. METHODS

The local ethics committee at Newcastle University approved this study (Ref: #20-DYS-050). Throughout the study, all UK government social distancing guidelines relating to COVID-19 were followed.

The clinical team provided instruction to the engineering team to ensure that the remote limb capture followed equivalent guidelines to the standard, in-clinic, plaster cast. Participants were instructed to hold their forearm at a 70° elbow flexion and to make a fist with their palm facing inward. Participants held this position and angle for the duration of the scan.

### A. Part 1: Engineering stages

The first stage was performed by engineers based at Newcastle University and is detailed below.

*1) Identification of surface EMG sites and notable anatomy:* Participants were asked to hold their limb in the aforementioned position. The researcher taking the scan measured the angle of elbow flexion with a protractor for accuracy. To identify where the surface EMG electrodes should be placed inside the bypass socket, the participant was asked to flex and extend their palm, whilst their arm was palpated by a researcher. Two DELSYS Trigno sensors were placed where the wrist extensor/flexor muscle groups were located. The locations of the sensors were validated by viewing raw EMG traces in real-time and asking participants to do short bursts of flexion and extension of the wrist to verify a distinct signal-to-noise ratio. If the EMG sites were deemed suitable, a mark was drawn around the sensor. Participant's limbs were then palpated around the epicondyles and olecranon to locate bony prominences, emulating how a prosthetist would fit a standard socket [14].

*This work was supported by Newcastle University, Edinburgh University and the University of Salford.

[1]Jennifer Olsen and Matthew Dyson are with Intelligent Sensing Laboratory, Newcastle University, UK j.olsen@newcastle.ac.uk, matthew.dyson@newcastle.ac.uk

[2]John Head and Lee Willan are with School of Health and Society, Prosthetics and Orthotics, University of Salford, UK j.head@salford.ac.uk, l.e.willan@salford.ac.uk

[3]Sigrid Dupan is with Edinburgh Neuroprosthetics Laboratory, Edinburgh University, UK sigrid.dupan@ed.ac.uk

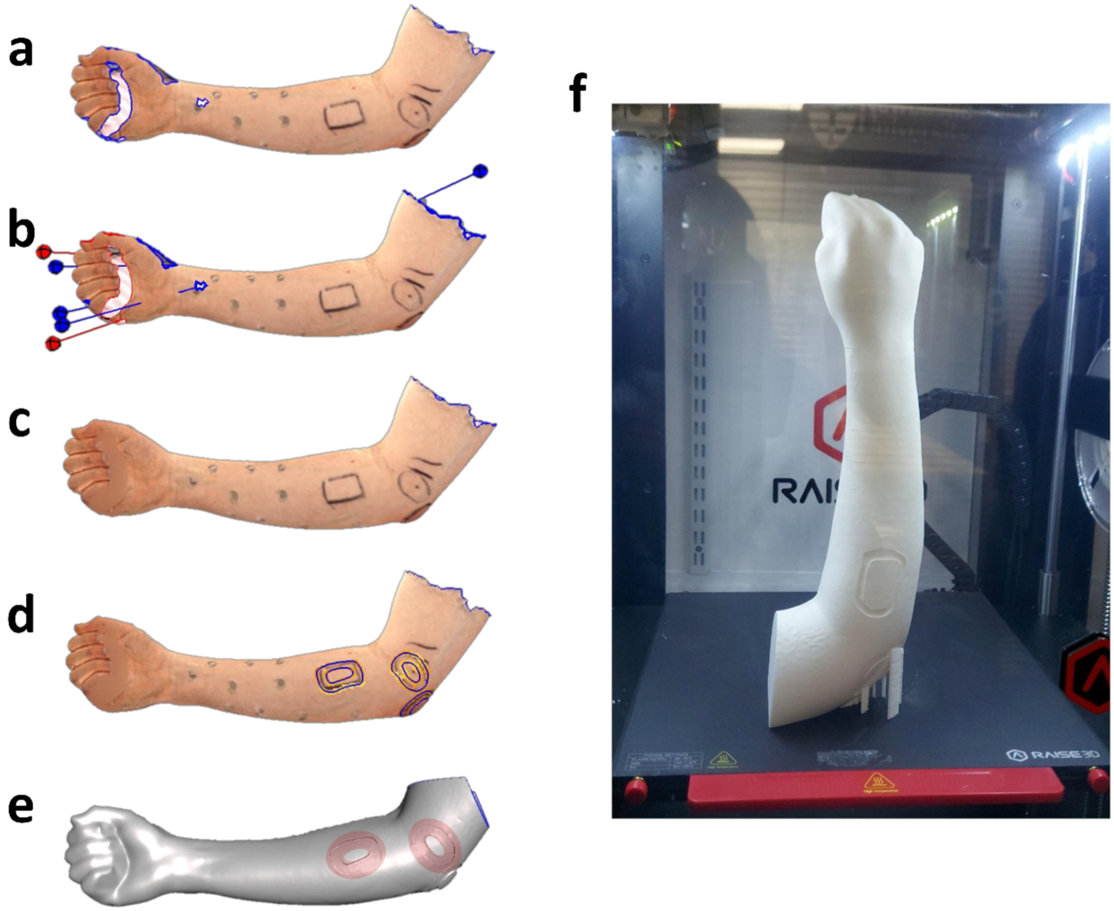


Fig. 1: The stages of digital rectification of the limb scans. (a) A raw scan. (b) The flaws in the scan are auto-detected in Meshmixer. (c) A scan which has had flaws removed to form a complete mesh. (d) Locations of the surface electrode sites and bony prominences are traced manually. (e) Drawings are recessed to produce a physical indention as highlighted in red. (f) A finished 3D printed limb model with recessed areas to mark the electrode sites, olecranon and epicondyles. The support material visible in the picture was removed manually before posting the clinical team.

Both areas were marked with a marker pen, as shown in Fig. 1a.

*2) Limb shape capture:* The limb was scanned with a Creaform GOScan! 50. The scanner was chosen as it allowed colour capture, so markings on the limb would be available when editing the scan in CAD. Reflective markers were affixed to the limb to assist the tracking of the scanner. The length and width of each participants limb was recorded for the clinical team to refer to. The entire scanning procedure was carried out in under 5 minutes per participant and complied with COVID-19 guidelines.

*3) CAD modifications:* The scans were edited in Autodesk Meshmixer. First, any obvious defects such as holes in the scan, shown in Fig. 1b, were manually rectified using the method detailed in [14]. A rectified model is shown in Fig. 1c. The fist of each scan was smoothed, as precision was not required in this area and to reduce the risk of 3D print failure. Next, the marker drawings were manually traced, as shown in Fig. 1d, and recessed into the digital model by 1mm, highlighted in Fig. 1e. This was intended to make the markings tactile to allow the clinical team to easily locate them after printing, with no significant effect on the geometry of the model.

*4) 3D printing:* The models were printed on Raise3D Pro2+ printers using PLA (poly-lactic acid) filament, with a layer height of 0.2mm, auto-generated breakaway support for overhangs exceeding 60 degrees and 20 percent infill to make the structure robust. A finished 3D printed arm is shown in Fig. 1f. After printing, the breakaway support was removed manually and the models were sanitised and posted to the clinical team.

### *B. Part 2: Clinical stages*

The second stage was completed by the clinical team at the University of Salford as detailed below. The clinical team created the bypass socket by modifying the standard process of creating a trans-radial socket via lamination.

*1) Plaster casting:* To obtain a negative mould, wraparound Plaster of Paris (POP) bandage casts of the 3D printed limbs were made. Once hardened, the outer shell was carefully removed and filled with POP mix and left to set. The outer bandage shell was removed to reveal the positive

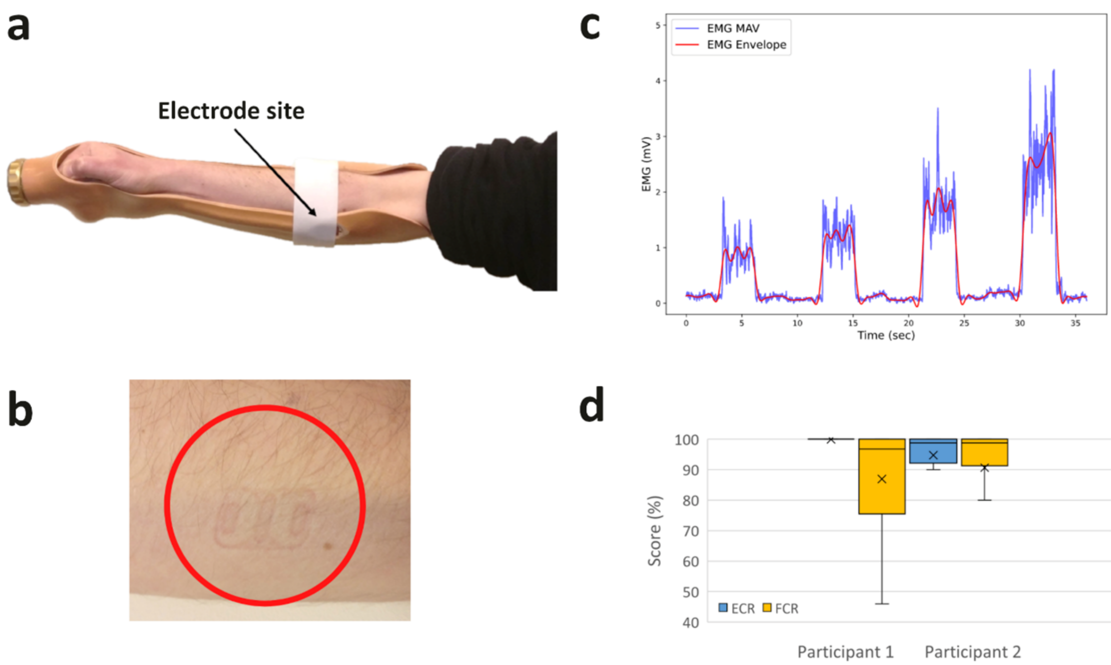


Fig. 2: A summary of results. (a) A completed bypass socket, with an adjustable strap to allow tightening. One of the EMG sites is highlighted in the figure. (b) The light indentation from the electrode indicating good skin-electrode contact observed after participants wore the sockets (highlighted in red). (c) An EMG signal obtained from one of the participants from their wrist flexor muscle group using clinical electrodes and a bypass socket at all four target heights. (d) A box plot of the scores obtained by the participants during the tracking task, where the whiskers represent the upper and lower quartiles. ECR denotes control with extensor carpi radialis, FCR control with flexor carpi radialis.

plaster cast, a direct copy of the 3D printed model made from plaster. The recessed areas indicating the locations of bony prominences and EMG sites transferred between both casting stages.

*2) Rectification:* The recessed areas were used to guide the rectification process. The positive mould was modified around the bony prominences for comfort, as deemed appropriate by the prosthetist conducting the rectification. The areas indicating the EMG sites were flattened to assist electrode contact with the skin. The entire cast was smoothed and left to dry.

*3) Lamination:* The clinical team produced double-layer bypass sockets, with an adjustable wraparound strap to ensure the sockets could be donned and doffed easily whilst also obtaining a close fit. The standard lamination process used by the clinical team was modified to make sockets suitable for able-bodied users. The design encapsulates the entire arm and hand, with a channel running along the length of the socket with the thumb and top of the arm exposed, as seen in Fig. 2a. A brief overview of the lamination process involves the following steps: dummy electrodes are placed on the electrodes sites of the positive plaster cast of the limb, nylon and nyglass stockinette is layered upon the positive plaster cast of the limb, the layers of textile are then set with resin under vacuum and trimmed to the correct shape. A wrist attachment was installed to allow the addition of any terminal device. The completed sockets were posted back to the engineering team for testing.

### C. Part 3: Testing

The sockets were tested for comfort and myoelectric functionality. Myoelectric functionality was defined as whether or not usable control signals could be obtained from both electrode sites while the socket was worn by participants. Clinical standard surface myo-electrodes (RSL Steeper SEA200) were interfaced with the Axopy experimental library for human-computer interface experiments at 1000Hz [15]. A simple, one-dimensional EMG tracking task was implemented in Axopy. The task involved 16 trials per run and was completed separately for the flexor and extensor muscle groups. Since the purpose of the EMG task was solely to demonstrate that the EMG sensor contact was sufficient for functional control, participants only performed one or two runs per muscle. Signals were calibrated to obtain a control signal by normalising to participant's comfortable contraction levels using the procedure described in [16], [17]. Participants used their muscle activity to control a cursor display on a monitor in a simple target reaching task. Static targets were presented at four different heights. Target sizes were scaled to be equivalent to those used in [16], [17]. The specific target ranges used were 0.15 - 0.26, 0.26 - 0.41, 0.41 - 0.65 and 0.65 - 1, where 1 equates to the normalised contraction value participants performed during the calibration phase.

Participants were asked to raise the cursor to the target and hold it within the target for the duration of the trial (2 seconds). Data was collected with an update rate of 10 ms smoothed using a 750 ms window.

## III. Results

Before commencing EMG testing, the fit of the sockets was validated visually by observing the light indentation on the skin created by electrode pads, indicating good skin-electrode contact had been achieved. An example indentation is shown in Fig. 2b. All sockets received from the clinical team fit participants and no areas of discomfort were reported. Both participants tested were able to control the cursor during the EMG tracking task and 'clean' EMG signals were observed in both participants experimental data. An example of the experimental EMG data obtained is shown in Fig. 2c. The mean score for targets held was 92.8% for the extensor group and 88.2% for the flexor group, as shown in Fig. 2d.

## IV. Discussion

A novel method of creating trans-radial bypass sockets was carried out as a collaboration between clinical and non-clinical teams of researchers during the COVID-19 lockdown period in the UK. All sockets produced fitted the participants comfortably and both participants were able to complete an EMG tracking task.

Although all of the sockets were successful, some manufacturing steps required multiple iterations to produce a successful workflow. Notably, the stages where the 3D printed model is converted to a positive plaster cast were found to be essential. Attempts were made to use the 3D printed model instead, however PLA is not compatible with the lamination process. As PLA has a low heat-deflection temperature of around 50°C, it would also be unsuitable for other socket creation methods such as thermoforming, hence the plaster model was created. Additionally, the fit of the socket was unknown until the try-on stage due to the remote nature of the process, which introduces a risk of wasted time and resources should an ill-fitting socket be created.

While this study describes the creation of trans-radial bypass sockets, the same method could potentially be furthered to allow remote-fitting of regular clinical-standard prosthetic sockets for patients unable to travel to clinics, without compromising the involvement of a qualified prosthetist or the materials used to make the final prostheses. This method also has the potential to facilitate more long-distance collaborations between clinical and non-clinical research groups. Despite a high-cost scanner being used in this study, a low-cost (≈£300) digital scanner and even smartphones have been used for similar prosthetics applications [14], [18], making digital scanning an accessible method for capturing the geometry of limbs.

In summary, this paper demonstrates a successful method to remote-fit clinical-standard trans-radial bypass sockets. The method detailed allowed several studies to progress despite COVID-19 lockdown, and could possibly be extrapolated to actual socket fittings, with future research.

## References


[1] L. Haverkate, G. Smit, and D. H. Plettenburg, "Assessment of body-powered upper limb prostheses by able-bodied subjects, using the box and blocks test and the nine-hole peg test," *Prosthetics and orthotics international*, vol. 40, no. 1, pp. 109–116, 2016.

[2] A. W. Wilson, D. H. Blustein, and J. W. Sensinger, "A third arm-design of a bypass prosthesis enabling incorporation," in *2017 International Conference on Rehabilitation Robotics (ICORR)*. IEEE, 2017, pp. 1381–1386.

[3] M. D. Paskett, N. R. Olsen, J. A. George, D. T. Kluger, M. R. Brinton, T. S. Davis, C. C. Duncan, and G. A. Clark, "A modular transradial bypass socket for surface myoelectric prosthetic control in non-amputees," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 27, no. 10, pp. 2070–2076, 2019.

[4] A. Chadwell, L. Kenney, S. Thies, A. Galpin, and J. Head, "The reality of myoelectric prostheses: understanding what makes these devices difficult for some users to control," *Frontiers in neurorobotics*, vol. 10, p. 7, 2016.

[5] H. Bouwsema, C. K. van der Sluis, and R. M. Bongers, "The role of order of practice in learning to handle an upper-limb prosthesis," *Archives of physical medicine and rehabilitation*, vol. 89, no. 9, pp. 1759–1764, 2008.

[6] H. Bouwsema, C. K. Van-der Sluis, and R. M. Bongers, "Changes in performance over time while learning to use a myoelectric prosthesis," *Journal of neuroengineering and rehabilitation*, vol. 11, no. 1, pp. 1–15, 2014.

[7] L. Van Dijk, C. K. Van Der Sluis, H. W. Van Dijk, and R. M. Bongers, "Learning an emg controlled game: Task-specific adaptations and transfer," *PloS one*, vol. 11, no. 8, p. e0160817, 2016.

[8] J. M. Zuniga, J. E. Pierce, C. Copeland, C. Cortes-Reyes, D. Salazar, Y. Wang, K. Arun, and T. Huppert, "Brain lateralization in children with upper-limb reduction deficiency," *Journal of NeuroEngineering and Rehabilitation*, vol. 18, no. 1, pp. 1–14, 2021.

[9] L. H. Huinink, H. Bouwsema, D. H. Plettenburg, C. K. Van der Sluis, and R. M. Bongers, "Learning to use a body-powered prosthesis: changes in functionality and kinematics," *Journal of neuroengineering and rehabilitation*, vol. 13, no. 1, pp. 1–12, 2016.

[10] J. Parr, S. J. Vine, N. Harrison, and G. Wood, "Examining the spatiotemporal disruption to gaze when using a myoelectric prosthetic hand," *Journal of motor behavior*, vol. 50, no. 4, pp. 416–425, 2018.

[11] M. M. Sobuh, L. P. Kenney, A. J. Galpin, S. B. Thies, J. McLaughlin, J. Kulkarni, and P. Kyberd, "Visuomotor behaviours when using a myoelectric prosthesis," *Journal of neuroengineering and rehabilitation*, vol. 11, no. 1, pp. 1–11, 2014.

[12] C. Lake, "Effects of prosthetic training on upper-extremity prosthesis use," *Assessment*, vol. 8, no. 11, p. 12, 1997.

[13] J. M. Zuniga, K. J. Young, J. L. Peck, R. Srivastava, J. E. Pierce, D. R. Dudley, D. A. Salazar, and J. Bergmann, "Remote fitting procedures for upper limb 3d printed prostheses," *Expert review of medical devices*, vol. 16, no. 3, pp. 257–266, 2019.

[14] J. Olsen, S. Day, S. Dupan, K. Nazarpour, and M. Dyson, "3d-printing and upper-limb prosthetic sockets: promises and pitfalls," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 2021.

[15] K. R. Lyons and B. W. L. Margolis, "AxoPy: A Python library for implementing human-computer interface experiments," *Journal of Open Source Software*, vol. 4, no. 34, p. 1191, 2019.

[16] M. Dyson, S. Dupan, H. Jones, and K. Nazarpour, "Learning, generalization, and scalability of abstract myoelectric control," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 28, no. 7, pp. 1539–1547, 2020.

[17] S. S. Dupan, A. Krasoulis, and K. Nazarpour, "Intramuscular emg for abstract myoelectric control: A proof of concept study," in *2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*. IEEE, 2020, pp. 3277–3280.

[18] A. Hernandez and E. Lemaire, "A smartphone photogrammetry method for digitizing prosthetic socket interiors," *Prosthetics and orthotics international*, vol. 41, no. 2, pp. 210–214, 2017.