AGILIS: Restoring Functional Grasping in Individuals with Tetraplegia using Epineural Electrodes

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***Abstract*— We propose a novel approach to restore grasping in individuals with complete tetraplegia using epineural stimulation. Two multi-contact cuff electrodes were positioned around radial and median nerves in 2 volunteers during a surgery. The electrodes were maintained for 28 days. A user interface allowed triggering pre-programmed stimulation sequences on demand by executing stereotyped movements or by contracting voluntarily muscle on the contralateral shoulder. The stimulation selectivity obtained with the epineural electrodes was sufficient to obtain functional palmar and key pinch grip.**

***Index Terms*—Functional Electrical Stimulation (FES), Tetraplegia, Neural electrodes.**

I. Introduction

Functional electrical stimulation (FES) is a means of restoring upper limb function in people with complete tetraplegia when functional tendon surgery or nerve transfer is not an option [1].

Intramuscular and epimysial electrodes have been used in the past to restore grip [2,3]. A disadvantage of this approach is the need for one electrode and one cable per muscle to be activated. Miniature, self-contained implant designed to be injected in or near muscles have also been proposed to avoid cables [10].

In the AGILIS approach, we propose to use 1 epi-neural electrode per nerve to activate the different muscles to reduce the number of implanted electrodes [4]. The cuff electrodes were designed to be self-adjusting to nerve diameter.

The objectives of the study we present here were to: 1) evaluate the safety of the procedures of implanting 2 cuff electrodes around the median and radial nerves respectively and maintaining them for 28 days, 2) evaluate the ability of the solution to elicit a functional grip in two participants with complete tetraplegia.

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II. Methods

Two volunteers with complete C4 tetraplegia, AIS A were included. They signed an informed consent. The study was approved by the National Ethics Committee (ClinicalTrials.gov ID NCT04306328).

The electrodes were placed during an initial surgical procedure and explantation surgery took place 28 days later. 2 multi-contact spinal electrodes (CorTec GmbH Freiburg Germany) were wrapped around the nerves above the elbow. Each electrode was connected to a percutaneous cable to connect the multi-source external stimulator (STIMEP, INRIA, Montpellier) [8]. The stimulator was controlled from a computer (Figure 1).

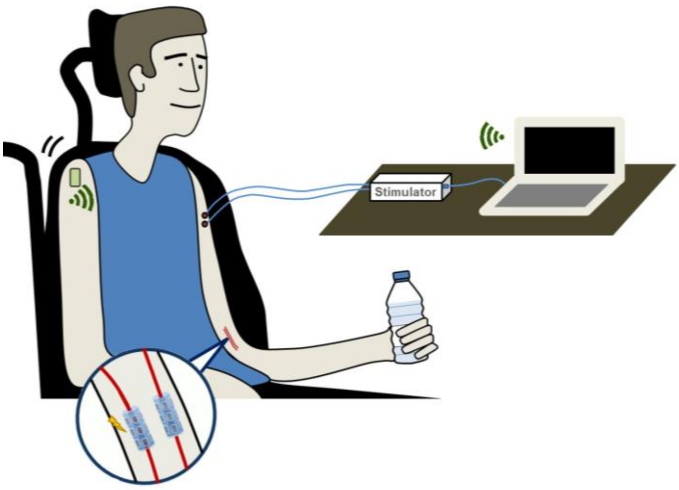

Fig. 1. AGILIS approach principle: 2 multi-contact cuff electrodes are wrapped around radial and median nerves. Percutaneous cables are connected on demand to an external pulse generator. Stimulation configuration patterns are pre-programmed to elicit hand opening/closing. The user controls contralateral shoulder movements or muscle contraction to send commands to the stimulator software: hand opening, palmar or key pinch grip…

Two control interfaces were tested to allow the user to trigger the pre-programmed stimulation patterns: 1) the participant used stereotyped voluntary shoulder movements of the contralateral limb captured by 1 IMU, 2) the participant used voluntary contractions of 2 muscles of the contralateral limb

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captured by 2 EMGs (trapezius and platysma). A finite state machine (FSM) was defined to associate user commands (EMG threshold detection or predefined movement recognition (IMU)) with actions depending on the current state of the FSM [6].

Various measurements were made wireless sensors (Delsys, Natick, MA) and offline processed using: electromyography (EMG), forces applied to objects (resistive force sensors (FSR)), movements (inertial measurement units (IMU)). The kinematics of the movements were also analysed (Leap Motion, Inc, San Francisco, California). FES-induced evoked muscle contractions (eEMG) were also acquired and post-processed to extract recruitment curves [9].

III. Results

Both participants were able to perform object grasping tasks using two types of grasp (key pinch and digito-palmar). Participant 1 was able to use both control interface modalities (muscle contraction and voluntary movements). Participant 2, due to a significant fatigability of the shoulder muscles, was able to use only voluntary shoulder movements to trigger the stimulation sequences, but in a rather non-robust manner, which led us to propose a third solution based on occipital contactors. Some results have been published in a recent article [7]. Additional results will be detailed during the presentation at the conference.

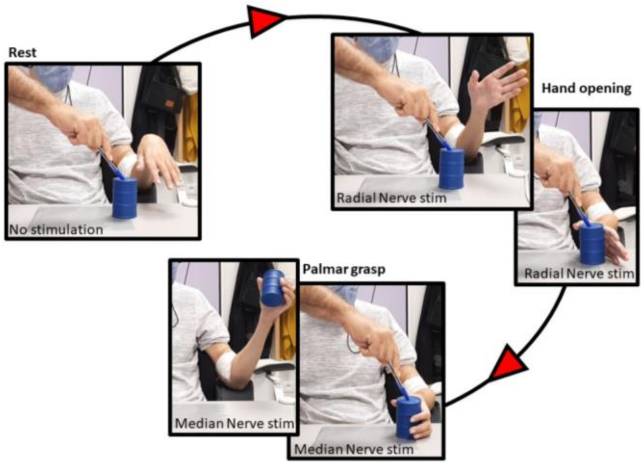

Fig. 2. Example of a sequence of movements for gripping a foam cylinder. The participant triggers the stimulation of the radial nerve which causes the hand to open (extension of fingers and wrist), he positions his hand on the object and then triggers the stimulation of the median nerve which causes the fingers to close around the object which he can then move.

IV. Conclusion

This preliminary study is a further step in the validation of the AGILIS approach which suggests the feasibility of a solution for grip restoration that minimises surgical complexity. Less than 2 hours were required to place the 2 multi-contact epineural electrodes with percutaneous cables around the radial and median nerves. These two electrodes associated with the electrical stimulator allow the injected currents to be controlled to achieve selective activation of the nerve fascicles. Two separate taps could be activated and associated with reproducible configurations (active electrode poles and stimulation parameters). The behaviour of the electrodes remained stable during the implantation period (28 days). Further studies are needed to strengthen the results.

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