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BILATERAL PROXIMAL FOREARM TRANSPLANTATION. CASE REPORT AT SEVEN YEARS.

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AUTHORSHIP

MI participated in research design, performance of surgical procedure, analysis patient follow-up and evaluation, and writing of the manuscript.

EVC participated in patient evaluation and follow-up, data collection, and writing of the manuscript.

JMG participated in patient follow-up and evaluation, performance and analysis of neurophysiological studies.

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ABBREVIATIONS PAGE

CMAP: Compound Motor Action Potential

DASH: Disabilities of the Arm, Shoulder, and Hand

DSA: Donor Specific Antibodies

HTSS: Hand Transplantation Score System

PFT: Proximal forearm transplants

SF-36: Short-form-36

ABSTRACT

Background. Although return of function has been reported in patients undergoing proximal forearm transplantations (PFT), reports of long-term function are limited. In this study, we evaluated the clinical progress and function 7 years postoperatively in a patient who underwent bilateral PFT.

Case Presentation. A 58-year-old man underwent bilateral PFT in May 2012. Transplantation involved all of the flexor and extensor muscles of the forearm. Neurorrhaphies of the median, ulnar, and radial nerves were epineural and 7 cm proximal to the elbow. Immunosuppressive maintenance medications during the first 3 years postoperatively were tacrolimus, mycophenolate, and steroids, and later, tacrolimus, sirolimus, and steroids. Forearm function was evaluated annually using the Disabilities of the Arm, Shoulder, and Hand (DASH); Carroll; Hand Transplantation Score System (HTSS); short-form-36 (SF-36); and Kapandji scales. We also evaluated his grip and pinch force.

Results. Postoperatively, the patient developed hypertriglyceridemia and systemic hypertension. He experienced 6 acute rejections, and none were resistant to steroids. Motor function findings in his right/left hand were: grip strength: 10/13 kg; key pinch: 3/3 kg; Kapandji score: 6/9 of 10; Carroll score: 66/80; HTSS score: 90/94. His preoperative DASH score was 50 vs 18, postoperatively; his SF-36 score was 90. This function improved in relation with the function reported in the second year.

Conclusions. Seven years following PFT, the patient gained limb strength with a functional elbow and wrist, although with diminished digital dexterity and sensation. Based on data presented by other programs and our own experience, PFT is indicated for select patients.

INTRODUCTION

Proximal forearm transplants (PFT) involve the difficulty of transferring all of the extrinsic muscles of the hand, as well as regenerating the length of the nerves to reach the intrinsic musculature.[1,2] Despite these disadvantages, 24 PFTs have been performed in 17 patients. Of these, results in only 10 patients have been published,[2–8] and the remaining 7 patients have been described in the media (Table 1).[9–15] One patient who underwent bilateral proximal forearm and leg transplantations died in the third month posttransplant,[9] and another patient underwent amputation 1 year after the transplant secondary to rejection because of poor adherence to immunosuppressive treatment.[3] Most maintenance immunosuppressive regimens include 3 medications[3,16,8]; however, there is a trend toward replacing triple-medication regimes with mammalian target of rapamycin inhibitors and/or early or late withdrawal of steroids.[4,17–19]

The first patients underwent PFT in China in 2000, and results in Western countries were reported up to 2012[3] (6 PFTs in 4 patients). Results showed that excellent digital mobility can be obtained with an almost normal grasping and pinching force.[16] However, although most authors reported rapid recovery of flexion and extension of the wrist and fingers, patients' ranges of mobility and grip strength were diminished, with weak pinching, diminished protective sensitivity, and with low likelihood of reinnervation of the intrinsic musculature.[4,19–21] Of all patients reported worldwide, only 8 have been followed for more than 2 years, and patients' function has been evaluated using different scales. Additionally, patients' hand intrinsic function has not been widely described.[3,8,16,22] Therefore, the maximum function that this type of transplant can achieve, as well as its benefits and complications, are unknown.

The aim of this article was to report the clinical progression and function 7 years postoperatively in a patient who underwent bilateral PFT, with an emphasis on the function of the intrinsic musculature.

CASE PRESENTATION

A 58-year-old man underwent bilateral PFT in May 2012. His demographic and surgical data and postoperative progress to 2 years were published previously.[8] In summary, the patient suffered bilateral proximal forearm amputation secondary to high-voltage electrical burns, which resulted in moderate axonal motor neuropathy of bilateral musculocutaneous, right median, and left ulnar nerves in the residual stumps. Bilateral donated upper extremities were obtained without a tourniquet. All of the flexor and extensor muscles of the forearm were transplanted, and osteosynthesis of the radius and ulna was at the level of the proximal third of each bone, in each forearm. Neurorrhaphies of the median, ulnar, and radial nerves were epineural and 7 cm proximal to the elbow. The warm ischemia time was 19 minutes for the right limb and 35 minutes for the left, with a total ischemia time of 361 minutes and 372 minutes, respectively. Immunosuppressive maintenance treatment during the first 3 years was with tacrolimus, at serum levels of 7 ng / ml; mycophenolate mofetil, and prednisone. After 3 years, mycophenolate was changed to sirolimus (7 ng/ml), and the patient continued a triple-drug regime with tacrolimus and prednisone. Initially, rehabilitation was performed for 6 hours each day. From 30 months postoperatively, rehabilitation was performed for 2 hours per day 5 days each week, and gradually became irregular, limited, and then totally stopped by the 5th postoperative year. Follow-up involved laboratory and imaging studies according to our institution's protocol. Hematoxylin and eosin-stained biopsies were evaluated annually according to the protocol or in case of rejection. Electrophysiological studies were performed annually. Limb function was evaluated annually using the following scales:

Disabilities of the Arm, Shoulder, and Hand (DASH); Carroll; Hand Transplantation Score System (HTSS); short-form-36 (SF-36); and Kapandji, and the Froment sign. We also evaluated his grip and pinch force.

RESULTS

The patient developed hypertriglyceridemia 2 years after transplantation, and he started treatment with atorvastatin 10 mg qd. At the time of this report, his triglyceride level was 146.5 mg/dl. Systemic hypertension of multifactorial origin was diagnosed in November 2017, and genetic factors and the adverse effects of immunosuppression therapy were considered the main etiologies. Amlodipine 5 mg qd was initiated. Serum glucose and creatinine values remained normal posttransplantation. Serological testing for cytomegalovirus, Epstein–Barr virus, toxoplasma, and herpesvirus 6 and 8 remained negative. Prostate-specific antigen, colonoscopy, and dermatological evaluations detected no neoplastic processes.

Immunological progression

In the third postoperative year, segmental stenosis was detected in the left ulnar artery, which led to the decision to change mycophenolate to sirolimus (serum levels: 7 ng/ml). At the time of this report, the patient was receiving tacrolimus 2 mg every 12 hours, sirolimus 2 mg every 24 hours, and prednisone 5 mg daily.

He has experienced 6 acute rejections (day 60, Banff I; day 385, Banff II; day 522, Banff II; day 766, Banff II; day 1034, Banff II; and day 1071, Banff II). The acute rejection in days 60, 522 and 1071 were treated exclusively with topic tacrolimus. IV methylprednisolone was administered in the other 3 AR episodes. No rejection episodes were resistant to steroids. The results of the control biopsy in the second year identified the fourth acute rejection, which was subclinical. An Important finding in this biopsy was the presence of deeply-located large interleukin-10-producing cluster of differentiation 20 B-cell aggregates resembling the morphology of tertiary lymphoid organs. Levels of donor-specific antibodies (DSA) were negative at that time. Because of the possibility of chronic rejection, three 0.5-g boluses of methylprednisolone were administered, for a total dose of 1.5 g. We also administered 330 mg rituximab and intravenous immunoglobulin at 1 g/kg body weight. Over the 7-year follow-up, the patient presented with only 2 DSA elevations; 1 at 8 months postoperatively (Cw10, DR17, DR52, and DQ7) and the other at 50 months postoperatively (DR52 and DR16), with maximum values up to 2000 MFI. None of these elevations was related to acute rejection reactions. DSA levels remained negative at the time of this report (Fig. 1).

Imaging Studies

High-resolution ultrabiomicroscopy detected segmental stenosis of the left ulnar artery at wrist level; therefore, we changed mycophenolate to sirolimus in 2015. At the 7-year follow-up, we saw no intima-media thickening in the radial and ulnar arteries at the wrist level (Fig. 1).

Grayscale ultrasonography showed increased thickness of the intima-media complex at the anastomosis sites of the brachial arteries compared with baseline. The 7-year postoperative thickness was 0.6 mm on the right and 0.5 mm on the left; no evidence of areas of significant stenosis were seen. The intima-media thickness in the distal and proximal segments remained stable from 2014 onward. A Doppler flow study showed the usual 3-phase appearance spectra and normal velocities in all of the evaluated segments (Fig. 1).

Full-body densitometry performed in 2017 showed normal bone mineral density values for age and sex with a T-score of 0.5, which corresponds to normal bone density according to the World Health Organization classification.

Functional magnetic resonance studies showed a constant change in brain activity associated with finger movement through a flexion-extension exercise, as well as in functional connectivity in the resting state.[23] Brain magnetic resonance imaging showed that the patient's brain activity appeared as a scattered and unusual pattern during the first acquisition. This pattern improved during rehabilitation, with the patient showing relatively normal brain activity from the fourth postoperative year onward. These changes correlated significantly with the DASH scale.

Electrophysiological Studies

Electromyographic studies with needle electrodes were recorded in the intrinsic musculature 15 months postoperatively in thenar eminences and dorsal interosseous muscles. The electromyographic progression of motor unit action potentials is shown in Figure 1. In the right hand, after the ulnar neuroma reconstruction, the motor unit action potentials improved. From the second postoperative year, continuous signs of reinnervation occurred up to the seventh postoperative year, when the motor unit action potentials normalized (1000–3000 μV) and polyphasia and duration increased. Seven years postoperatively, recruitment measures were better for the left forearm muscles, and some muscles still showed a single-unit interference pattern. Nerve conduction studies with superficial electrodes recorded compound motor action potentials (CMAP) in the median, ulnar, and radial nerves. Seven years postoperatively, all CMAPs had improved for all evaluated parameters except for the right radial nerve (Table 2).

Secondary Surgeries

Secondary surgery was performed 18 months posttransplant to treat a neuroma in the right ulnar nerve at the site of nerve repair. The patient was treated with neurolysis and 2 sural nerve grafts with end-to-side neurorrhaphy, placed to jump the neuroma. In postoperative year 4, Fowler-type tenodesis was performed with tendinous allografts to correct a claw deformity. The first tenodesis was performed on the left hand followed by the right, 4 months later.

Function

Bodily integrity was well-restored. We saw a discrepancy in the skin color of the grafts compared with the recipient's skin. Elbow flexion was normal at the 7-year follow-up, and prono-supination in both extremities was limited. Strength in the flexor and extensor muscles of the wrist and fingers is shown in Table 2.

Clinically, the left hand had good muscle volume in the thenar eminence with hypotrophy of the hypothenar eminence and the first interosseous dorsal muscle. Froment's sign was negative, the grafted skin exhibited normal sweating, and decreased sensation to light touch with normal sensation in the thumb (Semmes–Weinstein test). The patient's right hand has had a stable mixed-claw deformity since the second postoperative year, hypotrophy of thenar and hypothenar eminences, and atrophy of the first dorsal interosseous muscle and the abductors of the fifth finger. Froment's sign was positive, the limb exhibited normal sweating, has decreased sensation to light touch, and the fingers had diminished protective sensation except in the second and third fingertips, which had lost protective sensibility (Semmes–Weinstein test). Kapandji, Carroll, DASH, and HTSS scores are summarized in Table 2. The right hand, despite its mixed-claw deformity, was useful for grasping slim objects. The left hand had the greater strength, with the best opposition and the best grip for small- and medium-sized objects. (Video S1, SDC) With these abilities, the patient was able to eat, perform personal hygiene activities, use public transportation, and perform recreational activities by himself. He finished his law degree and reentered the labor force as a tax expert.

DISCUSSION

The viability, function, outcomes, and long-term complications of transplanted upper extremities are unknown because of the small number of cases reported and that the longest observation period is only 20 years. Even less is known about patients' final level of function in their proximal forearm transplants. Therefore, it is essential to report the progression and functional results of all upper extremity transplants, as we described in this study.

Seventeen of the 24 forearm transplants have remained viable, some for up to 15 years.[16] However, follow-up results have been published in formal medical journals for only 10 patients. The average follow-up of the 10 patients reported in the literature is 74.1 months (range: 6–156 months)[3,5,8,16,17,19,22,24,25]; however, forearm function after 12 months has been reported in only 7 of these transplanted patients. Our patient's function is reported after 84 months posttransplant and is exceeded in time only in patients undergoing PFT in China and Austria.[16]

The longest postoperative function evaluation of 12 years posttransplant was reported in a patient who underwent PFT at Harbin Medical University. The patient's digital mobility, grip strength, key pinch, and lifting strength were all within normal values.[16] However, the authors of the report did not report DASH scores, electromyographic results, or an assessment of the intrinsic musculature of the hand. It is important to point out that the cause of amputation in this patient was a crushing injury, compared with our patient who sustained injuries secondary to electrical burn, similar to patients in Austria, Mexico, India, and Turkey.[2,3,8] Our patient presented with moderate axonal motor polyneuropathy as a consequence of the electrical burn, which hinders the functional prognosis.

The most complete functional evaluation to date was reported in an Austrian patient. Reinnervation of the extrinsic musculature was achieved 6 months postoperatively, and reinnervation of the intrinsic musculature occurred 12 months postoperatively. Both extrinsic and intrinsic muscles showed greater reinnervation in the ensuing years.[2,26,27] This patient achieved maximum function 9 years postoperatively, then subsequently experienced a decrease in function. Eleven years posttransplant, the patient's grip strength was 9.2 kg in the right hand and 6.5 kg in the left; key pinch was 3.2 kg in the right hand and 1.3 kg in the left. This patient did not have discrimination at 2 points, although he was able to detect and discriminate stimuli, and had an HTSS score of 74 in his right hand and 71.5 in his left. Electrophysiological studies 9 years postoperatively showed reinnervation of the intrinsic musculature of the hand with CMAP varying from 1–2.1 mv.[27] His last functional follow-up was published 12 years postoperatively, and a DASH score of 55 was reported. Our patient's assessment at 7 years postoperatively was similar to that reported for the Austrian patient, but also included Carroll and SF-36 scores, and Froment sign evaluation. Comparing our patient's findings with those of an Austrian patient, the Mexican patient had better sensitivity and better function in the intrinsic musculature.

One of the most critical concerns during transplantation is ischemia. To reduce ischemia time at the University of Innsbruck, for the Austrian patient, the donor and recipient were in continuous operating rooms, and the authors reported the shortest ischemia time for all reported PFTs of 2.5 h. 2 The maximum ischemia time reported was 8 hr, in a Turkish patient. 5 In our case, the donor and the recipient were 16 km apart. To reduce the ischemia time, retrieval was performed without a tourniquet and prior to procuring the solid organs, but the time is still very long compared with the ischemia times reported by the University of Innsbruck.

Compared with our previous function report for our patient 2 years postoperatively, we saw slightly improved strength in some extrinsic muscles; improved reinnervation and function of the intrinsic muscles; and improved DASH, HTSS, and Carroll scores, despite the fact that rehabilitation decreased significantly after 2.5 years, and despite the mixed-claw deformity in the right hand. Our patient's quality of life likely decreased after the initial enthusiasm of having full arms.

Functional magnetic resonance findings in our patient suggested that: 1. the use of new limbs required recruiting brain areas that are not usually associated with simple movements; and 2. abnormal brain activity patterns decreased during rehabilitation, showing a favorable progression and normal patterns after 4 years.[23]

Complications secondary to immunosuppression have been reported in 6 proximal forearm transplantation patients, and these are expected in any transplanted organ, namely, hyperglycemia, increased serum creatinine, hypertension, hypercholesterolemia, hypertransaminasemia, hypertriglyceridemia, cytomegalovirus and herpesvirus infections, fungal infections, and cytokine release syndrome.[2–5] Our patient developed hypertriglyceridemia 2 years postoperatively, and later, systemic hypertension. Fortunately, both have been easy to control.

Acute rejections were reported in 7/17 patients, and in 6 patients, the number of rejections ranged from 4–7 over 72–156 postoperative months.[2,3,24,27] The Austrian patient has experienced 3 acute rejections resistant to steroids, and the Spanish patient experienced 1 such rejection. The remainder of the reported acute rejections responded to steroids alone.[24,27] Chronic rejections in the proximal forearm were reported in 2 Chinese patients.[3,16] This number of acute and chronic rejections in PFT is similar to the number of acute and chronic rejections reported in transplanted hands, with a similar follow-up period.[28–30] Our patient experienced 6 acute rejections in 6 years, and none were resistant to steroids. Two signs of chronic rejection were detected in our patient; 1 was diagnosed by ultrabiomicroscopy and was successfully reversed by changing mycophenolate to sirolimus. The second sign of chronic rejection was diagnosed by histopathology in the protocol biopsy. This biopsy was taken adjacent to a hypertrophic scar, which histologically has similarities to signs of chronic rejection. Therefore, we do not know if the biopsy finding identified a hypertrophic scar or a chronic rejection reaction.[8] Despite these signs, the patient showed no clinical signs of acute rejection, including no DSA elevation.

With the antecedent of 3 previous AR episodes in a patient with a history of de novo posttransplant DSA and the histological finding of the presence of large B-cell aggregates (CD20) of deep localization recalling the morphology of tertiary lymphoid organs, we thought to prevent the possible development of more de novo DSA directed to other antigenic specificities by the administration of Rituximab. Interestingly, the finding of large B-cell aggregates were not found in the fifth and sixth biopsies. It is not possible to assure whether the anti-CD20 antibody administration participated in this specific histological modification.

At the time of this report, the patient was asymptomatic and showed no chronic rejection data.

Our patient quickly sought his physical independence from his family and neglected his rehabilitation 2.5 years postoperatively. Additionally, and because of technical difficulties in the osteosynthesis of the radius and ulna, carelessness in the rehabilitation program by the medical team, and the late detection of the neuroma in the continuity of the right ulnar nerve, the right hand developed a mixed-claw deformity, which remained stable since it appeared. The left hand has shown continuous improvement in function since the second year, with function in the intrinsic median and ulnar muscles. With this level of function, the patient returned to his original job as an accountant, finished a new career as a lawyer, and is independent in all his personal activities. Therefore, our opinion is that these types of transplants are well indicated.

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Figure 1 Legend

(A) Donor specific antibodies and tacrolimus and sirolimus blood values through the seven years are shown in this graphic. The red arrows indicate acute rejection reactions. (B) Changes in brain activation during the rehabilitation period. Warm colors indicate the cortical activation during a flexion-extension task of each hand ($p < 0.05$ FDR corrected). The upper row shows the activity map for the right hand while the lower row shows the activity map for the left hand. Each column indicates the year after the surgery. Note that in the first year the brain activation is wide-spread over the cortex but in the fourth year the activation pattern is confined to the motor cortex in the hand-knob area. (C) Ultrabiomicroscopy of proper palmar digital artery of the third finger. (a) showed a 0.07 mm thickness of the intima on the right hand and (b) 0.09 mm on the left one. (D) Control skin biopsies at 7 years (H&E 200X) showing normal skin appearance (Banff Grade 0), no rejection, absence of inflammatory infiltrate in the dermis, unaffected epidermis without dyskeratosis or apoptic keratinocytes. (c) right forearm and (d) left forearm. (E) MUAP of intrinsic musculature of both hands registered with needle electrodes. By 7th year all MUAP are over 2000 microvolts, showing increased area of innervation in the recorded muscles.

Table 1. Proximal Forearm Transplanted Worldwide

Patient	Sex*/Age**	Year/month Transplantation	Country/Medical Center	Proximal Forearm Transplanted	Follow up (months)
1	M / 37	2000/09	China	2	108
2	M / 50	2001/06	China / Harbin Medical University´s Hospital	1	156
3	M / 52	2002/10	China / Harbin Medical University´s Hospital	2	144
4	M / 41	2003/02	Austria / Innsbruck Medical University	2	144
5	F / 37	2003/10	China***	1	12
6	M / 30	2007/11	Spain / Hospital La Fe, Valencia	1	72
7	M / 28	2010/09	Turkey / Akdeniz University's Hospital	1	6
8	F / 28	2011/09	USA / University of Pennsylvania´s Hospital	2	24
9	M / 34	2012/01	Turkey / Akdeniz University's Hospital ****	1	3.5
10	M / 52	2012/05	México / INCMNSZ	2	24
11	M / 26	2012/11	USA / John Hopkins Hospital	1	40
12	M / 40	2014/10	USA / Brigham & Women´s Hospital, Boston	1	30
13	F / 49	2016/01	Canada / Toronto Western Hospital	1	5
14	M / 21	2016/05	India / Amrita Institute of Medical Sciences	1	14
15	F / 29	2016/08	USA/France	2	6
16	M / 51	2016/11	France, Lyon	2	?
17	?	2017/03	Taiwan	1	?
Total				24	

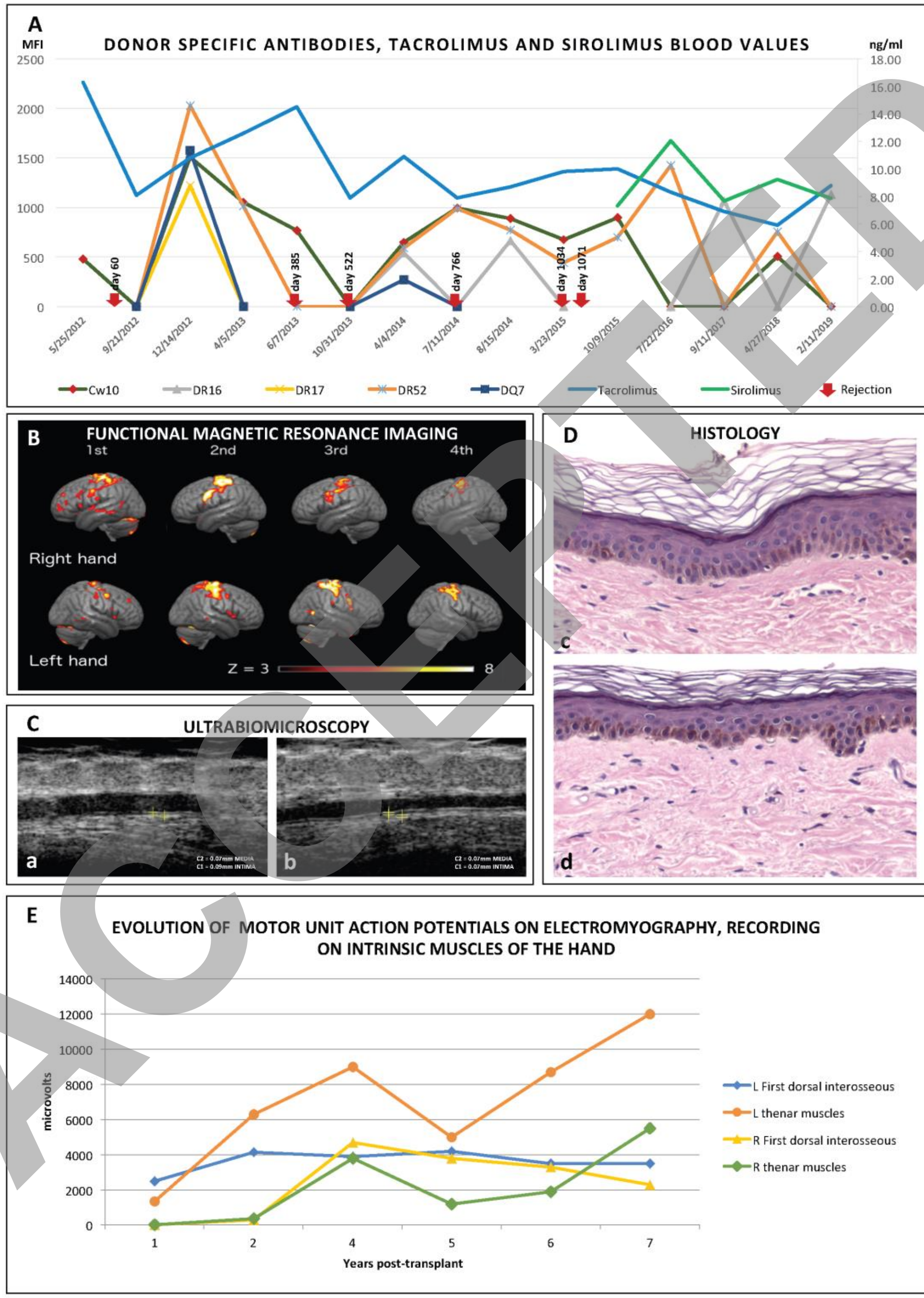
*F: Female; *M: Male; ** Years; *** Failure ; **** Dead

TABLE 2. Comparative Comprehensive evaluation at 2 and 7 years postransplantation

Year of evaluation	2 years		7 years		Evolution	
Forearm evaluated	Right	Left	Right	Left	Right	Left
Muscle strength, sensibility, and electrical activity						
Radial nerve						
Extensor carpi radialis longus	M5	M4	M5	M5	-	=
Supinators	M4	M5	M3	M3	-	=
Extensor digitorum	M0	M4	M3	M3	+	=
Abductor pollicus longus	M0	M4	M4	M4	+	=
Extensor pollicis longus	M0	M2	M4	M4	+	=
Heat, cold and pain sensibility	Yes	Yes	Yes	yes	=	=
Latency (m/s)	3.5*	2.6*	5 **	3.7**	=	+
Amplitude (mV)	0.3*	0.6*	5.1*	1.1*	+	+
Velocity (m/s)	27	31	28	50	=	+
Median Nerve						
Pronator teres	M3	M4	M4	M4	+	=
Flexor carpi radialis	M4	M5	M5	M5	+	=
Flexor digitorum superficialis	M0	M5	M5	M5	+	=
Flexor digitorum profundus II and III	M5	M5	M5	M4	=	-
Flexor pollicis longus	M3	M5	M4	M5	+	+
Opponens pollicis	M2	M4	M4	M5	+	+
S-W Monofilament testing	DPS	DPS	DLT	DPS	+	=
Two-point discrimination test(mm)	15	No	12	10	+	+
Latency (m/s)	4.7	5.0	3.3	4	-	+
Amplitude (mV)	1.4	3.5	4.7	6.7	+	+
Velocity (m/s)	27	31	32	41	+	+
Ulnar nerve						
Flexor carpi ulnaris	M4	M4	M5	M5	+	+
Flexor digitorum profundus IV and V	M5	M5	M5	M5	=	=
Abductor digiti minimi	M0	M0	M3	M3	+	+
Flexor digiti minimi	M0	M2	M0	M4	=	+
First dorsal interosseous muscle	M0	M1	M3	M5	+	+
Adductor pollicis	M3	M3	M3	M5	=	+
S-W Monofilament testing	DPS	DPS	DLT	DLT	+	+
Two-point discrimination test (mm)	No	No	15	12	+	+
Latency (m/s)	6.8	5.2	4.3	4.5	+	+
Amplitude (mV)	0.4	2.4	2.8	3.7	+	+
Velocity (m/s)	13	29	40	44	+	+
Motor function						
Grip strenght	6 kg	5 kg	10 kg	13 kg	+	+
Key-Pinch strenght	1 kg	1 kg	3 kg	3 kg	+	+
Kapandji trumb opposition score	3/10	6/10	6/10	9/10	+	+
Function testing						
Short Form-36 (SF-36)	93.19		90.22		-	
Carroll hand function test	60	49	66	80	+	+
DASH (pre-tx=50)	30.84		18		+	
Hand Transplantation Score System (HTSS)	69	73	90	94	+	+

Muscle strength graded according to the Medical Research Council. * Extensor carpi radialis ** Extensor Proprius indicis. S-W; Semmes-Weinstein; DPS, diminished protective sensation; DLT, Diminished light touch. Carroll test, HTSS and DASH scores are like outcomes reported in forearm transplantation. (-) Decrease in function; (=) without changes in values; (+) increase in function.

Figure 1



A
MFI
DONOR SPECIFIC ANTIBODIES, TACROLIMUS AND SIROLIMUS BLOOD VALUES
ng/ml
day 60
day 385
day 522
day 766
day 1034
day 1071
5/25/2012
9/21/2012
12/14/2012
4/5/2013
6/7/2013
10/31/2013
4/4/2014
7/11/2014
8/15/2014
3/23/2015
10/9/2015
7/22/2016
9/11/2017
4/27/2018
2/11/2019
Cw10
DR16
DR17
DR52
DQ7
Tacrolimus
Sirolimus
Rejection
B
FUNCTIONAL MAGNETIC RESONANCE IMAGING
1st
2nd
3rd
4th
Right hand
Left hand
Z = 3
8
D
HISTOLOGY
c
d
C
ULTRABIOMICROSCOPY
a
b
E
EVOLUTION OF MOTOR UNIT ACTION POTENTIALS ON ELECTROMYOGRAPHY, RECORDING ON INTRINSIC MUSCLES OF THE HAND
microvolts
Years post-transplant
L First dorsal interosseous
L thenar muscles
R First dorsal interosseous
R thenar muscles