QUANTITATIVE PREDICTION OF GRASP IMPAIRMENT FOLLOWING PERIPHERAL NEUROPATHIES OF THE HAND

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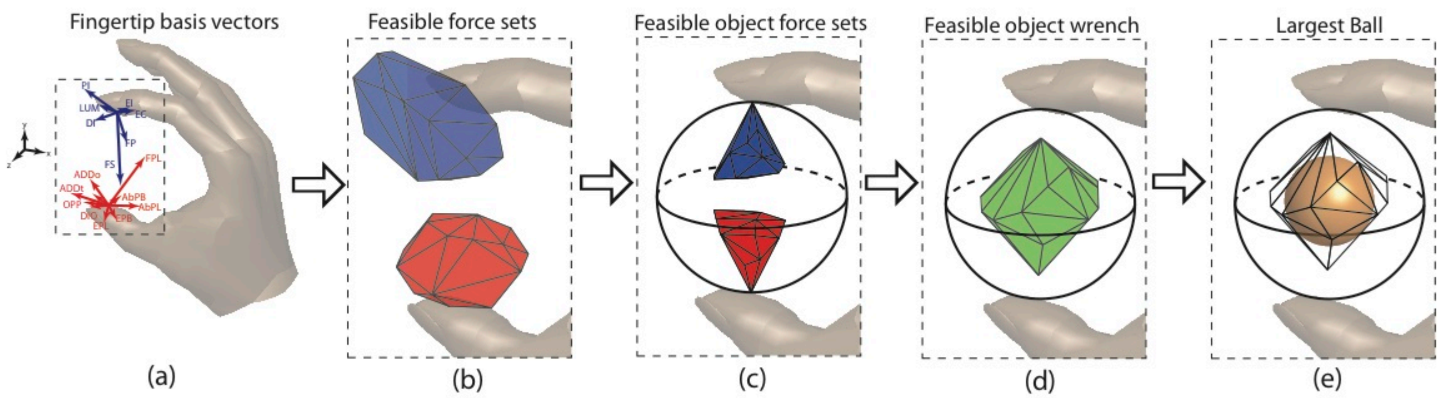

Figure 1: Grasp quality calculation steps. (a) Basis vectors. (b) Feasible force sets. (c) Feasible object force sets. (d) Feasible object wrench illustrated in 3-D. (e) Grasp quality metric of radius of largest ball (illustrated in 3-D; actual calculation is in 6-D).

INTRODUCTION

Grasping is a fundamental hand function that is impaired or eliminated following peripheral neuropathies of the hand [1]. Using a novel computational framework for calculating grasp quality of tendon-driven hands [2], we predicted grasp quality for various degrees of simulated peripheral neuropathies: (i) carpal tunnel syndrome, (ii) low median nerve palsy, (iii) low ulnar nerve palsy, and (iv) low radial nerve palsy.

METHODS

Calculation of grasp quality for tendon-driven hands involves several steps [2]. The first is determination of the fingertip forces that each tendon produces when tension is applied. We use previously-published cadaveric data from the thumb and index finger [3,4] to determine these "basis vectors" (Fig. 1a), from which the feasible force set (the set of 3-dimensional forces that the fingertip can produce) can be calculated, shown in Fig. 1b. These sets are then intersected with friction cones, producing feasible object force sets: the sets of forces that the fingertip is able to apply to the object, shown in Fig. 1c. From these sets, the set of all forces and torques on the object (i.e., the feasible object wrench) that the grasp can resist may be calculated, shown in Fig. 1d.

The first grasp quality metric we used was the weakest wrench (combination of force and torque) magnitude (in N—torque is scaled to N with the radius of the object) that could be resisted by the grasp. This is equivalent to the radius of the largest ball, centered at the origin, that the feasible object wrench set can contain, and is illustrated in Fig. 1e in 3-D, although the actual measure is in 6-D (3 dimensions for force and 3 for torque). For example, if the grasp quality is 5, then the grasp can resist at least 5N of force or scaled torque in any direction. We call this the *radius of largest ball*.

The second grasp quality metric we used was the radius of the 6-D ball with the same volume as the feasible object wrench, which we call the *characteristic length*.

Using this framework, we simulated various degrees of nerve palsies and carpal tunnel syndrome by progressively "weakening" muscles controlled by these innervation groups from their maximal force [3,4]. We modeled carpal tunnel syndrome as low median nerve palsy that does not affect extrinsic muscles, since they are innervated proximal to the wrist [5]. The muscles for each innervation group are shown in Table 1.

Table 1: Muscles in each nerve pathology group. M: median, R: radial, U: ulnar, CTS: Carpal Tunnel Syndrome.

Finger	Muscle	Innervation group
Index	Flexor digitorum profundus (FDP)	M
	Flexor digitorum superficialis (FDS)	M
	Extensor indicis proprius (EIP)	R
	Extensor digitorum communis (EDC)	R
	First lumbrical (LUM)	M,CTS
	First dorsal interosseous (FDI)	U
	First palmar interosseous (FPI)	U
Thumb	Abductor pollicis brevis (AbPB)	M,CTS
	Abductor pollicis longus (AbPL)	R
	Adductor pollicis oblique (ADDo)	U
	Adductor pollicis transverse (ADDt)	U
	First dorsal interosseous (DIO)	U
	Extensor pollicis brevis (EPB)	R
	Extensor pollicis longus (EPL)	R
	Flexor pollicis brevis (FPB)	M,CTS
	Flexor pollicis longus (FPL)	M
	Opponens pollicis (OPP)	M,CTS

RESULTS AND DISCUSSION

The impairment of grasp quality with simulated advancement of peripheral neuropathy is shown in Fig. 2. We see that low median nerve palsy quantitatively affects both measures of grasp quality most severely. In addition, we observe that complete loss of any innervation group causes the radius of largest ball to be zero. This means that there are some directions of perturbation in 6-D wrench space that the grasp cannot resist, and therefore the grasp does not have *force closure,* which is considered to be a maximally deficient grasp. As expected, carpal tunnel syndrome decreases grasp quality less than full low median nerve palsy. Although low radial nerve palsy affects the extensors of the fingers, it has a comparable effect to carpal tunnel syndrome because they, counterintuitively, also contribute to grasp, as described earlier [6].

CONCLUSIONS

Our ability to predict grasp quality enables a rigorous comparison of functional deficits across peripheral neuropathies. Comparison of patient outcomes with these quantitative predictions will enable development of efficient treatment modalities

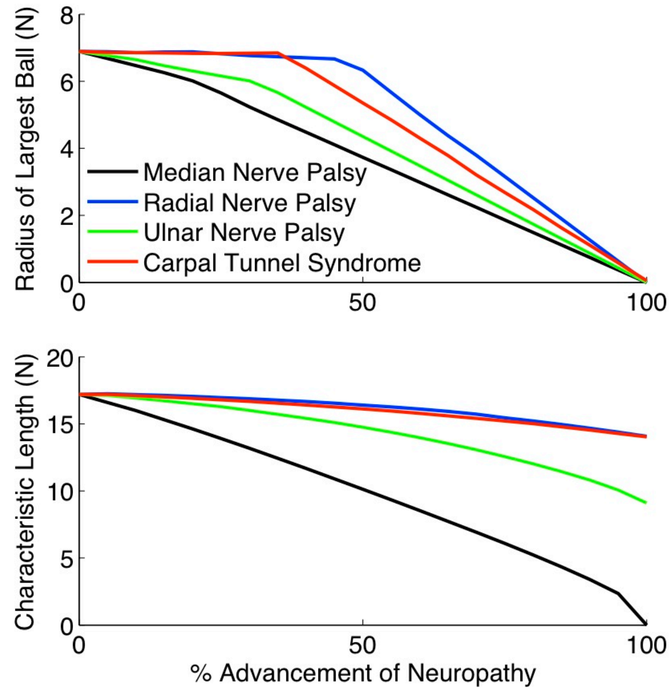

Figure 2: Grasp quality deterioration as a function of % advancement of neuropathy.

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