JSES Open Access 1 (2017) 63–71

Contents lists available at ScienceDirect

JSES Open Access

journal homepage: www.elsevier.com/locate/jses

Effect on muscle strength of the upper extremities after open elbow arthrolysis

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ARTICLE INFO

Keywords:
Elbow stiffness
Arthrolysis
Isometric strength
Handgrip
Dominance
Range of motion
Prognosis

Level of evidence: Level IV, Case Series, Treatment Study

Background: Open elbow arthrolysis manipulates tendons and soft tissues surrounding the elbow and may lead to strength decline after the operation. We hypothesized that strength of elbow and wrist motions and handgrip could be compromised after the procedure and that the strength recovery pattern may differ between men and women and between the dominant and nondominant side.
Methods: This was a prospective cohort study. We monitored 32 patients with post-traumatic elbow stiffness who underwent open arthrolysis between June 2014 and December 2014. All patients underwent standardized postoperative physical therapy. Preoperative and postoperative isometric strength were measured by a handheld dynamometer. Mayo Elbow Performance Score (MEPS) and arc of motion (AOM) were also analyzed.
Results: Mean follow-up was 26.13 months. Significant improvement was noticed in mean AOM (from 46° to 127°) and MEPS (from 67.97 to 96.86). No significant decline was noted in isometric strength at the last follow-up day. The strength ratios between men and women showed no significant difference from postoperative day 7 to the last follow-up day. At all follow-up assessments, isometric strength showed no significant difference between the dominant and nondominant side.
Conclusions: AOM and MEPS achieved significant enhancement after open elbow arthrolysis. The procedure did not lead to isometric strength decline. Postoperative gain of strength was proportional to the baseline strength level of each muscle group, and men had a more prominent gain of strength than women during the entire follow-up. Dominance had no effect on postoperative strength recovery.

Elbow stiffness is a common post-traumatic complication that extensively reduces elbow activities, compromises quality of life, and decreases occupational function.[14,34,37,51] Surgical intervention, including open or arthroscopic elbow arthrolysis and elbow arthroplasty, are indicated for those who do not respond to conservative approaches[7,8,35,45,49] to restore the arc of motion (AOM) and elbow functions.

Complications of the procedure, such as elbow instability, wound infection, pin-related infections, and recurrence of elbow stiffness, have been studied.[6,22] Only a few studies,[2,9,51,53] however, have reported muscular strength compromise after the procedure, and they mainly focused on elbow flexors and extensors. We have observed clinically that all patients experience an abrupt strength decline for all elbow, wrist, and grip movements shortly after the operation and gradually recover afterward. We conducted a more systemic research to study strength recovery to the end point.

Ligaments and muscles surrounding the elbow contribute to its stability, motions, and strength. Besides regular capsulotomy, heterotopic ossification removal, or remodeling of the olecranon,[27,28,44] many authors[6,12,23,39,55] reported excision of the posterior and transverse bundle of the medial collateral ligament and partial excision of lateral collateral ligament complex for better release of elbow stiffness. If release is unsatisfactory, lengthening[38] or pie-crusting of the triceps,[51] or detachment of common tendons of flexors would be applied. We hypothesized that open elbow arthrolysis and manipulation of surrounding soft tissues may permanently compromise the muscular strength of elbow flexors and extensors, wrist flexors and extensors, and handgrip.

For studying the postoperative strength recovery of each individual, isometric strength needs to be measured, and the widely used

All procedures performed in studies involving human participants were in accordance with the ethical standards of the Institutional and National Research Committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by Institutional Review Board of Shanghai Sixth People's Hospital East Branch (No. 2014-003).

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http://dx.doi.org/10.1016/j.jses.2017.06.006

descriptive Oxford Scale of Muscle Strength (grade 0-5) was replaced by a handheld dynamometer (HHD; ReHabKit1 System, NCC Medical Co. Ltd, Shanghai, China). This HHD is a portable and cost-friendly device for measuring isometric strength and is regarded as being as a reliable and viable instrument as an isokinetic dynamometer[26,47] for strength assessment. We also studied the recovery pattern between the sexes and between the dominant and nondominant sides because these helped to guide intraoperative skills and create an individualized rehabilitation regimen.

Materials and methods

Patients

This prospective cohort study evaluated all patients with elbow stiffness who underwent open arthrolysis at our institution between June 2014 and December 2014. Patients were considered eligible when the following inclusion criteria were met: (1) age 18 years or older, (2) post-traumatic elbow stiffness, and (3) elbow stability confirmed by physical examination in patients with history of dislocation. Exclusion criteria included (1) elbow stiffness due to severe burn, head injuries, spinal injuries, or nontraumatic arthritis; (2) preoperative or postoperative elbow instability; (3) a history of trauma or musculoskeletal diseases of the opposite upper limb; (4) decreased muscular strength caused by stroke or brain or spinal cord injuries; (5) recurrent elbow stiffness; or (6) elbow stiffness treated with total elbow arthroplasty, interposition arthroplasty, or arthroscopic arthrolysis.

Between June 2014 and December 2014, 52 patients with elbow stiffness underwent open elbow arthrolysis. Elbow instability was detected in 3 patients, including 2 before the procedure and 1 after the procedure. Excluded were 8 patients aged younger than 18 years, 2 with trauma history with the opposite upper extremity, 1 patient with elbow stiffness caused by brain trauma, 1 by burn, and 2 by rheumatoid arthritis, and 1 patient with recurrent elbow stiffness after arthrolysis in another hospital.

Among the 34 patients who met the criteria, 2 patients were lost during the follow-up. Finally, 32 patients (13 women and 19 men) were included in the study, with an average age of 35.5 ± 11.4 years (range, 22-62 years) at the time of the operation. Demographics, types of initial injuries, and other clinical characteristics of these patients are summarized in Table I. The average interval from injury to arthrolysis was 21.22 ± 12.24 months (range, 11-62 months). The mean follow-up period was 26.13 ± 2.59 months (range, 22-31 months).

Table I
Patient demographics and clinical characteristics

Characteristics	No. or mean ± SD (range) (n = 32)
Sex	
Male	19
Female	13
Affected side	
Right	15
Left	17
Age, y	35.5 ± 11.4 (22-62)
Follow-up time, mo	26.13 ± 2.59 (22-31)
Duration from injury to arthrolysis, mo	21.22 ± 12.24 (11-62)
Pathogenesis, No	
Radial head fracture	6
Ulnar fracture	1
Humeral fracture	
Distal	14
Distal (lateral epicondyle)	2
Distal with ulnar fracture	1
Medial (medial epicondyle)	2
Olecranon fracture	9
Elbow dislocation	1
Coronoid fracture	1
Initial treatment, No	
ORIF	28
Splint immobilization	4
Open arthrolysis approaches	
Medial and lateral (%)	20 (62.5)
Posterior (%)	12 (37.5)

ORIF, open reduction and internal fixation; *SD*, standard deviation.

Surgical technique

All operations were performed by the same senior surgeon (C.-y.F.). The procedure was conducted under brachial plexus block or general anesthesia, with the patient placed supine. A sterile tourniquet was used to avoid bleeding during the operation. A combination of the lateral and medial approaches was used in 28 operations and a posterior approach in the other 5. All implanted hardware, including plates, cannulated screws, Kirschner wires, and steel cables, were completely removed in all patients.

The techniques were applied as described previously.[27,44,51] At the medial side, the ulnar nerve was released and transposed. Then, posterior capsulotomy and incision of the posterior and transverse bundle of the medial collateral ligament were performed. The olecranon was remolded, posterior osteophytes were resected, and the olecranon fossa was cleared so that no resistance was left to restrict elbow extension. If elbow extension was still more than 10° to 15° (arc of extension <10° was considered to be adequate), the origin of common flexor tendons could be released after we confirmed that antecubital skin and subcutaneous tissues would not be too tightened to achieve another 5° to 10° of extension.

At the lateral side, the extended Kocher approach was performed to achieve further release. Reflection of brachioradialis and extensor carpi radialis longus was necessary to enter the joint. The anterior capsule was released, osteophytes were removed, and the humeroradial joint and contracted ligaments complex were routinely released. Elbow flexion of more than 130° was considered adequate.

The posterior approach was applied for those with posterior midline incision to achieve cosmetic benefits. Then, the soft tissue flats were reflected, and the same procedure was undertaken within joints as in the medial and lateral approach.[16,40,43,55] The anterior bundle of the medial collateral ligament and the lateral collateral ligament complex were repaired. The origin of the common flexor tendons was reattached 0.5 to 1 cm distal to the original site on the humeral condyle by nonabsorbable anchors (Fig. 1). We named this procedure the “flexor tendon advancement.” A hinged external fixator (Orthofix, Verona, Italy) was applied for approximately 1.5 months to provide assistance of postoperative physical therapy and elbow stability.[7,46,55]

Measurement of muscle strength and AOM

Preoperative and postoperative muscle strength was detected in the same way. The HHD was used to measure isometric strength (kg) of elbow flexors and extensors and wrist flexors and extensors. A grip force meter (CAMRY, City of Industry, CA, USA) was used to measure handgrip strength (kg). Andrews et al[1] reported the measurement skill for different muscle groups of the upper extremities, detailing the position of joints and limbs, dynamometer placement, and stabilization of subjects. McGarvey et al[30] studied the timing of isometric strength measurement in 1 day and showed a significant difference among the measurements in the morning, noon, and late afternoon. Therefore, bilateral upper limbs were measured between 9 and 10 AM, which was approximately 1 to 2 hours after

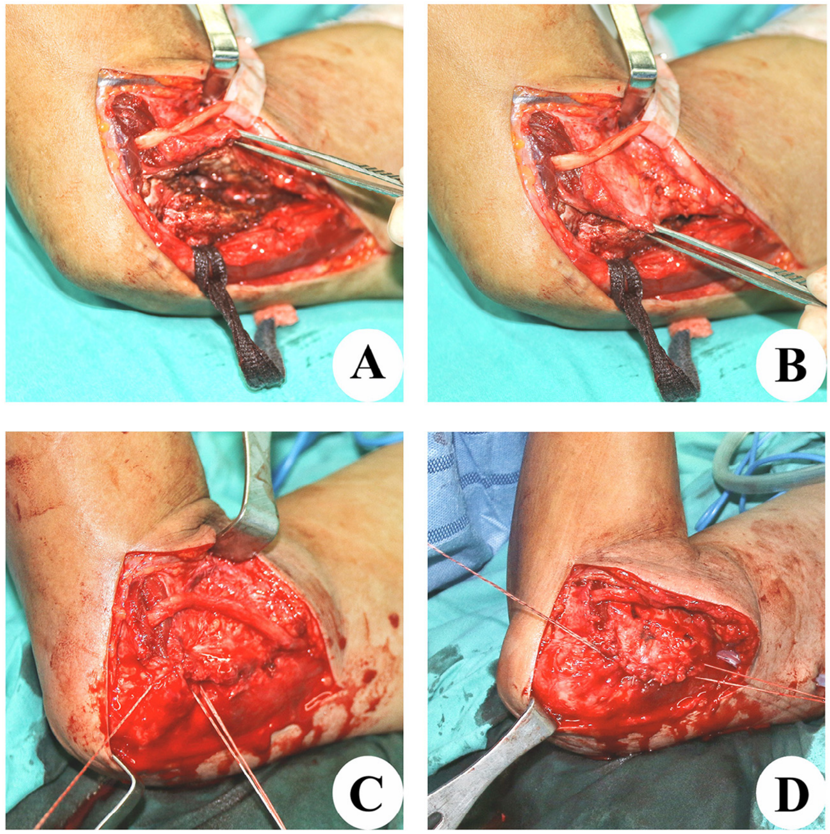

Figure 1 The surgical procedure shows (**A** and **B**) excised insertion of common flexor tendon and (**C** and **D**) reattachment distal to its original site on the medial condyle of the humerus.

1 cycle of standardized morning physical therapy between 7 and 8 AM. Measurement was done twice separately with a 10-minute interval. The isometric strengths of the noninjured side were also measured as a comparison. A handheld goniometer (Tianyu, Beijing, China) was used to measure preoperative and postoperative AOM.

Postoperative management

All patients were included in a standard physical therapy program beginning on postoperative day (POD) 1. During hospitalization (POD 1-14), every patient underwent guided rehabilitation of the elbow and wrist. Passive and active flexion and extension of elbow and wrist were performed daily. Patients were required to do a 60-minute cycle of exercises 3 times a day. Indomethacin (25 mg, 3 times daily) or celecoxib (200 mg, once daily) were prescribed for 4 consecutive weeks after the operation to achieve analgesia and prevent heterotopic ossification.[50] The hinged external fixators were removed at an outpatient office visit 1.5 months after the procedure. Patients were asked to continue the original physical therapy for another successive 4.5 months.

Statistical analysis

Preoperative and postoperative strength and ratio of strength (injured side/noninjured side) were both analyzed by the unpaired *t* test. The preoperative and last follow-up day (LFUD) AOM and Mayo Elbow Performance Scale (MEPS) were compared. A *P* value of .05 was considered statistically significant. All statistical analyses in our study were accomplished with SPSS 19.0 software (IBM, Armonk, NY, USA).

Results

MEPS and AOM

We monitored 32 patients with elbow stiffness for 26.13 ± 2.59 months (range, 22-31 months). At the LFUD, mean AOM increased from 46° to 127° (range, 115°-150°; $P < .001$). The MEPS showed a significant increase from 67.97 preoperatively to 96.86 at the LFUD (range, 85-100; $P < .001$). As for patients' satisfaction, the outcome of elbow function was graded as excellent in 27 patients and good in 5. All patients returned to their original lifestyle at 6 months postoperatively, among whom 28 patients were back to their original professions and 4 were retired.

Isometric muscle strength

The injured side was comparatively weaker than the uninjured side before the operation. Strength of the injured elbow flexors was 0.95 of the uninjured side, elbow extensors was 0.99, wrist flexors was 0.97, wrist extensors was 0.96, and handgrip was 0.95. After the operation, all muscle strengths had a significant loss on POD 1, as shown in Fig. 2. The isometric strength ratio of the elbow flexors decreased to 0.20 ($P < .001$), elbow extensors to 0.28 ($P < .001$), wrist flexors to 0.21 ($P < .001$), wrist extensors to 0.22 ($P < .001$), and handgrip to 0.15 ($P < .001$). After that, strength recovered in a time-dependent manner. Until the LFUD, all strengths recovered to their preoperative baseline level. The isometric strength ratio of the elbow flexors rose to 0.94 ($P = .91$), elbow extensors to 0.95 ($P = .06$), wrist flexors to 0.95 ($P = .25$), wrist extensors to 0.95 ($P = .63$), and handgrip to 0.95 ($P = .98$).

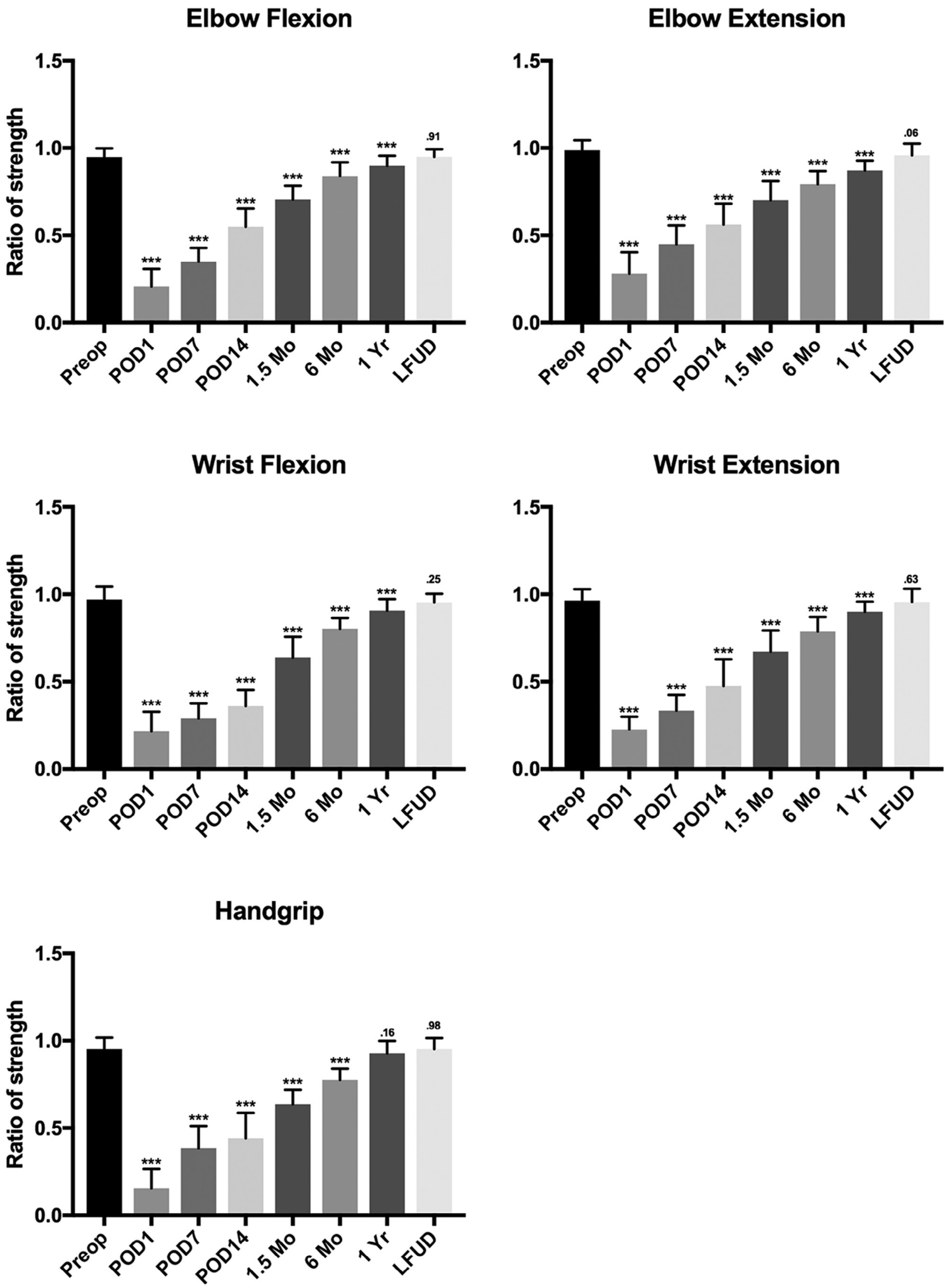

Figure 2 The isometric strength on the injured side was relatively weaker before the operation, approximately 95% to 99% of the uninjured side. When comparing postoperative vs. preoperative ratio of strength, we found significant decline of muscle strength on postoperative day (*POD*) 1 and a gradual recovery pattern afterwards in all muscle groups, and on the last follow-up day (*LFUD*), all muscle strengths recovered to their preoperative level (elbow flexors, $P = .91$; elbow extensors, $P = .06$; wrist flexors, $P = .25$; wrist extensors, $P = .98$; handgrip, $P = .98$). The *range bars* indicate the standard deviation. $^{***}P < .001$.

Differences between the sexes were compared, as shown in Fig. 3. At the preoperative baseline level, men were significantly stronger than women in all muscle strengths ($P < .001$) at the injured side. Isometric strengths in both sexes dropped to the bottom level on POD 1 and gradually recovered in the next follow-up days. The strength ratios between the sexes showed no significant difference at any time point, which indicated strength was gained in proportion to its baseline strength level. Therefore, isometric strength at each time point showed a significant difference between men and women (mostly $P < .001$), except handgrip strength on POD 7. The total gain of strength from POD 1 to the LFUD was more prominent in men than in women, but the general recovery pattern was similar between the sexes. All muscle strengths recovered to their preoperative level at LFUD in men (elbow flexion, $P = .44$; elbow extension, $P = .10$; wrist flexion, $P = .48$; wrist extension, $P = .80$; and handgrip, $P = .49$) and women (elbow flexion, $P = .29$; elbow extension, $P = .38$; wrist flexion, $P = .36$; wrist extension, $P = .64$; and handgrip, $P = .53$).

The effect of dominance on strength recovery was also analyzed, as shown in Fig. 4. All patients in the study were right-handed, and all preoperative muscle strengths and strength ratios showed no significant difference between the dominant (right) and nondominant (left) side. After the operation, isometric strengths of both sides decreased to a minimal level on POD 1, and strengths recovered in the similar pattern at both sides in the next follow-up days. For an unknown reason, the dominant side was significantly stronger at 2 occasions; namely, strength of elbow flexors on POD 14 and that of wrist extensors at 1.5 months. We thought this occurred by chance and was not relevant with the general recovery pattern. Therefore, dominance has no effect on the strength of the upper extremity and does not affect recovery pattern of all muscle groups after open elbow arthrolysis.

Discussion

The study analyzed the postoperative isometric strength recovery after open elbow arthrolysis. In the lateral and medial approach and also the posterior approach, the anterior medial collateral ligament and the lateral collateral ligament complex were excised and repaired and origin of the common flexor tendons was reattached distal to the original site on the humeral condyle. Manipulation of surrounding soft tissues during the operation makes postoperative muscle strength quite a concern. Our analysis of the isometric strength of elbow flexors ($P = .91$) and extensors ($P = .06$), wrist flexors ($P = .25$) and extensors ($P = .63$), and handgrip ($P = .98$) found that the procedure did not lead to a significant loss of strength in a midterm follow-up duration.

Only a few studies have focused on postoperative strength recovery after open elbow arthrolysis. Cikes et al[9] studied the effects of open elbow arthrolysis on post-traumatic elbow stiffness and measured isokinetic strength of elbow flexors and extensors. Data were analyzed by European Society for Shoulder and Elbow Surgery Score (100 points in total), within which strength accounted for 25 points: 15 points for elbow flexors and 10 points for elbow extensors. At the LFUD, strength of both the elbow flexors and extensors recovered well (flexor: 11.6 [range, 4-15; standard deviation {SD}, 3.3] at the injured side and 12.7 [range, 7-15; SD, 2.5] at the uninjured side; extensor: 8.8 [range, 5-10; SD, 8.8] and 9.0 [range, 6-10; SD, 1.3]).

In another study, Yamamoto et al[53] measured strength with manual muscle testing (MMT), with strengths evaluated by 0 to 5 points. In 47 patients with open elbow arthrolysis, strength of elbow flexors of 40 patients were graded MMT 5 (normal) and 7 were graded MMT 4 (good) at the LFUD, which showed a significant progress compared with preoperative status. However, 12 patients had lower MMT points for elbow extensor strength than the preoperative level. Based on our clinical observations, arm and forearm weakness at elbow, wrist, and handgrip were apparent after operations; thus, a mere analysis of strength of elbow flexors and extensors is not complete. To the best of our knowledge, this is the first study to assess isometric strength recovery of upper extremities after open elbow arthrolysis in the English literature.

Profound loss of strength in all muscle groups was found on POD 1. A good explanation for this phenomenon could be failure of voluntary muscle activation, which means reduction of maximal strength output of a muscle caused by an inability to recruit all of the muscle's motor units or to attain the maximal motor discharge rate from the motor units that are recruited.[32,41] Some studies have illustrated that reduction in muscle activation contributes to early postoperative weakness.[20,48] The concept is more widely studied in strength loss of quadriceps after total knee arthroplasty, and only a few studies have reported similar phenomena on the upper extremities.[18] Further research is warranted to illustrate the exact mechanism of abrupt loss of strength after open elbow arthrolysis.

After POD 1, strength of various muscle groups steadily rose in a time-dependent manner, and the most rapid recovery occurred within 1.5 months postoperatively: elbow flexors, from 21% to 70%; elbow extensors, from 28% to 70%; wrist flexors, from 29% to 64%; wrist extensors, from 23% to 67%; and handgrip, from 15% to 64%. Handgrip and wrist flexors and extensors were noted to recover more slowly than elbow flexors and extensors within 1.5 months, which likely resulted from the retraction feeling and pain caused by forearm pin of the external fixator while patients tried to maximally extend/flex wrist.[55] There were 24 patients who complained of discomfort while actively moving their wrists forcefully. Moreover, the similar recovery pattern of all elbow, wrist, and hand strengths also demonstrated that effect of the procedure was general on the upper extremity and nonspecific to any particular muscle group.

Studies have reported that skeletal muscle strength between men and women is different and that men are significantly stronger than women,[19,31] as confirmed by the preoperative baseline strength results presented in our study. Shortly after the procedure, the difference of strength between the sexes was minimal. After that, men had a higher gain of strength than women at each interval of follow-up days, whereas the strength ratio between the sexes remained similar, which indicated that at each follow-up assessment, isometric strength of the injured side was proportional to that of the uninjured side. Therefore, strength recovery of all muscle groups was proportional to the baseline strength level, the general recovery pattern of men and women was similar, and men had a more prominent gain of strength than women in the entire postoperative recovery process. Men have been reported to have more muscle mass (larger fat-free cross-sectional area),[17,19,36] larger muscle fibers,[31] quicker growth of fast-twitch fibers during training,[5,15] and better capability for contraction failure[33] than women but have a similar amount of motor units and similar ability for voluntary muscle activation.[4,54] These natural features may explain the similarity and difference in strength recovery. However, more research is need to find out which is the major underlying mechanism.

Handedness or dominance is classically defined as the preference for one hand in the execution of various unimanual tasks.[10] The classic cutoff "10% rule" says that the dominant side is approximately 10% stronger than the nondominant side.[42] However, more recent studies show variable relationship between dominance and muscular strength. Jocelyn et al[52] studied biceps and forearm supination peak torque in both sides and found that the dominant and nondominant sides had similar peak torque and endurance for supination and flexion.[13,25,29] Matsuoka et al[29] reported strength of forearm supination, pronation, and handgrip of 51 normal individuals and demonstrated a significant difference in pronation and handgrip strength but no significant difference in supination. Therefore, effect of dominance is variable in different muscle groups. Some researches[3,10,11] even contradicted the effect of dominance on strength

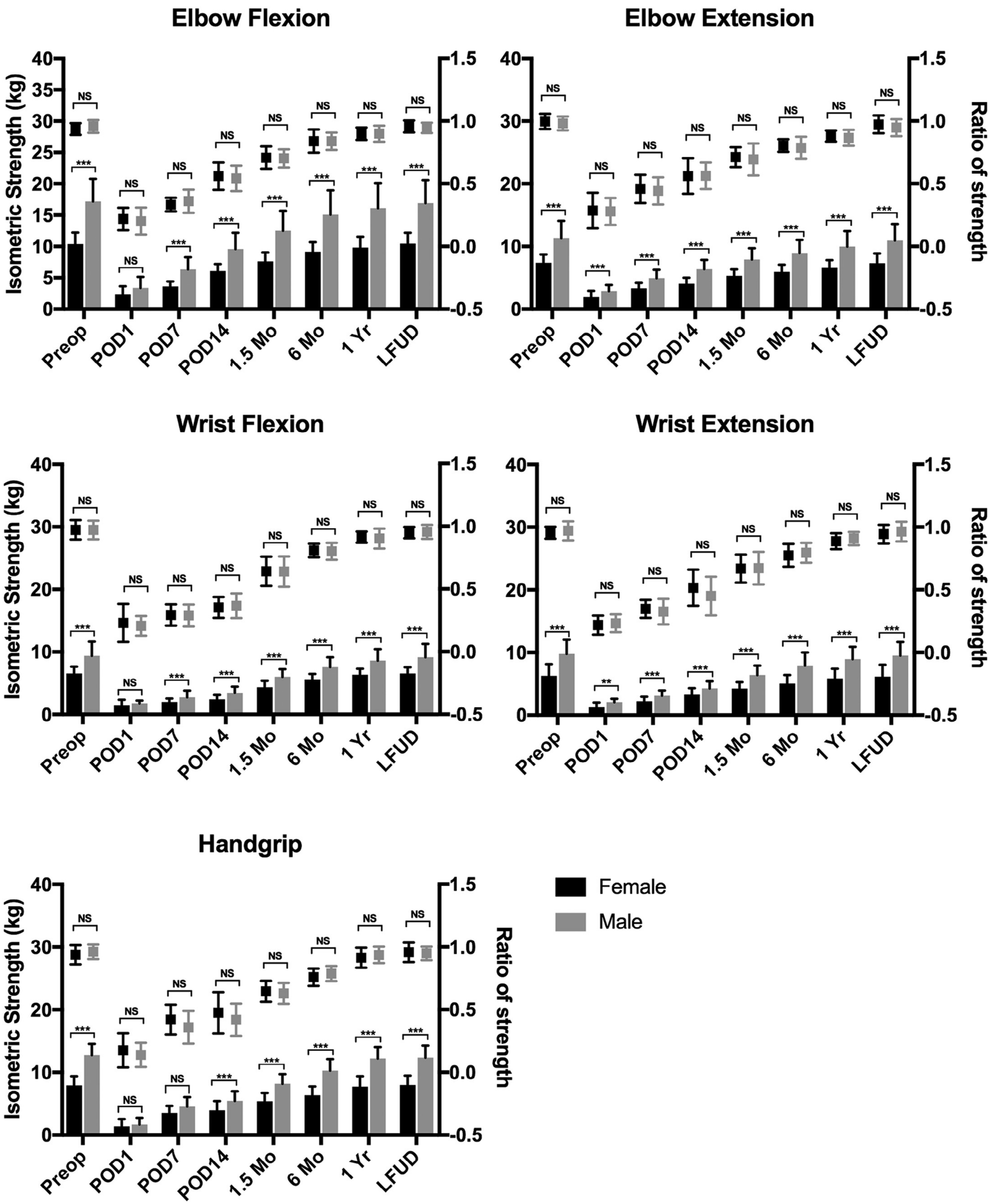

Figure 3 Isometric strength was significantly stronger in men than in women at most follow-up times in all muscle groups; however, the ratio of strength was not significantly different. These demonstrated (1) that the general recovery pattern between the sexes was similar and (2) that isometric strength recovery during follow-up days was proportional to the baseline strength level. Men had a more prominent gain of strength than the women. The *range bars* show the standard deviation. *LFUD*, last follow-up day; *NS*, not significant; *POD*, postoperative day. ***$P < .001$.

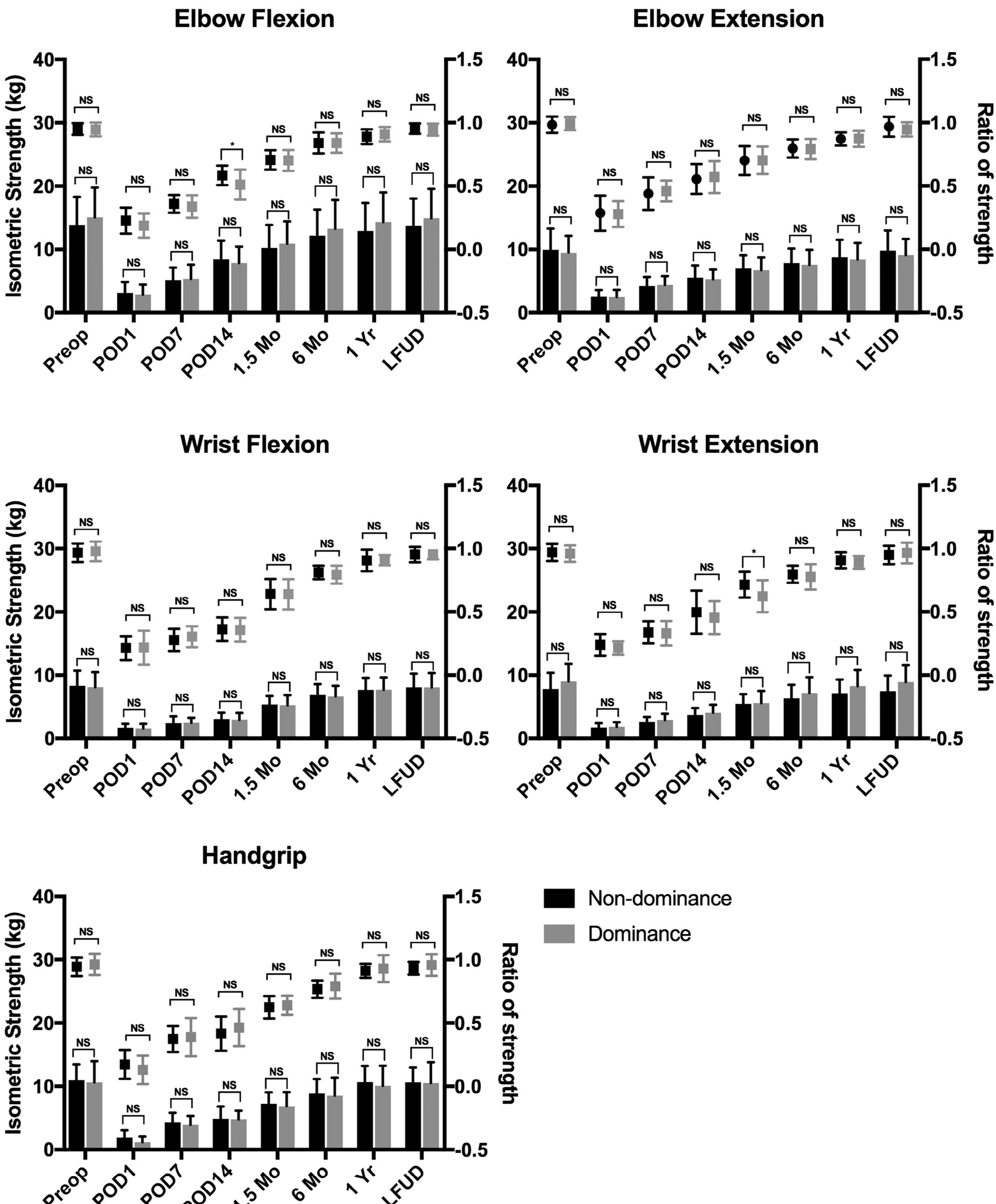

Figure 4 Isometric strength and ratio of strength were both similar between the dominant and non-dominant side. Therefore, dominance was not an impact factor for isometric strength recovery. *LFUD*, last follow-up day; *NS*, not significant; *POD*, postoperative day. The *range bars* show the standard deviation.

recovery. In our study, dominance showed no effect on isometric strength in the preoperative or postoperative duration. The 2 exceptional occasions—elbow flexion at POD 14 and wrist extension at 1.5 months—were considered opportunistic for an unknown reason and not relevant to the general recovery pattern.

Isokinetic dynamometers are capable of providing peak force, angle of maximal force, endurance, and power[26,47] and are widely considered as the gold standard of measuring muscle strength. One weakness of this study is that an isokinetic dynamometer was not available, and we only detected isometric strength by HHD. However, the HHD is also regarded as a reliable and viable instrument for muscle strength assessment,[1,21,24,47] and it also has advantages in portability, convenience, compact size, and cost.

The second weakness is that the portable device could not measure strength of supination or pronation of the forearm. Further studies are expected to give a more comprehensive assessment of postoperative recovery of muscle strengths.

Conclusions

AOM and elbow functions achieved significant enhancement after open elbow arthrolysis. The procedure does not lead to isometric muscular strength decline in a midterm follow-up period, including elbow flexors and extensors, wrist flexors and extensors, and handgrip. Postoperative gain of strength is proportional to the baseline strength level and is more prominent in men than in women. Dominance has no effect on strength and its postoperative recovery.

Disclaimer

This work was supported by the Shanghai Municipal Commission of Health and Family Planning (2013SY043), Health Science Project of Pudong New Area (PW2013D-7), and Science Development Foundation of Pudong New Area (PKJ2013-Y66). The funders had no role in data collection, data analysis, or the preparation of or editing of the manuscript.

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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