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Analysis of hand pressure in different crutch lengths and upper-limb movements during crutched walking

Shahoub Sherif, Syed Hasan, Graham Arnold, Rami Abboud, Weijie Wang *

Institute of Motion Analysis and Research, Department of Orthopaedic and Trauma Surgery, Tayside Orthopaedics and Rehabilitation Technology Centre, Ninewells Hospital and Medical School, University of Dundee, Dundee, DD1 9SY, United Kingdom

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ABSTRACT

Hand pressure in crutch is important as it is directly related to the comfort of the patients using crutches. However, little research has been done on dynamical hand pressure during crutched walking. This study investigated hand pressures and joint movements in the upper limb with the different crutch lengths during crutched walking. Twelve healthy male adults participated in the study, and performed crutch-supported walking at bi-crutch and single-foot way. A specific mat of pressure sensors was designed to measure the hand pressure of the palm and fingers and a motion capture system used to capture the movements at the shoulder and elbow. It was found that when walking speeds were between 0.5 and 1.0 m/s, maximum pressure and force were approximately 120 kPa and 100 N respectively in the hand; the ranges of motion were from 28 to 60 deg at the shoulder and from 15 to 30 deg at the elbow. The results showed that the pressure-time integral and force-time integral in the hand are higher when using a traditional standard crutch length than using longer or shorter lengths. The visual analogue scores of conformable degree showed that the participants are favourite for a traditional standard crutch length. The pressure and kinematic data collected provide a set of database available for crutch manufacturer, glove designer and clinicians as reference when they need.

Relevance to industry: Crutched walking usually causes hand uncomfortable or injury. Our study provides the first experimental data of hand pressures and the joint movements in the upper limbs at different crutch lengths. These results are valuable for devising gloves for patients, thus improving the life quality of the patients using crutch.

1. Introduction

Injuries of the lower extremities following a fall or an accident are very common. Such injuries make walking difficult because the lower limbs cannot bear the body weight properly. Elbow crutches are designed for the ambulation of injured patients allowing weight bearing via the arms and hands until full recovery. The handle position or crutch length and pressure distribution on the hands are directly related to the comfort of the patients using crutches, thus should be investigated.

Walking with different crutch lengths during non-weight bearing, swing-through axillary crutch gait showed no significant effect on the forces exerted on the hand, however while changing gait speed from slow to normal it did have a significant effect (Stallard et al., 1980; Sala et al., 1998; Reisman et al., 1985; Aldien et al., 2005). These gait patterns are a common practice following orthopaedic operations or leg injury, and involve leaning on crutches, extending hips and spine, raising the body free from the ground and swinging forward through the crutches. There is full transfer of body weight to the crutches during the stance phase of the gait cycle (Sala et al., 1998). There has been no published literature studying the relationships among crutch length, hand pressure, upper limb kinematics and walking speeds.

What crutch length is suitable for the patients using crutches? Previous authors have recommended specific criteria for optimal length of crutches during ambulation (Mulley, 1988). They have placed particular emphasis on the effect of energy expenditure and activity intensity during non-weight bearing walking (Mullis and Dent, 2000) or on metabolic intensity by measuring oxygen consumption (Smith and Enright, 1996). However these studies have not investigated the relationship

* Corresponding author.
E-mail address: w.wang@dundee.ac.uk (W. Wang).

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between hand pressure and crutch lengths during crutched walking.

Previous studies have reported different hand forces and pressures in different situations, e.g. hand forces in griping cylindrical handles (Aldien et al., 2005), max griping strengths (Rossi et al., 2012), and male griping strength (Seo et al., 2007); also the pressures in handgrip measurements (Ugurlu and Ozdogan, 2011) and in falling down (Choi and Robinovitch, 2011). Aldien et al. (2005) observed a high peak pressure in the thenar area following an application of high grip and push force on a large diameter cylindrical handle, or low grip and high push force on a smaller diameter handle. Sala et al. (1998) reported that palmar load distributions for cylindrical and wide elbow crutch handle design were similar during ambulation through modified three-point partial weight-bearing gait pattern. Nicholas et al. (2012) measured the static pressures of the hand grasping cylinders. Recently, Kabra et al. (2015) measured hand pressure during wheelchair propelling, and Medola et al. (2014) used a glove instrumented system with ten force sensors to assess how different handrim designs influence the force distribution on hands. However, there was little research directly measuring hand pressures on the crutch handle during walking and associated with upper limb movements.

Therefore, this study aimed to investigate the effect of different crutch heights on hand pressure and on the movement of shoulder and elbow joints during single leg and bi-crutch supported gait. The particular objectives were to measure hand pressure at different crutch heights, and collected and analysed the movements of the shoulder and elbow joints during crutch-supported walking. Hopefully, the data measured would benefit manufactures of crutch, designers of glove, and clinicians who guide patients using crutches, ultimately to improve the quality of patient comfort during ambulation.

2. Methods

2.1. Participants

Twelve healthy male subjects participated in the study. Their ages were between 22 and 45 years (mean: 35.2 years, standard deviation [S.D.] 7.7) with a mean height of 175.6 cm (S.D. 7.6) and a mean weight of 77.6 kg (S.D. 9.8). Subjects had no previous injuries, dysfunction or surgeries to the upper limbs and hands. The study was approved by the university research ethics committee. All subjects signed the consent forms prior to data collection.

2.2. Crutch length

The standard elbow crutch was selected in this study. This crutch is adjustable, light-weight, and is commonly used in clinical practice. The crutch height was measured according to Mulley's guidelines (Mulley, 1988) which suggest that both the distance from the floor to the handle and from the floor to the ulnar styloid should be equal with elbow joint in 15° of flexion. In this study, this crutch height was defined as the standard length; 5 cm higher being defined as long length and 5 cm lower as short length. All subjects were instructed on how to walk with single supported leg on bi-crutch, and were allowed to practice several times before recording data.

2.3. Equipment

The main apparatus used for data collection was the Vicon® motion capture system with 12 high resolution digital cameras covering a 25 m walkway. The Novel Pliance® matrix sensors were specifically designed to measure hand pressure distribution and contact forces while gripping a cylinder during walking. The individual sensor elements were elastic and arranged in a matrix which conformed to three-dimensional shapes. The matrix typed S2022-44 was calibrated on a cylinder of 28 mm diameter up to 400 kPa then connected to the Pliance® X32 analyser via the CX2032 cable as shown in Fig. 1. The calibration procedure is given in Appendix.

2.4. The model to calculate joint angles

A model was developed in-house to calculate the joint angles in the shoulder and elbow. This model employed a set of reflective markers attached over bony landmark on the body to construct three segments, the trunk, arm and forearm.

These marker placements were:

- the acromioclavicular joint
- the manubrium sterni
- the xiphisternum
- the seventh cervical and tenth thoracic vertebrae
- the contralateral acromioclvicular joint
- the greater tuberosity of the humerus
- the medial and the lateral epicondyle of the humerus
- the radial and the ulnar styloid processes

Each foot had two makers applied, one over the 5th metatarsal shaft and the other on the posterior aspect of the heel. Two more markers were used for each crutch, one at the upper end close to handgrip. These markers enabled us to calculate joint angles at the shoulder and elbow and also to analyse walking parameters such as speed, cadence and phase proportion (Fig. 2). A similar model was used and validated in several studies (Kolwadkar et al., 2011; Kabra et al., 2015; Jafri et al., 2015). This model has been modified by adding a couple of markers on the trunk and thus worked more reliably than previous ones during movement.

2.5. Data collection

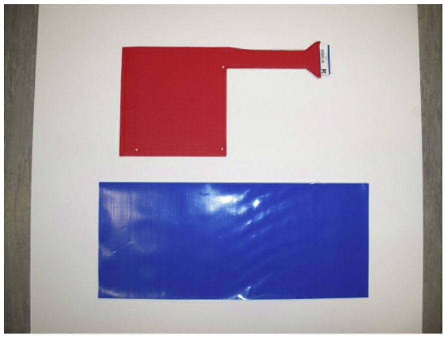
Firstly, the Vicon® motion capture system was calibrated statically and dynamically by using the Vicon® standard calibration frame. Then subjects stood still while all markers on the body were captured in order to calculate the joint angles for subject standing situations. Then, the dynamic trial was carried out by requesting the subject to walk with single supported leg and bi-crutch within the motion capture area. Each subject was required to walk under the three different crutch lengths, standard, long and short, in a randomised order. Each subject walked six trials for each crutch length, and from these, three respective trials were analysed.

2.6. Stance and swing phases

Stance phase was defined as the period when the crutches made contact with the ground. Swing phase was defined as the period when the crutches had no contact with the ground. A cycle of crutch walking was defined from an initial strike of the crutch on the ground to the next initial strike. Only one cycle on the centre area of walking way was analysed as the speed there was more stable than beginning and finishing phases.

2.7. Visual analogue score (VAS)

After the subjects had walked with three different crutch lengths, they were asked to complete a 10 point scoring scale for

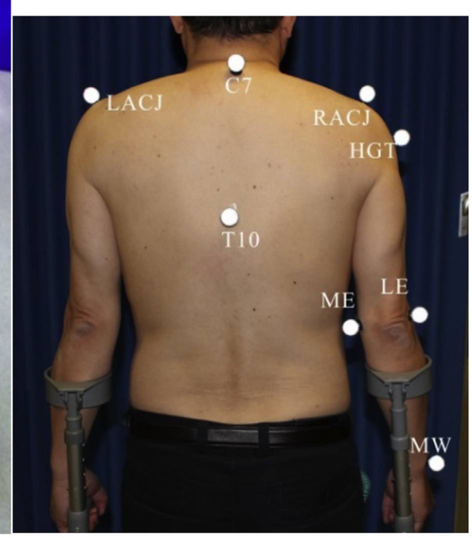


(A)

(B)

Fig. 1. Novel Pliance® Matrix sensors wrapped around the crutch handle. (A) Before wrapped and (B) after wrapped.

(A)



(B)

Fig. 2. Reflective markers on subject body and pressure mat on the handle. (A) RACJ & LACJ – right and left acromioclavicular joints; HGT – humerus greater tuberosity; STE-manubrium sterni; XI – xiphisternum; LW&MW – the radial and the ulnar styloid processes; (B) C7&T10 – the seventh cervical and tenth thoracic vertebrae; ME&LE – the medial and lateral epicondyle of humerus. Modelled segments: trunk (ACJs, STE, XI, C7&T10), humerus (HGT, LE&ME), arm (ME, LE, LW&MW). The pressure matrix typed S2022-44 was connected to the Novel Pliance® X32 analyser via a CX2032 cable.

comfort evaluation, with 0 meaning the discomfort and 10 the most comfort.

2.8. Data analysis

The hand surface was divided into five regions: total, mid-palm, thenar, thumb, and fingers. By using Novel® software, the contact area (cm^2), maximum force (N), peak pressure (kPa), maximum mean pressure (kPa), contact time (ms), pressure-time integrals (kPa·s), and force-time integrals (N·s) were recorded and calculated from all trials. All data obtained were statistically compared using SPSS® (v. 21) software. General Linear Model for repeated measures, signed ranks test and paired t-test were used to compare hand pressures and kinematical data in terms of crutch length. The $p < 0.05$ (*) or $p < 0.01$ (**) were considered as significant levels in the comparisons.

3. Results

3.1. Hand pressure

The parameters on hand pressure were obtained from multi-step in multi-trial from each subject. Table 1 includes maximum force and peak pressure at different regions of hand.

Table 2 shows maximum mean pressure and mean force at different regions of hand.

Table 3 highlights the pressure-time integral and force-time integral at different regions of hand. Table 4 reports the contact area and contact time at different regions of hand.

3.2. Kinematics

The ranges of joint angles at the shoulder and elbow are reported in Table 5. The information on phase proportions is shown in Table 6. The joint movements are shown in Fig. 3.

The cadences (steps/min) for short, standard and long length of crutch walking were mean 41.4 (S.D.7.6), 40.6 (8.2) and 41.9 (7.1) respectively, with no significant differences ($p = 0.662$). The speeds (m/s) for short, standard and long length of crutched walking were 0.76 (0.23), 0.69 (0.23) and 0.83 (0.25) respectively, with significant difference between the long and short crutch walking ($p = 0.04$).

3.3. Subjective scores

The VAS were 7.31 (1.2) for the standard length of crutch, 6.06 (1.73) for the short and 5.37 (2.16) for the long, with significant differences between the standard crutch walking and the long and short crutched walking ($p < 0.05$).

4. Discussion

4.1. Hand pressure

Statistical analysis showed that most of the parameters, including contact area, maximum force, peak pressure and maximum mean pressure, showed no significant differences between three crutch heights. This indicated that crutched walking requires necessary hand pressures and forces to drive the body forward, similar to the opinions in previous studies (Reisman et al., 1985; Aldien et al., 2005). In this study, it was found that the pressure-time and force-time integrals were higher in the standard crutched walking than in the long or short ones (Table 3), and main reason is that the contact time increase in the standard-crutch walking when compared to the other two (Table 4).

Why did the standard crutch length demand a longer contact time? As the cadences in the three crutch lengths' walking and walking speeds were similar (Table 5), the duration of a walking cycle should be similar. The ratio of the stance to swing phases may have affected the contact time. In the standard length crutch walking, the stance phase took a relatively small proportion in a cycle as compared with the long and short crutch walking (Table 6). In other words, a longer swing phase might require the hands to be more involving in handling the crutches.

Alternatively, the stance phase was directly related to the force exerted by the upper limbs. Thus, a relatively short proportion of the stance phase may allow the upper limbs some rest. Therefore, the ratio of the stance to swing phases in the standard crutch walking should be better than other length crutched walking (Table 6). This point was mirrored by the subjective feelings where

Table 1
The measured maximum force and peak pressure in different hand areas ($n = 12$ with 88 repeated trials).

Variable	Crutch length	Mean	Std. Error	95% Confidence interval	
				Lower bound	Upper bound
Total maximum force (N)	Short	96.1	3.5	89.0	103.1
	Standard	107.9	105.4	5.1	95.2
	Long	93.3	3.2	86.9	99.6
MID-PALM	Short	29.4	1.7	25.9	32.8
Max force (N)	Standard	34.4*	2.5	29.5	39.3
	Long	27.4*	1.5	24.4	30.4
THENAR	Short	30.4	0.6	29.1	31.6
Max force (N)	Standard	29.8	0.5	28.9	30.7
	Long	30.8	0.5	29.9	31.7
THUMB	Short	10.5*	0.3	10.0	11.1
Max force (N)	Standard	11.8	0.5	10.9	12.7
	Long	12.6	0.5	11.7	13.5
FINGERS	Short	39.8	1.7	36.3	43.2
Max force (N)	Standard	44.0*	2.5	39.0	49.0
	Long	36.9*	1.6	33.7	40.1
Total peak pressure (kPa)	Short	98.7	4.8	89.1	108.3
	Standard	109.9**	5.1	99.7	120.0
	Long	87.4**	6.1	75.1	99.6
MID-PALM	Short	84.0	5.1	73.8	94.2
Peak pressure (kPa)	Standard	94.8*	5.2	84.4	105.1
	Long	71.8*	6.4	59.0	84.6
THENAR	Short	75.8	1.0	73.8	77.8
Peak pressure (kPa)	Standard	77.9	0.8	76.3	79.6
	Long	77.5	0.8	75.9	79.1
THUMB	Short	45.4	1.5	42.4	48.4
Peak pressure (kPa)	Standard	45.6	2.0	41.6	49.5
	Long	45.1	1.4	42.3	48.0
FINGERS	Short	85.5	5.1	75.3	95.8
Peak pressure (kPa)	Standard	98.2*	5.3	87.6	108.8
	Long	75.8*	6.4	63.0	88.6

Note: *$p < 0.05$ and **$p < 0.01$. If a mean has a */**, it means that this mean is significantly different from other two ones. If two means have */**, it means that the two means are significantly different from each other.

Table 2
The measured max-mean pressure and mean force in different hand areas (n = 12 with 88 repeated trials).

Variable	Crutch length	Mean	Std. Error	95% Confidence interval	
				Lower bound	Upper bound
Total maximum mean pressure (kPa)	Short	41.5	0.7	40.0	42.9
	Standard	42.8	1.5	39.7	45.9
	Long	43.0	0.6	41.8	44.2
MID-PALM	Short	28.3	0.7	27.0	29.6
Mean pressure (kPa)	Standard	31.6	1.6	28.4	34.8
	Long	29.2	0.6	27.9	30.4
THENAR	Short	40.8	0.8	39.3	42.3
Mean pressure (kPa)	Standard	40.5	0.6	39.4	41.6
	Long	41.7	0.6	40.5	43.0
THUMB	Short	18.2*	0.7	16.7	19.6
Mean pressure (kPa)	Standard	19.6	1.0	17.6	21.6
	Long	20.5*	0.9	18.7	22.3
FINGERS	Short	29.6	0.5	28.6	30.7
Mean pressure (kPa)	Standard	32.7	1.8	29.2	36.2
	Long	32.5	0.7	31.1	33.8
Total mean force (N)	Short	59.6**	1.3	57.1	62.2
	Standard	63.3	1.6	60.1	66.6
	Long	64.9**	0.9	63.2	66.8
MID-PALM	Short	12.7**	0.2	12.2	13.2
Mean force (N)	Standard	14.0	0.7	12.6	15.3
	Long	14.0**	0.3	13.5	14.6
THENAR	Short	19.6	0.5	18.6	20.7
Mean force (N)	Standard	19.4*	0.4	18.7	20.1
	Long	20.5*	0.3	19.8	21.1
THUMB	Short	5.8**	0.2	5.4	6.1
Mean force (N)	Standard	6.9	0.4	6.2	7.6
	Long	7.4	0.3	6.8	8.1
FINGERS	Short	21.4*	0.5	20.3	22.4
Mean force (N)	Standard	22.8	0.8	21.2	24.4
	Long	22.9*	0.4	22.1	23.6

Note: $*p < 0.05$ and $**p < 0.01$. If a mean has a */**, it means that this mean is significantly different from other two ones. If two means have */**, it means that the two means are significantly different from each other.

Table 3
The measured pressure-time integral and force-time integral (n = 12 with 88 repeated trials).

Variable	Crutch length	Mean	Std. Error	95% Confidence interval	
				Lower bound	Upper bound
Total pressure-time integrals (kPa·s)	Short	580.8	15.9	549.0	612.6
	Standard	678.4**	19.4	639.8	717.1
	Long	559.8	9.7	540.5	579.0
MID-PALM	Short	418.1	11.0	396.2	440.1
PTI (kPa·s)	Standard	492.7**	18.7	455.5	529.9
	Long	394.2	8.2	377.7	410.6
THENAR	Short	543.7	15.9	512.0	575.5
PTI (kPa·s)	Standard	619.7**	12.4	595.1	644.4
	Long	526.0	9.5	507.1	544.8
THUMB	Short	276.0	11.3	253.4	298.7
PTI (kPa·s)	Standard	322.3**	15.2	292.0	352.6
	Long	264.6	11.3	242.1	287.1
FINGERS	Short	422.6	11.2	400.2	445.0
PTI (kPa·s)	Standard	506.6**	19.8	467.2	545.9
	Long	411.8	8.0	395.8	427.8
Total force-time integrals (N·s)	Short	661.8	22.5	617.0	706.6
	Standard	753.5**	20.3	713.0	794.0
	Long	645.5	14.3	616.9	674.1
MID-PALM	Short	140.6	4.7	131.2	150.0
FTI (N·s)	Standard	167.1**	7.2	152.8	181.5
	Long	139.7	3.8	132.0	147.4
THENAR	Short	214.5	8.1	198.5	230.6
FTI (N·s)	Standard	229.0**	6.1	216.8	241.2
	Long	203.0**	4.6	193.9	212.2
THUMB	Short	67.5	2.8	61.9	73.2
FTI (N·s)	Standard	86.16**	4.4	77.5	94.8
	Long	73.5	3.4	66.7	80.2
FINGERS	Short	237.3	8.7	220.0	254.6
FTI (N·s)	Standard	269.1**	8.7	251.8	286.5
	Long	227.6	5.9	215.7	239.4

Note: $*p < 0.05$ and $**p < 0.01$. If a mean has a */**, it means that this mean is significantly different from other two ones. If two means have */**, it means that the two means are significantly different from each other. PTI: pressure-time integral and FTI: force-time integral.

Table 4
The measured contact area and contact time at different areas of hand ($n = 12$ with 88 repeated trials).

	Crutch length	Mean	Std. error
Total contact area (cm^2)	Short	74.3	1.1
	Standard	74.4	1.1
	Long	76.0	1.0
MID-PALM Contact area (cm^2)	Short	22.8	0.4
	Standard	22.5	0.5
	Long	23.1	0.4
THENAR Contact area (cm^2)	Short	20.3	0.3
	Standard	19.8*	0.3
	Long	20.7*	0.3
THUMB Contact area (cm^2)	Short	6.3*	0.2
	Standard	7.0	0.3
	Long	7.0	0.2
FINGERS Contact area (cm^2)	Short	24.6	0.3
	Standard	24.8	0.3
	Long	24.9	0.3
Contact time total (ms)	Short	10958.3**	267.5
	Standard	11822.0**	239.0
	Long	9906.8**	167.9
MID-PALM Contact time (ms)	Short	10953.8**	267.3
	Standard	11821.4**	239.0
	Long	9906.8*	167.9
THENAR Contact time (ms)	Short	10956.0**	267.4
	Standard	11822.0**	239.0
	Long	9907.0**	167.9
THUMB Contact time (ms)	Short	8748.9	357.3
	Standard	9517.3**	421.5
	Long	7857.0**	340.1
FINGERS Contact time (ms)	Short	10914.7**	255.7
	Standard	11822.0**	239.0
	Long	9901.2**	167.7

Note: *$p < 0.05$ and **$p < 0.01$. If a mean has a */**, it means that this mean is significantly different from other two ones. If two means have */**, it means that the two means are significantly different from each other.

Table 6
The ratio of the stance and swing phases in different crutched walking ($n = 12$).

Crutch length	Parameter	Mean	Std. Deviation	p (Sign test)
Short	Stance percentage	53.1%	3.7%	0.007**
	Swing percentage	46.9%	3.7%	
Standard	Stance percentage	51.8%	5.4%	0.302
	Swing percentage	48.2%	5.4%	
Long	Stance percentage	53.8%	5.3%	0.007**
	Swing percentage	46.2%	5.3%	

**$p < 0.01$.

the VAS in the standard length was higher than the other two lengths, indicating that standard length crutch made crutch walking more comfortable than the other two crutch lengths. From this study, it indicates that a higher pressure-time or force-time integral in standard crutch length is good for people using crutch. It is unlikely that this higher integral expose the users to a risk of hand injury in long term injury, because the mean pressures and forces in the hand are not significantly increased (Table 2) when using the standard length.

Previous studies have reported different hand pressures/forces in various situations, e.g. 25–75 N and 45–198 kPa in griping cylindrical handles (Aldien et al., 2005), 800–900 N in max griping strengths (Rossi et al., 2012), 400 N in male griping strength (Seo et al., 2007), 33–50 kPa in handgrip measurements (Ugurlu and Ozdogan, 2011), 600–300 kPa in falling down (Choi and Robinovitch, 2011), averaged force 36 N (Medola et al., 2014) and 200 kPa in wheelchair pushing (Kabra et al., 2015). Though the situations researched are different from ours, the peak pressure (approximately max 132 kPa) from our study are similar to the previous reported in griping situations (Aldien et al., 2005) but the max forces (approximately 120 N) in our study are larger than the previous.

Table 5
The angle means and angular range means of joint angles ($n = 12$).

Parameter	Crutch Type	Mean	Std. error	95% Confidence interval for mean	
				Lower bound	Upper bound
Speed (m/s)	Long	0.83	0.07	0.66	0.99
	Standard	0.69	0.06	0.55	0.83
	Short	0.76	0.06	0.61	0.90
Elbow angle range	Long	23.49	2.75	17.44	29.55
	Standard	20.64	1.99	16.26	25.01
	Short	20.30	1.94	16.03	24.58
Shoulder flex/ext range	Long	38.87	3.14	31.97	45.77
	Standard	46.32	4.82	35.71	56.93
	Short	39.19	5.07	28.02	50.36
Shoulder adduction/abduction	Long	23.25	2.99	16.67	29.84
	Standard	18.95	1.08	16.57	21.32
	Short	17.13	2.20	12.28	21.98
Shoulder rotation range	Long	30.01	4.15	20.88	39.14
	Standard	26.26	4.16	17.10	35.43
	Short	22.19	2.85	15.93	28.46
Elbow flexion mean	Long	62.15**	2.96	55.63	68.68
	Standard	58.29	2.63	52.50	64.08
	Short	55.30	2.25	50.35	60.25
Shoulder flex/ext mean	Long	−22.87**	5.02	−33.91	−11.82
	Standard	−5.60	4.35	−15.17	3.98
	Short	3.05	5.21	−8.42	14.53
Shoulder add/abd mean	Long	−20.01	2.78	−26.13	−13.89
	Standard	−22.24	3.18	−29.25	−15.23
	Short	−22.94	2.61	−28.68	−17.19
Shoulder rotation mean	Long	35.45**	4.17	26.26	44.63
	Standard	26.17	2.93	19.73	32.61
	Short	22.66	2.32	17.55	27.77

Note: **$p < 0.01$ means that this mean is significantly different from other two ones.

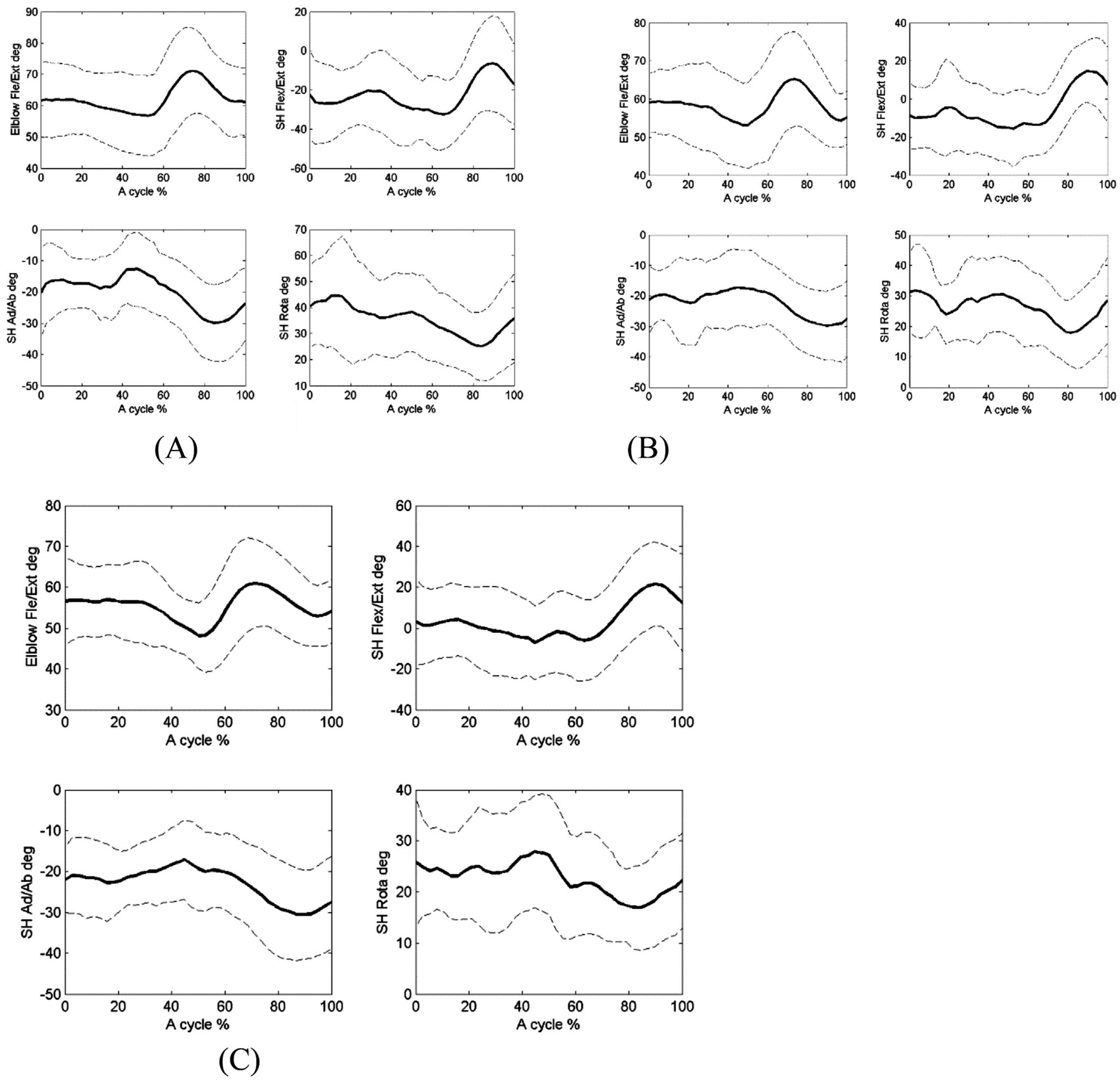


Fig. 3. Joint angle dynamic changes during a cycle of crutched walking with (A) longer, (B) standard and (C) shorter lengths of crutch. A cycle starts at the position where the crutch initially contacts on the ground, and finishes at the next crutch initial contacting. Note: the angles include the elbow flexion, shoulder-flexion/extension, shoulder adduction/abduction and shoulder rotation. Solid lines are means and dashed lines are ±standard deviation.

From the results, it was found that the fingers and mid-palm have higher pressures and forces than other areas, which indicates that the mid-palm plays an important role in stance phases while the fingers play an important role in swing phase. Ergonomically, the two areas should be paid more attention in the design of glove and use of protective material.

4.2. Movement of shoulder and elbow joints

Although most joint angle ranges at the shoulder and elbow were similar, the long length crutch showed larger joint angles than the standard and short lengths (Table 5). In crutch walking, a larger angle at the shoulder and elbow may cause discomfort while the short crutch walking led longer stance phase contact than the standard crutch (Table 6). This could be a reason why subjects favoured the standard length.

4.3. Shortcomings

We realised that using male healthy subject is a shortcoming due to placing reflective markers on female body being not convenient. In the future studies, female subjects and patients using crutch should be considered as they may have different response to the crutched walking from the healthy male adults.

4.4. Significance

To the best of our knowledge, this study is unique and the first to measure hand pressure and analyse associated upper limb joint motion with different crutch lengths. The data presented will be useful not only for the manufactures of crutch and designers of gloves, e.g. which area in the gloves should be strengthen, but also for clinicians who provide guides to patients using crutch, which potentially improve patient quality of life.

5. Conclusions

This study reported detailed pressure parameters on the hand and joint movements at the shoulder and elbow during walking with different crutch lengths. It was found that hand peak pressure reaches approximately 120 kPa, the max forces are as high as 100 N, and the elbow and shoulder flexion/extension ranges of motion are as large as approximately 30° and 60°. It was also found that the participants are favourite for standard crutch length although pressure-time integral and force-time integral are higher in standard length than other two lengths. The data reported could help manufactures of crutch and glove as reference when they design crutch and gloves and also help clinicians in guide to the patients using crutches.

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Appendix

The calibration was performed at the factory by the manufacturer, the researchers only performed a ‘zero’ reading at the start of each trial. The calibration was performed in a pressure chamber with the sensor wrapped around a solid bar of the correct diameter (in this case 28 mm). The calibrated pressure was applied in 10 stages: 20, 50, 75, 100, 150, 200, 250, 300, 350 and 400 kPa and the readings for each cell at each calibrated pressure were stored in a calibration file. Minor variations were seen from cell to cell as can be seen in the calibration graphs in Fig. A.1, but since each cell has its own calibration data this difference does not affect the result data. There was no dynamic calibration performed.

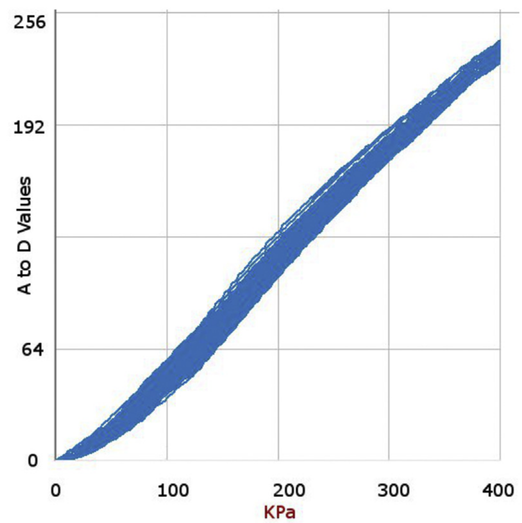

Figure A.1

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