



Original Article

## Clinical method to assess shoulder strength related to front crawl swimming power in male collegiate swimmers

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**Abstract.** [Purpose] Although a correlation has been reported between shoulder strength and maximum swimming power during arm-only swimming, the correlation between shoulder strength and maximum swimming power during front crawl swimming remains unclear. This study aimed to confirm the validity of a clinical assessment method for shoulder strength related to front crawl swimming power. [Participants and Methods] Study participants included 9 healthy male collegiate swimmers. Shoulder strength, including extension and internal rotation torque and swimming power, were measured. [Results] Maximum swimming power was significantly correlated with extension torque in the position of maximum shoulder abduction on the dominant side ( $r=0.844$ ). No significant correlations were observed between the swimming velocity-to-swimming power ratio and the rate of bilateral differences in extension torque in the position of maximum shoulder abduction. [Conclusion] The extensor strength in the position of maximum shoulder abduction was significantly correlated with the maximum swimming power, suggesting that this assessment method is useful for front crawl swimmers. Notably, measurements on the dominant side may provide useful data that are essential in training to improve front crawl swimming propulsion.

**Key words:** Correlation, Validity, Extensor strength

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### INTRODUCTION

The front crawl stroke consists of an arm pull and leg kick. In particular, arm-only swimming is used for swim training and rehabilitation to improve propulsion<sup>1-3)</sup>. The shoulder joint is one of the most important joints used during arm pull. We investigated the relationship between arm-only swimming and shoulder strength and found that maximum swimming power (MSP) was significantly associated with internal rotator strength in the position of abducted and external rotation ( $r=0.85$ ;  $p<0.001$ )<sup>4)</sup>. Additionally, we reported that the swimming velocity-to-swimming power ratio (SVPR) was significantly correlated to the rate of bilateral difference in the shoulder extensor strength in the position of maximum shoulder abduction ( $r=-0.728$ ;  $p=0.006$ )<sup>4)</sup>. Although the link between shoulder strength and MSP in arm-only swimming has been investigated, the correlation between shoulder strength and MSP during front crawl swimming is still unclear.

Swimming power is important to improve swimming velocity; therefore, studies have shown that swimming power and swimming velocity are significantly positively correlated<sup>5-7)</sup>. Similarly, shoulder strength is important for improving MSP because muscular strength and technique are necessary for propulsion. However, because differences in the trajectory of the arm during front crawl swimming and arm-only swimming have been reported<sup>8)</sup>, there is a possibility that the relation-

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ship between shoulder strength and MSP may be different between front crawl swimming and arm-only swimming. Thus, to determine appropriate muscular strength measurement methods for swimming athletes' rehabilitation and training, it is necessary to conduct research regarding front crawl swimming and arm-only swimming.

It would be beneficial to determine the relationship between muscle strength and MSP and SVPR during front crawl swimming is important for understanding how to improve training and rehabilitation. The purpose of this study was to confirm the validity of a clinical method used to assess shoulder strength related to front crawl swimming power.

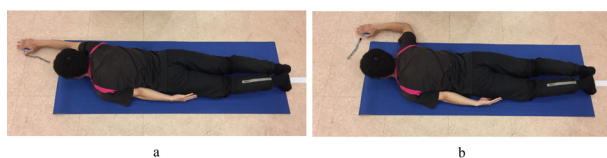
## PARTICIPANTS AND METHODS

This study was approved by the Research Ethics Committee of Kyushu Kyoritsu University (approval no. 2017-11). Nine healthy male collegiate front crawl swimmers participated in this study (age,  $19.2 \pm 1.2$  years; body weight,  $64.7 \pm 9.3$  kg; height,  $169.4 \pm 6.8$  cm; all values expressed as mean  $\pm$  standard deviation [SD]). Participants had no shoulder pain or shoulder surgery during the past 6 months. They received an oral and written explanation of the study and provided informed consent. Experienced examiners performed muscle strength and swimming power measurements.

Swimming power was measured after muscle strength measurements. The maximum isometric force was measured using a hand-held dynamometer (HHD) (Mobie MM100C; Minato Medical Science Co., Ltd., Japan), and extremity length, using a digital calliper (D-500; Niigata seiki Co., Ltd., Japan). Maximum isometric force and extremity length were used to calculate torque<sup>4</sup>). Extension force in the position of maximum shoulder abduction and internal rotation force in the position of abducted and external rotation were also measured. The measurement position of the extension force was maximum shoulder abduction with the elbow extended and the forearm in neutral<sup>9</sup>) (Fig. 1). For the extension force measurements, participants stayed in a prone position with their toes, abdomen, chest, and mentum in contact with the floor. The measurement positions used to determine the internal rotation force were 90 degrees of abduction and 90 degrees of external rotation, with the elbows in 90 degrees flexion and the forearms in the neutral position<sup>9</sup>) (Fig. 1). For the internal rotation force measurements, participants stayed in a prone position with their toes, abdomen, chest, elbow of on the measurement side, and mentum in contact with the floor. The opposite upper extremity made contact with the body. The HHD was placed on a floor and touched the heads of the metacarpal bones on the palmar side during both measurements. Participants performed a 3-second maximum isometric contraction 3 times per session with more than 5 minutes of rest between sessions. The examiner verified the measurements, which were repeated if the position changed or an error occurred<sup>9</sup>). The average of 3 repetitions was calculated. Upper extremity length was defined as the distance from the acromion to the distal head of the third metacarpal bone on the dorsal side<sup>4</sup>). The forearm length was defined as the distance from the lateral joint line of the elbow to the distal head of the third metacarpal bone on the dorsal side<sup>4</sup>). The extension torque (ET) was calculated from the upper extremity length and the extension force. The internal rotation torque (IT) was calculated from the forearm length and the internal rotation force. The rate of bilateral difference, defined as the bilateral difference between the dominant and non-dominant sides, was calculated using the equation  $[\text{absolute (difference of both sides)} / \text{mean of both sides} \times 100]$ <sup>4</sup>). The rate of bilateral differences in ET (RBET) and the rate of bilateral differences in IT (RBIT) were calculated.

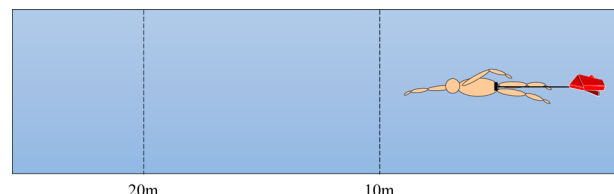
Swimming power was measured four times during swimming in a 25-m indoor pool. Front crawl swimming was performed 25 m once and 15 m three times using a simple swimming power device (drag boat)<sup>7</sup>) (Fig. 2). The 15-m swim was performed from the 5- to 20-m point. Swimming velocity was defined as the average velocity of 10 m and calculated using transit time of the head in 10 m (from the 10- to 20-m point). The maximum swimming velocity (MSV) was defined as the swimming velocity during the 25-m swim. Swimming performances were captured using a moving image recorded by a digital video camera (HDR-CX270V; Sony Marketing Inc., Japan) (at 60 fps) poolside. Swimming velocity and the towing force of the 15-m swim were measured using the drag boat at three load levels<sup>4</sup>).

The regression equation (towing force = regression coefficient  $\times$  swimming velocity + regression constant) was used to



**Fig. 1.** Measurements of shoulder muscle strength using a hand-held dynamometer.

- a: The extension force in the maximum shoulder abducted position.
- b: The internal rotation force in the abducted and external rotated position.



**Fig. 2.** The swimming power measurement using the drag boat. The swimming velocity was defined as the average velocity of 10 m and was calculated using transit time of the head in 10 m (from the 10-m point to the 20-m point). The swimming velocity and the towing force of the 15-m swim were measured using the drag boat for three load levels. The swimming power was calculated using the swimming velocity and the towing force.

calculate the regression coefficient and the regression constant. Swimming velocity and towing force values were obtained during front crawl swimming when pulling the drag boat with three different load levels and during normal front crawl swimming. Swimming power was calculated using swimming velocity and towing force (swimming power = towing force × swimming velocity)<sup>7</sup>. MSP was defined as the maximum value of the curve representing the relationship between swimming power and swimming velocity<sup>7</sup>. SVPR was calculated using power-to-weight ratio (SVPR = MSV / MSP / kg)<sup>4</sup>.

Averages, SD, and 95% confidence intervals (CI) were calculated using basic statistics. Torque was used to analyse muscle strength. The correlation between MSV and MSP, MSP and shoulder strength, shoulder extensor strength and shoulder internal rotator strength, and SVPR and the rate of bilateral difference were examined. These relationships were evaluated using Pearson’s product-moment correlation coefficient. Excel for Windows 2013 (Microsoft Japan Co., Ltd.) and R2.8.1 were used for statistical analysis; a p-value<0.05 was considered statistically significant.

Holm-Bonferroni correction was performed for statistically significant p values<sup>10, 11</sup>. Coefficient values of significant correlations were defined based on the criteria of Hinkle et al.<sup>12</sup>: negligible, 0.00 to 0.30; low, 0.30 to 0.50; moderate, 0.50 to 0.70; high, 0.70 to 0.90; and very high, 0.90 to 1.00.

## RESULTS

MSP was significantly correlated with ETD and ETN. No significant correlations were observed between MSP and ITD, MSP and ITN, SVPR and RBET, or SVPR and RBIT.

Upper extremity length was 64.6 ± 3.1 cm (mean ± SD) on the dominant side and 64.6 ± 2.8 cm on the non-dominant side. Forearm extremity length was 32.6 ± 1.5 cm on the dominant side and 32.6 ± 1.3 cm on the non-dominant side. Results of measurements are shown in Table 1.

MSV was significantly associated with MSP (r=0.927; p<0.001) (Table 2). MSP was significantly correlated with ET

**Table 1.** Results of the muscle strength measurement

	Mean (standard deviation)
EFD (N)	134.2 (21.9)
EFN (N)	130.5 (25.2)
IFD (N)	129.6 (20.3)
IFN (N)	123.6 (12.8)
ETD (Nm)	87.0 (16.7)
ETN (Nm)	84.6 (17.9)
ITD (Nm)	42.4 (8.1)
ITN (Nm)	40.4 (5.1)
RBET (%)	3.1 (5.5)
RBIT (%)	4.0 (10.5)

EFD: The extension force of the dominant side; EFN: The extension force of the non-dominant side; IFD: The internal rotation force of the dominant side; IFN: The internal rotation force of the non-dominant side; ETD: The extension torque of the dominant side; ETN: The extension torque of the non-dominant side; ITD: The internal rotation torque of the dominant side; ITN: The internal rotation torque of the non-dominant side; RBET: The rate of bilateral difference in extension torque; RBIT: The rate of bilateral difference in internal rotation torque.

**Table 2.** Results of the front crawl swimming measurement

	Mean (standard deviation)	Pearson’s correlation coefficient between MSV	
		Mean (95% Confidence Interval)	assessment
MSV (m/s)	1.82 (0.09)		
MSP (W)	99.62 (20.01)	r = 0.927** (0.684 to 0.985)	very high
MSP/kg (W)	1.55 (0.29)	r = 0.807** (0.308 to 0.958)	high
SVPR	1.21 (0.23)		

Holm–Bonferroni correction were performed on statistically significant p values. \*p<0.05, \*\*p<0.01.

MSV: The maximum swimming velocity; MSP: The maximum swimming power; SVPR: The swimming velocity-to-swimming power ratio.

on the dominant (ETD) ( $r=0.844$ ;  $p=0.017$ ) and non-dominant (ETN) sides ( $r=0.779$ ;  $p=0.04$ ) (Table 3). No significant correlations were observed between MSP and IT on the dominant (ITD) side ( $r=0.72$ ;  $p=0.057$ ), MSP and the non-dominant (ITN) side ( $r=0.624$ ;  $p=0.073$ ), SVPR and RBET ( $r=-0.426$ ; 95% CI,  $-0.85$  to  $0.332$ ;  $p=0.253$ ), or SVPR and RBIT ( $r=0.002$ ;  $p=0.995$ ) (Table 3).

In addition, ETD was significantly associated with ETN ( $r=0.965$ ;  $p<0.001$ ), and ITD was significantly associated with ITN ( $r=0.84$ ;  $p=0.046$ ) (Table 3). No significant correlations were seen between ETD and ITD ( $r=0.777$ ;  $p=0.11$ ), ETN and ITN ( $r=0.667$ ;  $p=0.299$ ), ETD and RBET ( $r=0.042$ ;  $p=0.914$ ), ETN and RBET ( $r=-0.169$ ;  $p=0.663$ ), ITD and RBIT ( $r=0.478$ ;  $p=0.193$ ), ITN and RBIT ( $r=0.212$ ;  $p=0.585$ ), or RBET and RBIT ( $r=-0.479$ ;  $p=0.192$ ) (Table 3).

## DISCUSSION

This study found significant correlations between MSV and MSP ( $r=0.927$ ) and MSP and ETD ( $r=0.844$ ). The sample size was calculated to be 6 when using an effect size of 0.844, significance level of 5%, and detection power of 0.8; therefore, the number of participants in this study was valid.

MSP was significantly correlated with ETD ( $r=0.844$ ) and ETN ( $r=0.779$ ). In addition, ETD was highly correlated with ETN ( $r=0.965$ ). We reported that ITD was most strongly correlated with MSP in arm-only swimming<sup>4</sup>). These results differ from those of this study. The stroke phases are classified as the entry and catch phase, the pull phase, the push phase, and the recovery phase<sup>13</sup>). In addition, other report has classified the glide phase, the early pull-through phase, the mid-pull-through, the late pull-through phases, the end of the pull-through phase, and the recovery phase<sup>14</sup>). The entry and catch phase<sup>13</sup>) and the glide phase<sup>14</sup>) are the non-propulsive phase or the phases without backward movements. However, Maglischo<sup>15</sup>) noted that the catch phase is the first propulsive phase. Riewald and Rodeo<sup>16</sup>) noted that the catch and insweep is the pull phase. Therefore, the definition of the catch phase is different for each researcher. Colwin<sup>17</sup>) noted applying pressure on the water during the same phase as the early pull-through phase or the catch phase. Therefore, the shoulder extension in the position of maximum shoulder abduction is similar to the early pull-through phase; the hand reaches maximum forward extension and begins a downward motion<sup>14</sup>). Furthermore, the shoulder internal rotation in the position of abducted and external rotation is similar from the early pull-through phase to the mid-pull-through phase.

**Table 3.** The results of the Pearson's product-moment correlation coefficient

		ETD	ETN	ITD	ITN	RBET	RBIT
MSP	r	0.844**	0.779**	0.72	0.624	-	-
	95%CI	0.409 to 0.966	0.238 to 0.951	0.107 to 0.936	-0.069 to 0.911	-	-
	assessment	high	high	-	-	-	-
SVPR	r	-	-	-	-	-0.426	0.002
	95%CI	-	-	-	-	-0.85 to 0.332	-0.663 to 0.665
	assessment	-	-	-	-	-	-
ETD	r		0.965**	0.777	0.788	0.042	-
	95%CI		0.838 to 0.993	0.233 to 0.951	0.26 to 0.953	-0.64 to 0.687	-
	assessment		very high	-	-	-	-
ETN	r			0.737	0.667	-0.169	-
	95%CI			0.143 to 0.941	0.005 to 0.922	-0.749 to 0.558	-
	assessment			-	-	-	-
ITD	r				0.84*	-	0.478
	95%CI				0.397 to 0.965	-	-0.273 to 0.867
	assessment				high	-	-
ITN	r					-	0.212
	95%CI					-	-0.526 to 0.768
	assessment					-	-
RBET	r						-0.479
	95%CI						-0.867 to 0.271
	assessment						-

Holm-Bonferroni correction were performed on statistically significant p values. \* $p<0.05$ , \*\* $p<0.01$ .

95%CI: 95% Confidence Interval; MSP: The maximum swimming power; SVPR: The swimming velocity-to-swimming power ratio; ETD: The extension torque of the dominant side; ETN: The extension torque of the non-dominant side; ITD: The internal rotation torque of the dominant side; ITN: The internal rotation torque of the non-dominant side; RBET: The rate of bilateral difference in extension torque; RBIT: The rate of bilateral difference in internal rotation torque.

According to another report<sup>8)</sup>, front crawl swimming has a larger forward amplitude than arm swimming, but the downward and backward amplitudes are small. Additionally, during front crawl swimming, there is a correlation between swimming velocity and downward amplitude<sup>8)</sup>; the velocity is fast if the downward amplitude is large. In other words, front crawl swimming involves a great forward reach and generates swimming velocity by downward movement. Because front crawl swimming is faster than arm swimming, a fast stroke rate is required<sup>18)</sup>. In addition, extensor strength in the position of maximum shoulder abduction, which is similar to the downward movement of the early pull-through phase, was correlated with MSP in this study. Generally, the early pull-through phase may be more important for front crawl swimming than for arm-only swimming. Therefore, measuring extensor strength in the position of maximum shoulder abduction is an important assessment method for front crawl swimmers. In particular, the dominant side may be one of the most important measurements. However, Deschodt et al.<sup>8)</sup> reported that the downward amplitude of arm swimming had no correlation with swimming velocity. In addition, leg kicking raises the lower extremity and keeps the body horizontal, and the downward movement of the upper extremity was reported to have an effect on lower extremity sinking<sup>19)</sup>. Internal rotator strength in the position of abducted and external rotation, which is similar to the position during backward movement phases, was correlated with swimming velocity. Therefore, because arm swimming cannot compensate for the effect of lower limb sinking due to downward movements, internal rotator strength in the position of abducted and external rotation may be correlated.

We reported that RBET was highly correlated with SVPR in arm-only swimming ( $r = -0.728$ )<sup>4)</sup>. Furthermore, Toussaint and Truijens<sup>20)</sup> noted that each stroke cycle has varying propulsion and drag. These fluctuations are considered to be associated with swimming efficiency, which is determined on the basis of the following indicators: the stroke index, the efficiency of propulsion generation of the arm stroke, and the coefficient of variation of the hip intra-cyclic velocity variation<sup>21)</sup>. Therefore, swimming efficiency conserves propulsion generated by each arm. RBET may be associated with swimming efficiency because its magnitude is negatively associated with SVPR. However, this study did not observe that SVPR was significantly correlated with RBET; this differed from our past results<sup>4)</sup>. Because front crawl swimming includes the arms and various factors of the limbs, only shoulder strength was not related to SVPR. Therefore, future studies including propulsion efficiency and the coefficient of variation for velocity are needed.

These data show a significant correlation between ETD and MSP and validate this tool in front crawl swimmers. Athletes with a shoulder injury should seek to improve MSP and shoulder muscle strength during training and rehabilitation for front crawl swimming. In these cases, shoulder muscle strength should be evaluated. This study suggests that muscle strength of front crawl swimmers can be suitably evaluated using extensor strength measurements in the position of maximum shoulder abduction during training and rehabilitation. In addition, this measurement method may have high specificity for front crawl swimmers. Notably, measurements on the dominant side may provide useful data that are essential in training to improve front crawl swimming propulsion. However, the relationship between the strength of other muscles and MSP remains unclear. Altogether, these data may help create strength training programs and improve swimming performance in front crawl swimmers. A limitation of this study was that the assessments were performed on dry land and not during swimming under water. Future studies that include motion research or electromyographic analysis are needed, as they were not used in this study.

### *Conflict of interest*

None declared.

## ACKNOWLEDGEMENTS

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