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Abstract

To find an effective way to handle wheelchairs, 3-dimensional floor reactions of the hand and angular deviation of the elbow and wrist joints during push-up motion were studied in 10 healthy men. The push-up was carried out using 3 hand positions (fist, finger and palm) and a push-up device. In all hand positions, anteroposterior force (Fx) and the mediolateral force (Fy) appeared after the vertical force (Fz). The end point of Fx and Fy was observed before that of Fz. Among the 4 different hand positions, Fx and Fy appeared first in the palm, followed by the finger and fist positions, and lastly in the push-up devices. The results indicate that the more unstable pushing-up the body is, the earlier and longer Fx and Fy are. Thus, Fx and Fy are considered to be good indicators of body balance during the push-up motion. The elbow joint showed a hyperextended position only when using the palm position in the maintenance phase. The wrist joint showed palmar flexion only when using the fist position.

KEYWORDS: force plate, push-up montion, body balance, three-dimensional floor reaction of the hand

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Kinesiological Study of Push-up Motion Using a Three-Dimensional Floor Reaction on a Force Plate

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To find an effective way to handle wheelchairs, 3-dimensional floor reactions of the hand and angular deviation of the elbow and wrist joints during push-up motion were studied in 10 healthy men. The push-up was carried out using 3 hand positions (fist, finger and palm) and a push-up device. In all hand positions, anteroposterior force (Fx) and the mediolateral force (Fy) appeared after the vertical force (Fz). The end point of Fx and Fy was observed before that of Fz. Among the 4 different hand positions, Fx and Fy appeared first in the palm, followed by the finger and fist positions, and lastly in the push-up devices. The results indicate that the more unstable pushing-up the body is, the earlier and longer Fx and Fy are. Thus, Fx and Fy are considered to be good indicators of body balance during the push-up motion. The elbow joint showed a hyperextended position only when using the palm position in the maintenance phase. The wrist joint showed palmar flexion only when using the fist position.

Key words: force plate, push-up motion, body balance, three-dimensional floor reaction of the hand

For patients in wheelchairs, the push-up motion is an essential part of their physical rehabilitation, and is necessary for developing and maintaining the transfer ability, and preventing pressure sores. The muscles involved in this movement have two significant functions: one is to move the body up and down and the other is to stabilize the joints of the upper extremities and shoulder girdle to support the elevated body while maintaining balance against gravity.

Not only are there few kinesiological studies of this motion (1-4), but the ones that were done focused on the electromyographic activity of the upper extremity. In the present study, the stability of the wrist and elbow joints and the balancing mechanism of normal subjects during push-ups were investigated in several different hand positions currently employed in physical therapy based on the three-dimensional floor reactions of the hand.

Subjects and Methods

Ten healthy men ranging in age from 21 to 35 years (27.5 ± 4.1 years) were studied. Height ranged from 160 to 181 cm (171 ± 7.0 cm) and body weight ranged from 48 to 72 kg (60.5 ± 6.8 kg).

A force plate was used to measure the three-dimensional floor reactions of the hand during push-ups. The force plate used was originally made for gait analysis and consisted of a matrix system (Anima Co., Ltd., Tokyo, Japan). An attachment was designed consisting of two box-shaped platforms with a steel frame, and these were fixed onto the force plate. The subjects sat on a rack, the legs of which were set just outside the force plates (Fig. 1) and they performed the push-up motion in three hand positions, fist, finger and palm, as well as with a push-up device which was fixed firmly onto the platform (Fig. 2). Thus, three-dimensional floor reactions were recorded by the force plate when the subjects pushed up their bodies.

To measure the angular deviation of the elbow joint (flexion and extension) and the wrist joint (palmar flexion and dorsal flexion), an electrogoniometer was attached to each joint. The electrogoniometer was made of a flexible steel plate on which four strain gauges were attached. A Wheatstone's bridge was assembled from the four strain gauges (5). When the steel plate was flexed, the electric

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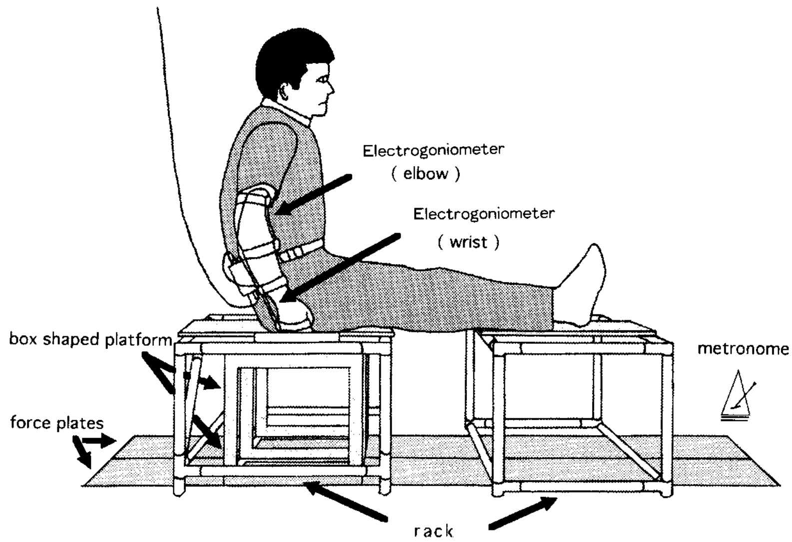

Fig. 1 Schematic representation of measuring system used in the study.

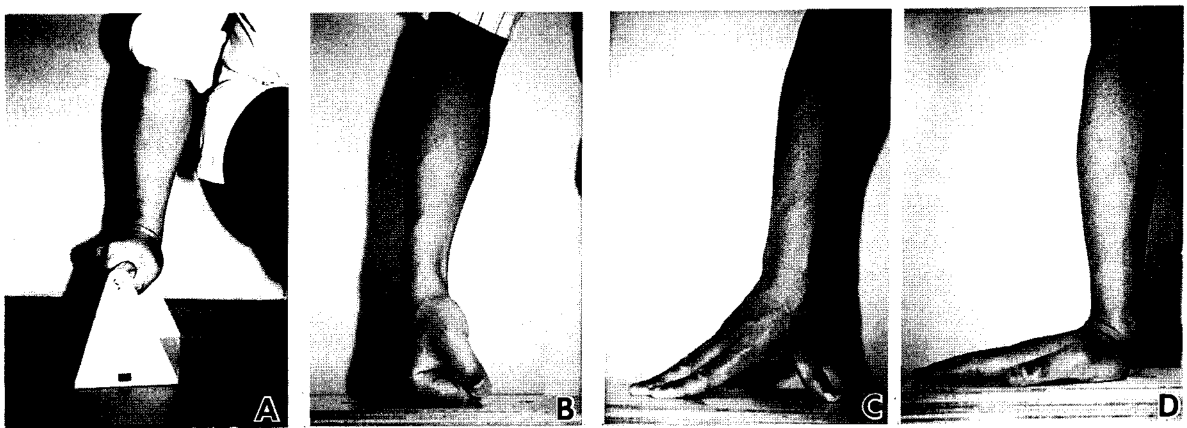

Fig. 2 Push-up motion carried out under four different hand positions. **A**) push-up device **B**) fist **C**) finger **D**) palm

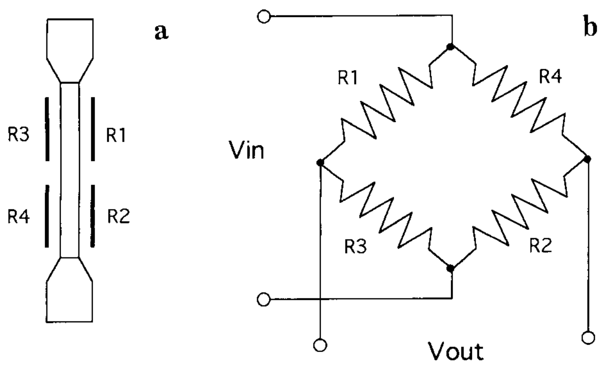

Fig. 3 Electrogoniometer used in the experiment. **a**) strain gauges; **b**) Wheatstone's bridge.

current obtained was in direct proportion to the angular deviation of the joint (Fig. 3). Information from the force plate and electrogoniometers was recorded simultaneously on a polygraph. The subjects were asked to extent their elbows for 1 s, and to maintain their elbows in this extended position for 1 s, then to flex their elbows returning to the starting position for 1 s. A metronome was used to control the timing of this motion as closely as possible.

Results

There were essentially no differences in the three-

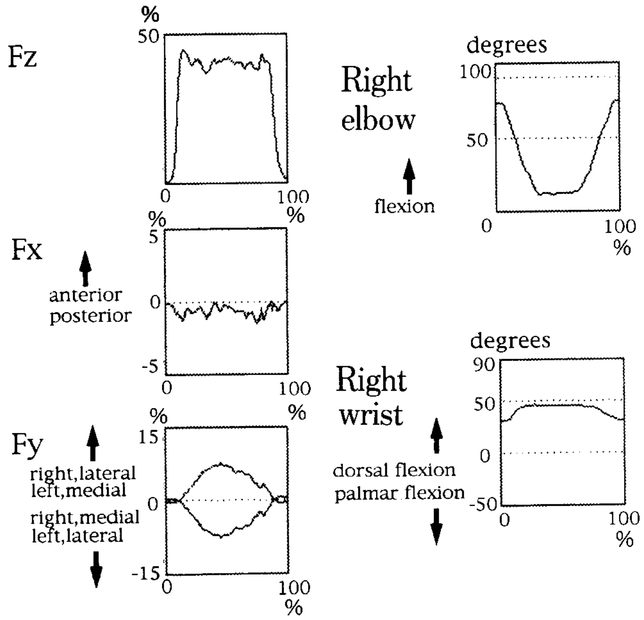

Fig. 4 Three-dimensional floor reactions and angular deviation (push-up device).
Fx: Anteroposterior force (right side)
Fy: Mediolateral force (both sides)
Fz: Vertical force (right side)
Fx, y, z: Ordinate, percent of body weight
Fx, y, z and angular deviation: Abscissa, time component with duration of one push-up corresponding to 100%, therefore this indicates the percent of a cycle of a push-up.

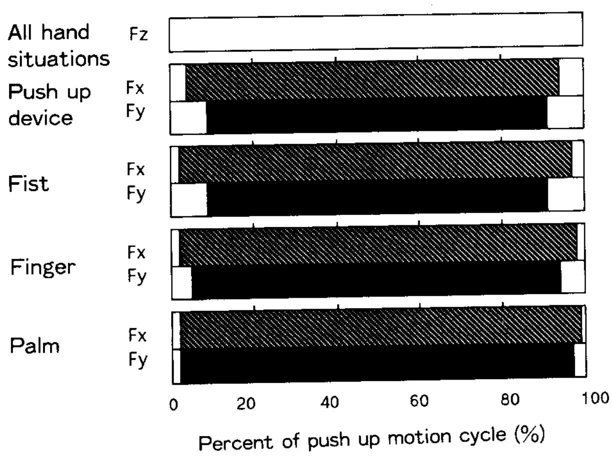

Fig. 5 The start and end points of Fx, Fy and Fz in four hand positions. Fx, Fy, Fz,; See Fig. 4.

Table I Starting and ending points of the anteroposterior force (Fx) and the mediolateral force (Fy) under different hand positions

Force		Cycle of a push-up (%)			
		Push up devices	Fist	Finger	Palm
Fx					
	Start point	3.9	2.3	2.2	2.0
	End point	94	97	98	99
Fy					
	Start point	8.8	8.5	5.6	2.0
	End point	91	91	94	97

dimensional floor reactions or in the angular deviation of the elbow and wrist joint among the three hand positions and the push-up device. Moreover, there were no differences seen between the right and left sides (Fig. 4). Regarding floor reactions, each component was standardized according to the subject's body weight. The floor reaction components indicated vertical force (Fz), anteroposterior force (Fx) and mediolateral force (Fy) with the starting point of Fx and Fy in all situations occurring after the starting point of Fz. Similarly, the end point of Fx and Fy in all situations ended before the end point of Fz (Fig. 5, Table 1).

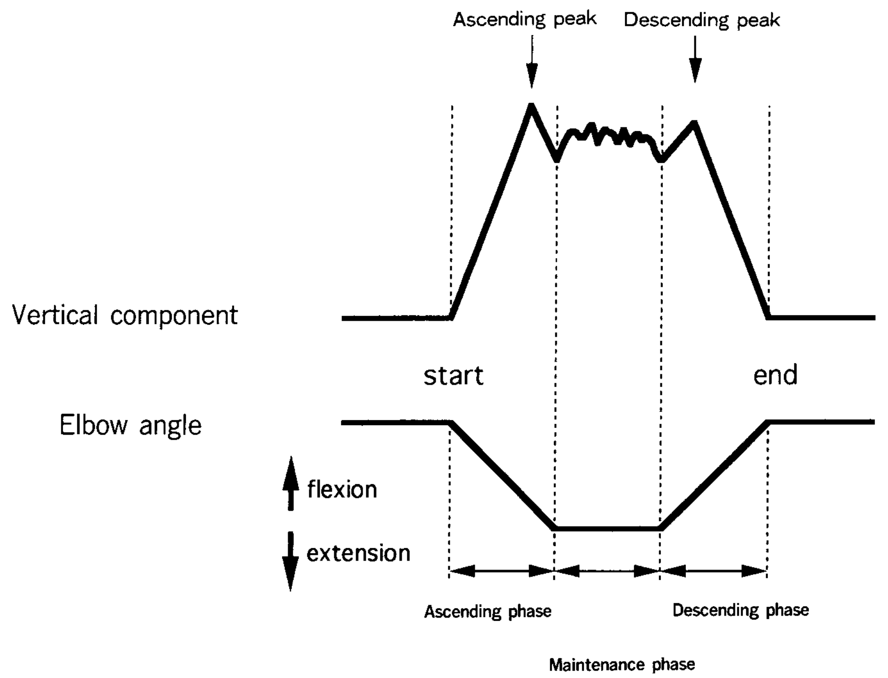

Fig. 6 Schematic representation of vertical component and elbow angle curve

Table 2 Vertical force (Fz) under different hand positions in different phases

Phase	Fz under different hand positions (%)[a]			
	Push up devices	Fist	Finger	Palm
Peak value of ascending phase	43.0	44.3	45.4	42.8
Peak value of descending phase	41.6	43.6	43.8	42.0
Mean value of maintenance phase	39.1	42.7	42.8	41.4

[a]: % indicates percent of body weight.

According to angular deviation of the elbow, the push-up motion was divided into the following three phases: the first phase, extension, corresponding to the ascending phase in Fz; the second phase, in which the elbow joint was kept extended, corresponding to the maintenance phase in Fz; and the third phase, flexion, which corresponded to the descending phase in Fz (Fig. 6).

Vertical component (Fz). Fz in the four hand positions showed a trapezoidal shape. The ascending peak value, descending peak value and the mean value of the maintenance phase (percent of body weight) are shown in Table 2.

Anteroposterior (A-P) component (Fx). Four types of A-P curves were observed in four hand positions. The first group always showed a posterior force. The second group recorded a small trembling curve near the zero line with a peak in the posterior force in the ascending and descending phases. The third group showed a biphasic pattern, always beginning posteriorly then becoming anterior. The fourth group always showed an anterior force. The relation between the hand positions and the curve pattern is shown in Table 3 and Fig. 7.

Mediolateral (M-L) component (Fy).

Table 3 Ten subjects grouped by the anteroposterior curve paterns during push-ups under different hand positions

Curve pattern[a]	Number of subjects under different hand positions			
	Push-up devices	Fist	Finger	Palm
Group				
1				
a	1	5	6	5
b	6	1	1	2
2	1	2	1	2
3	1	1	0	1
4	1	1	2	0
Total	10	10	10	10

[a]: Group patterns are shown in Fig. 7.

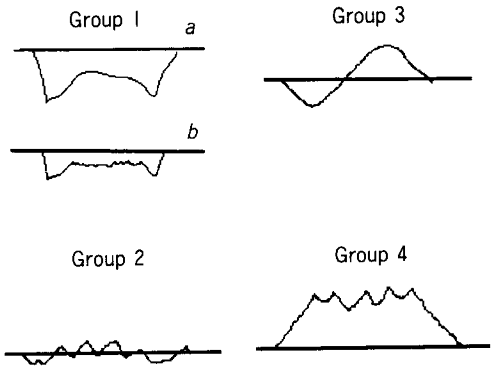

Fig. 7 Four groups of different anteroposterior curve patterns shown during push-ups under different hand positions. The area above the zero line represents the anterior component of the right hand side. The area below the zero line represents the posterior component of the right hand.

Table 4 Ten subjects grouped by the mediolateral curve patterns during push-ups under different hand positions

Curve pattern[a]	Number of subjects under different hand positions			
	Push-up devices	Fist	Finger	Palm
Group				
1	5	9	0	1
2	4	1	0	0
3	1	0	10	9
Total	10	10	10	10

[a]: Group patterns are shown in Fig. 8.

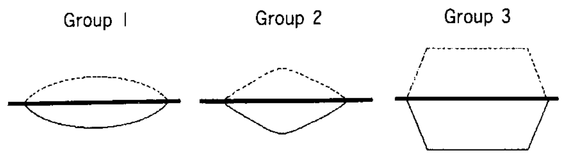

Fig. 8 Three groups of different mediolateral curve patterns shown during push-ups under different hand positions. The solid line is the wave of the right-hand side component. The broken line is the wave of the left-hand side component. The area above the zero line represents the lateral component of the right-hand side or the medial component of the left-hand side.

Table 5 Angle and range of motion of elbows

	Hand positions			
	Push up devices	Fist	Finger	Palm
Starting angle (degrees)	75.1	40.3	37.1	25.7
Angle of maintenance phase (degrees)	3.8	3.6	2.3	-2.0
Range of motion (degrees)	71.3	36.7	34.8	27.7

Three types of M-L curves were observed in the four hand positions. All three groups always showed a medial force, but the first group had an ellipsoid curve on the right and left sides. The second group had a spindle-shaped curve on both sides, and the third group had a hexagonal curve on both sides with the hexagonal plateau starting at the ascending Fz peak and stopping at the descending Fz peak. The relationship between the hand positions and the curve patterns is shown in Table 4 and Fig. 8.

Angular deviation of the elbow. Although the amplitude of angular deviation was different in the four hand positions, the angular deviation curve showed almost the same pattern with the angle in the initiation and maintenance phases, and the elbow's range of motion is shown in Table 5.

Angular deviation of the wrist. The starting angle, direction of motion, maintenance angle and range of motion are shown in Table 6.

Table 6 Angle and range of motion of wrists

	Push up devices	Hand positions Fist	Finger	Palm
Starting angle	31.4	-14.8	20.0	67.9 degrees
Direction of motion	Dorsal flextion	Palmar flextion	Dorsal flextion	Dorsal flextion
Maintenance angle	46.1	-23.5	28.3	74.7 degrees
Range of motion	14.7	8.7	8.3	6.8 degrees

Negative values of angle idicate palm flexion.

Discussion

There are few reports on the push-up motion of normal subjects and patients with spinal cord injuries, and those studies that were conducted were focused on the neuromuscular activity associated with push-ups (1-4). Therefore, in this study we analyzed the three-dimensional floor reactions of the hand and the angular deviation of the elbow and wrist joint during the push-up motion.

In all hand positions, the floor reaction first appeared at Fz, then Fx and finally Fy. The floor reaction first disappeared at Fy, then Fx, and finally Fz (Fig. 5, Table 1). From these results, we concluded that the subject first elevated his own body vertically, then controlled this movement in a mediolateral direction followed by the anteroposterior direction in order to achieve body balance. Among the four hand positions investigated, Fx and Fy successively appeared first in the palm, followed by the finger and fist positions, and by the push-up device. The duration of Fx and Fy incresed in the same order. These findings indicate that the more unstable pushing-up the body is, the earlier and longer Fx and Fy are.

In the four hand positions, the most common Fx curve pattern was the first group.

Compared with Fx of other hand positions, Fx of the push-up device showed a lower amplitude (Table 3), delayed starting and early ending (Table 1). These observations indicate that push-ups were carried out more effectively using push-up devices. In other words, the minimum body balance was required using a push-up device, because the low amplitude and short duration of Fx indicated that a smaller effort was required for body balancing. The most common Fy curve pattern with push-up devices was the first and second group; for the fist position, the first group was most common; and for both the finger and palm positions, the third group was more common (Table 4). Concerning the start and end points of Fy, both push-up devices and the fist position showed delayed start and early end points (Fig. 5, Table 1). The amplitude of Fy decreased in the following order: palm > finger > push-up device > fist. From these observations, the curve pattern of the first and second groups was seen to be essentially the same, because any differences in the curve pattern or amplitude were believed to depend on wrist joint stability.

The elbow joint was hyperextended position when using the palm position; however, it remained slightly flexed in the other hand positions during the maintenance phase. Therefore, the elbow joint was locked using the palm position, because multi-joint muscles such as wrist and finger flexors pulled the distal end of the humerus anteriorly, when the wrist was maximally dorsiflexed.

Furthemore, the wrist remained in palmar flexion when using the fist to get the maximum supporting surface.

In other hand positions, the wrist flexed dorsally and the supporting point at the wrist moved gradually under these conditions.

In conclusion, the two components of body elevation and body balance were integral to achieving a push-up motion. The body balance, which consisted of a mediolateral and anteroposterior floor reaction in the push-up motion, was maintained best condition when a push-up device was used, while it was most unstable under palm hand position.

These results suggest patients in wheel chairs how to do push-up motion with the least load.

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