# An Analysis of Sit-to-Stand Movements

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**ABSTRACT. Kotake T, Dohi N, Kajiwara T, Sumi N, Koyama Y, Miura T. An analysis of sit-to-stand movements. Arch Phys Med Rehabil 1993;74:1095-9.**

**• We analyzed the movements involved in rising from a knee-high chair in 12 healthy men weighing within ±10% of standard body weight. A regular series of transition points was observed in the angles of the hip, knee, and ankle joints throughout the sit-to-stand movement, which was classified into six stages. As the duration of sit-to-stand movements increased, the duration of Stage 2 decreased, whereas Stage 3 grew longer. The durations of stages 4 and 5 remained constant. We also calculated the minimum unilateral hip and knee extension torque per weight in kilograms required for natural sit-to-stand movements, or N-Stand (1.7-2.3 seconds), and found that minimum hip extension torque was 0.7Nm and minimum knee extension torque was 0.9Nm. The minimum hip and knee extension torque required for N-Stand corresponds to a mean 27% and 30%, respectively, of the actual maximum hip and knee extension torque.**



Rising from a sitting position is a very common, yet essential activity in daily life. The ability to stand from a sitting position, of course, makes other vital activities such as walking possible. Patients who are unable to stand not only are severely limited in terms of daily activities; they present a greater burden to those who must care for them. In these days of ever-increasing elderly populations, the rehabilitation of such patients is becoming a topic of greater concern. This study aims to provide fundamental data concerning the execution of the sit-to-stand movement, and in particular the following:

1. How do the angles of the lower limbs change throughout the process of rising from a chair, and how are these angles affected by the speed of rising (Trial 1)?
2. How much hip and knee extension torque is required per kilogram of body weight to complete the sit-to-stand movement (Trial 2)?
3. During the sit-to-stand movement, how much load is being exerted on the muscles required for extension (Trial 3)?

## SUBJECTS

Trials 1, 2, and 3 of the study were conducted among 12 healthy men aged 22 to 40 years, mean age 30.7. Mean height was 169.6cm, and mean body weight was 62.2kg. All subjects were within ±10% of standard body weight. (For purposes of this study standard body weight was calculated using the following equation: [height in centimeters − 100] × 0.9).

## METHODS

### Trial 1: Measurement of Course-of-Time Changes in the Angles of the Hip, Knee, and Ankle Joints During Sit-to-Stand Movement

We attached light-emitting diodes (LED) to all subjects at the acromion of the right shoulder; the greater trochanter of the femur; the joint space on the outer side of the knee; the lateral malleolus of the ankle joint; and the fourth metatarsal (at the same height as the lateral malleolus). We then used a Locus IIID Motion Analyzer[a] to record movements as subjects rose from a sitting position on a round stool with no armrests. Subjects were asked to place their feet flat on the floor at shoulder's width, and to stand with arms folded. The chair was adjusted to knee height for each subject, and legs were positioned before standing so that dorsiflexion of the ankle joint was 15° (fig 1). Vectors were analyzed every 0.05 seconds so that changes in leg joint angles could be calculated while the subject was in motion.

Three categories were set based on the time required to complete the sit-to-stand movement. Subjects were asked to practice rising naturally several times at each speed before conducting the actual measurements. Two trials were recorded at each speed. From these measurements we obtained a chronological record of changes in the angle of the hip, knee, and ankle joints. The categories were as follows: (1) Fast sit-to-stand (0.8-1.4 seconds) (F-Stand); (2) Slow sit-to-stand (3.0-4.0 seconds) (S-Stand); and (3) Natural sit-to-stand (1.7-2.3 seconds) (N-Stand).

### Trial 2: Computation Models of the Minimum Unilateral Hip Joint and Knee Joint Extension Torque Required to Complete the Sit-to-Stand Movement

At a given moment, the value for expressing torque for flexion of the hip joint is as follows (when force is applied by the weight of the torso): $w_1 f_1 \cos\theta_1/2$ (fig 2). Similarly, the

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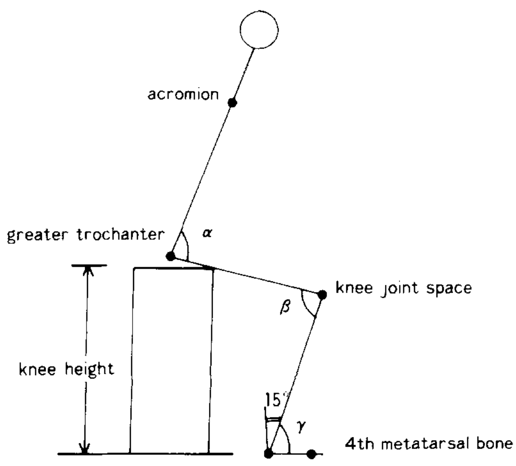


**Fig 1—Posture at time of measurements during Trial 1. Dots show position of LEDs. The seat of the chair was adjusted to knee height. The ankle was inclined forward at a 15° angle. Angles of the hip, knee, and ankle joints are designated, respectively, as $\alpha$, $\beta$ and $\gamma$.**

torque for flexion of the knee joint using the weight of the torso and thigh is: $w_1(f_0 \cos\theta_2 - f_1 \cos\theta_1)/2 + w_2 f_2 \cos\theta_2$.

If only the following factors involving torque at the hip joint and knee joint are considered, the subject should be able to stand if torque is maintained in the direction of joint extension throughout the standing process ($H = w_1 f_1 \cos\theta_1/2$); ($K = w_1[f_0 \cos\theta_2 - f_1 \cos\theta_1]/2 + w_2 f_2 \cos\theta_2$). It must be noted, however, that the success of this theoretical model depends on the assumptions presented in table 1.[1,2]

Using the data from Trial 1, we calculated $\theta_1$ and $\theta_2$ and measured each of the actual values for $w_1$, $f_1$, $w_2$, $f_2$, and $f_0$. These measurements are based on a report by Matsui[2] (table 1).

We then calculated K and H at 0.05-second intervals for

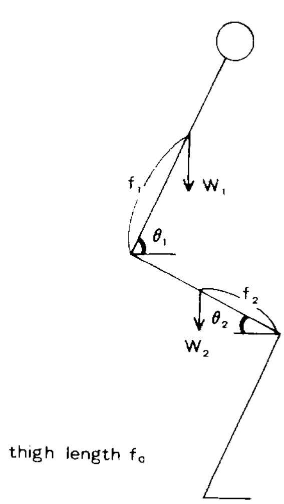


**Fig 2—Definitions of values used in the computational model for Trial 2. $W_1$, torso weight, including head and arms; $f_1$, distance from the center of gravity of the torso to the hip joint; $W_2$, thigh weight; $f_2$, knee joint distance from the center of gravity of the thigh; $f_0$, femur length; $\theta_1$, angle between the horizontal plane and the torso; $\theta_2$, angle between the femur and the horizontal plane.**

**Table 1: Hypotheses Necessary for Computational Model in Trial 2[1,2]**

1. Motions of various parts of the body occur in a vector plane so that rotation of the body may be disregarded.
2. Various joints of the body may be expressed as a series of links.
3. Each joint has a single axis.
4. The center of gravity for each body segment is located along the line extending from one joint to the other.
5. The upper body, including the arms, may be expressed as a single, uniform volume.
6. No consideration will be made of inertial torque from acceleration.
7. Joint torque necessary for rising is distributed evenly between the two legs.
8. $W_1 f_1 W_2 f_2 f_0$ are defined as follows, according to the report by Matsui: $W_1$, 56% of body weight; $f_1$, 45% of sitting height; $W_2$, 10% of body weight; $f_2$, 58% of femur length; $f_0$, actual measured distance from the outer knee joint space to the greater trochanter of the femur.

Data from Yamazaki[1] and Matsui.[2]

each second of N-Stand in Trial 1. The maximum values of H and K ($H_{max}$ and $K_{max}$) were obtained and then divided by each subject's body weight to yield $H_{max}$ and $K_{max}$ per kilogram of body weight ($H_{max}/BW_{kg}$, $K_{max}/BW_{kg}$).

During N-Stand, the subject must be able to exert extension torque in excess of $H_{max}$ and $K_{max}$ at each joint throughout the sit-to-stand movement. In this respect, therefore, $H_{max}$ and $K_{max}$ represent the minimum unilateral joint extension torque required for completing the sit-to-stand movement.

## Trial 3: Calculation of the Percentage of $H_{max}$ and $K_{max}$ for the Actual Maximum Hip and Knee Joint Extension Torque in Each Subject

In Trial 3, we divided the $H_{max}$ and $K_{max}$ obtained from Trial 2 by the actual maximum joint extension torque for each of the 12 subjects and determined the average figures.

An isometric dynamometer was used to measure actual maximum knee and hip joint extension torque. Hip joint extension torque measurements were gathered using the isometric method; subjects were placed in the supine position and hip joints and knee joints were flexed to 90°. When measuring knee extension torque by the isometric method, the subject was seated in a chair with both knees flexed to 90°. Knee extension and hip extension were measured twice at maximum strength. The largest figure was used as the actual maximum extension torque.

# RESULTS

## Trial 1

Figure 3 A shows the course-of-time changes in the angles of the hip, knee, and ankle joints during the sit-to-stand movement. Using overall movement and the transition points of the various joints as indices for analyzing sit-to-stand patterns, we found that the same pattern exists regardless of the speed of the action. The following pattern was observed:

From a seated position in the chair ($T_1$), the subject first flexes the torso forward slightly ($T_2$). The hips are lifted off the chair ($T_3$), then the hip joint reaches maximum flexion ($T_4$). Maximum dorsiflexion is then exerted at the ankle

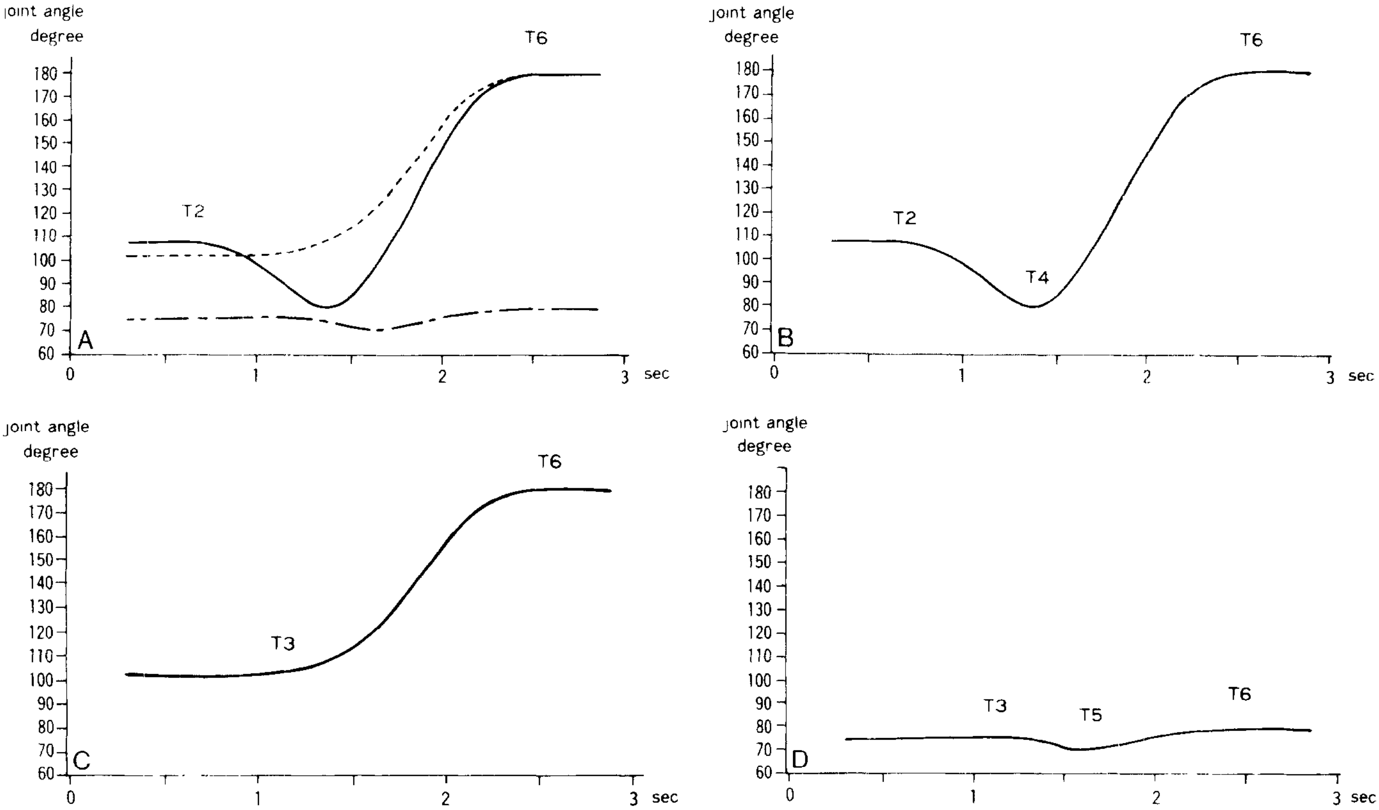


**Fig 3—(A) Course-of-time shift in angles of each joint during sit-to-stand movement. $T_2$, flexion of the torso commences; $T_6$, standing; (B) Course-of-time shift in angles of the hip joint during sit-to-stand movement. $T_2$, flexion of the torso commences (Flexion phase $T_2$-$T_4$); $T_4$, hip joint achieves maximum flexion (Extension phase $T_4$-$T_6$); $T_6$, standing. (C) Course-of-time shift in angles of the knee joint during sit-to-stand movement. $T_3$, buttocks leave chair (lift-off) (Extension phase $T_3$-$T_6$); $T_6$, standing. (D) Course-of-time shift in angles of the joint during sit-to-stand movement. $T_3$, buttocks leave chair (Dorsiflexion phase $T_3$-$T_5$); $T_5$, ankle joint achieves maximum dorsiflexion (Plantar flexion phase $T_5$-$T_6$); $T_6$, standing. ——, hip joint; - - -, knee joint; — - — ankle joint.**

joint ($T_5$), after which the subject attains a standing position ($T_6$) and stabilized balance ($T_7$).

Changes in the hip joint angle throughout this sequence can be divided into two basic phases: the flexion phase ($T_2$-$T_4$), in which the joint angle is gradually reduced by the forward inclination of the torso until the hip joint is fully flexed, and the extension phase ($T_4$-$T_6$), in which the joint angle increases until the body is fully erect (fig 3 B).

The knee joint passes through only the extension phase. The angle of the knee joint increases from the moment the buttocks leave the surface of the chair until the knees are fully extended (extension phase: $T_3$-$T_6$; fig 3 C).

Changes in the angle of the ankle joint are somewhat different. The angle decreases during the dorsiflexion phase ($T_3$-$T_5$) until the joint reaches maximum dorsiflexion. The angle then increases until the subject comes to a full stand (plantar flexion phase: $T_5$-$T_6$; fig 3 D).

Based on the above ($T_1$ to $T_7$), we divided the entire sequence of sit-to-stand motions into six stages, similar to those shown in table 2.

Healthy subjects normally have no difficulty in maintaining balance while seated or standing, so there is very little change in the joint angle at stages 1 ($T_1$-$T_2$) and 6 ($T_{6-7}$).

We then determined the amount of time spent on each stage. The total time from stage 2 to stage 5 was considered 100. Figure 4 shows the average percentage of time spent on each stage by the 12 healthy subjects. During N-Stand, which is most similar to the normal rising action, Stage 2 occupied 20.9% of the total time; Stage 3, 9.5%; Stage 4, 14.7%; and Stage 5, 54.9%.

We next compared the percentage of time required for each stage in F-Stand, N-Stand, and S-Stand. The results showed that the longer it takes to rise, the weights in Stage 2 decrease significantly ($p < 0.001$). Conversely, the time required for Stage 3 increases significantly ($p < 0.001$). The durations of Stages 4 and 5, on the other hand, changed very little regardless of the overall time taken to complete the sit-to-stand movement.

## Trial 2

The results of H for N-Stand, as obtained by the above computational model, were plotted on a course-of-time graph (fig 5). Hip extension torque continued to increase after the buttocks left the chair ($T_3$) and maximized when the forward inclination of the torso also reached maximum. Afterward, torque gradually decreased.

K in N-Stand was similarly calculated using the computational model above and plotted chronologically (fig 6). Knee extension torque was at its greatest when the buttocks left the chair ($T_3$), then gradually decreased.

We calculated the average $H_{max}/BW_{kg}$ and $K_{max}/BW_{kg}$

**Table 2: Breakdown of Stages in the Sit-to-Stand Movement**

| Stage | Indicator | | Hip Joint | Knee Joint | Ankle Joint |
|---|---|---|---|---|---|
| 1 | Seated in chair | ($T_1$) | | | |
| 2 | Flexion of torso commences | ($T_2$) | — | | |
| | Buttocks leave chair surface | ($T_3$) | Flexion | — | — |
| 3 | Hip joint achieves maximum flexion | ($T_4$) | — | Extension | Dorsiflexion |
| 4 | Ankle joint achieves maximum dorsiflexion | ($T_5$) | Extension | | — |
| 5 | Standing | ($T_6$) | — | — | Plantar flexion |
| 6 | Stabilize in standing position | ($T_7$) | | | — |

(± standard deviation) during N-Stand for the 12 subjects and found that mean $H_{max}/BW_{kg}$ was 0.7 ± 0.1Nm and mean $K_{max}/BW_{kg}$ was 0.9 ± 0.1Nm. These figures represent theoretical values for the minimum hip joint and knee joint extension torque necessary for completing the sit-to-stand movement.

## Trial 3

We found that the mean (± standard deviation) was 0.27 ± 0.08 and 0.30 ± 0.07, respectively; therefore, an average of 27% of the actual maximum hip extension torque and 30% of the actual maximum knee extension torque represent the minimum torque necessary for completing N-Stand.

## DISCUSSION

Standing is an act of voluntary muscle control, and movements may be altered by the individual at will; in this study, however, a definite pattern was seen when able-bodied people stood up without thinking.

Experiments have shown that standing is an action involving whole-body movement.[3] In the end, however, it is the motions of the hip, knee, and ankle joints that are most important.

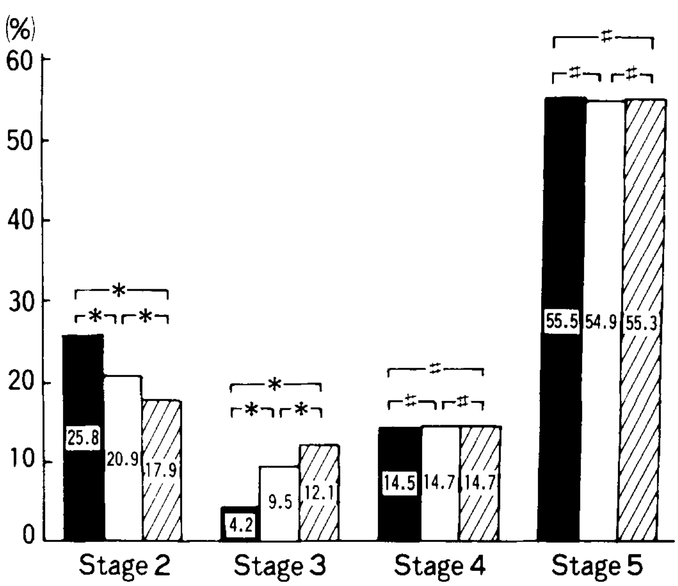


**Fig 4—Proportion (%) of time required for each stage based on a total time of 100% for stages 2 through 5. ■, F-Stand; □, N-Stand; ▨, S-Stand.**
**$^*P < 0.001$.**
**#Not significant (paired $t$ test).**

In this study we chose to focus on the transition points of the hip, knee, and ankle joints, and divided the sit-to-stand process into six stages. This system of classification enabled us to determine more accurately the stage at which patients experience difficulty. It is essential that therapists understand which stages of the sit-to-stand movement present the most difficulty to patients so that rehabilitation programs can be tailored accordingly.

Under our classification, when the length of time it takes to stand is prolonged, Stage 2 shortens while Stage 3 lengthens. This suggests that when standing takes longer, the hip joint must be in flexion for a longer period after the hips leave the surface of the chair. This also shows that subjects' torsos are inclining to a greater degree.

In general, the inability to stand may result from one or more of the following: (1) loss of muscle strength[4,5]; (2) paralysis or muscle coordination disorders; (3) loss of balance; (4) neurological or psychological disorders leading to a lack of interest in physical activity; and (5) pain in the joints, limited range of motion,[6] and other factors.

Whatever the cause, a loss of muscle strength always follows. This becomes an extremely important factor in the loss of the ability to stand. In the case of rising from a seated position, the main features of the action place vital importance on the actions of the muscles that control extension of the knee joint and the hip joint.

Various computational models have been used for calculating joint torque for certain movements.[7-11] For this study, we devised the computational model described above, based on the assumptions stated in table 1, for investigating only those factors related to muscle strength and for determining $H_{max}$, $K_{max}$, $H_{max}/BW_{kg}$ and $K_{max}/BW_{kg}$. Iner-

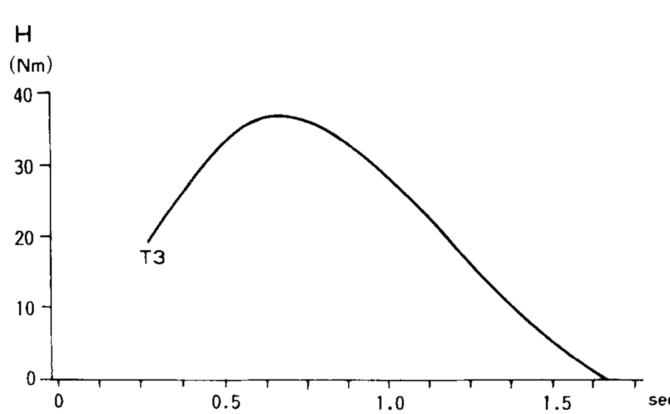


**Fig 5—Course-of-time shifts in H in N-Stand as calculated by the computational model. $T_3$, buttocks leave chair; $H = w_1f_1\cos\theta_1/2$.**

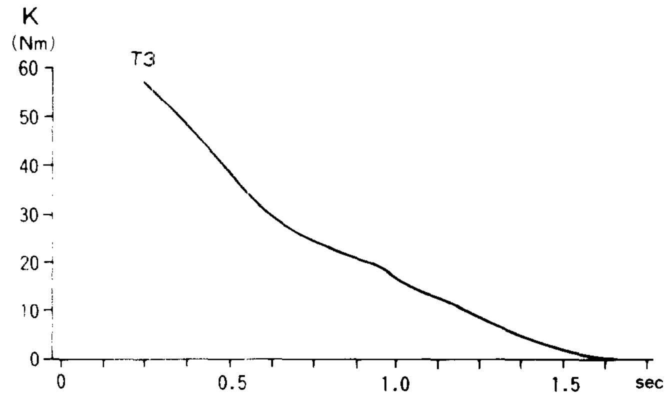


**Fig 6—Course-of-time shifts in K in N-Stand as calculated by the computational model. $T_3$, buttocks leave chair; $K = w_1 (f_\theta \cos\theta_2 - f_1 \cos\theta_1)/2 + w_2 f_2 \cos\theta_2$.**

tial moment naturally plays a part in the sit-to-stand movement, but studies comparing inertial and noninertial experimental models have reported no significant disparity in overall results.[12]

In this study, subjects were limited to individuals weighing within ±10% of standard body weight. This experiment may not be applicable to extremely obese or emaciated individuals, but should be eminently workable for subjects of standard build.

Hettinger[13] studied the relation between load in isometric training and its effectiveness. He reported that at loads of 20% to 30% of maximum muscle strength, muscle power neither increases nor decreases. At loads of less than 20%, however, muscle strength actually declines. This data, combined with the results from Trial 3 of our study, indicate that the muscle load during sit-to-stand movement is sufficient for maintaining muscle strength.

The inability to stand severely limits full participation in everyday activities, ensuring an overall deterioration of muscle function. Therefore, standing is important not only in terms of increasing one's participation in everyday activities, but also for its role in maintaining and improving muscle strength.

Standard muscle strengthening exercises using weights or muscle exercisers[14-16] may be inappropriate therapy in the rehabilitation of some patients with symptoms of muscular atrophy. In many such cases it may be better to focus on muscle training that involves repetition of basic movements. Standing, an activity of inestimable value to the patient, should definitely be incorporated in such therapy programs.

## CONCLUSIONS

As elderly and disabled populations continue to grow, we recognize the impact that a common activity such as rising from a seated position can have concerning the quality of life. A basic understanding of the sit-to-stand movement is therefore an essential component to rehabilitation studies.

We studied sit-to-stand movements in 12 healthy men whose weight fell within ±10% of standard body weight. A consistent pattern was observed throughout these movements and a series of transition points was identified and analyzed in the ankle joint, knee joint, and hip joint angles as they passed through the various stages of sit-to-stand.

Hip joint and knee joint extension torque was also analyzed and a computational model was developed to establish minimum unilateral hip and knee extension torque necessary for the sit-to-stand movement.

We then compared the minimum required hip joint and knee joint extension torque with the actual maximum extension torque and found that the muscle load during the sit-to-stand movement is sufficient for maintaining muscle strength.

We are hopeful that further attention will be paid to this important area of rehabilitation research and believe that this study provides useful fundamental data for further research.

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### Supplier

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