

Research article

## Characteristics of maximum performance of pedaling exercise in recumbent and supine positions

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### Abstract

To determine the characteristics of maximum pedaling performance in the recumbent and supine positions, maximum isokinetic leg muscle strength was measured in eight healthy male subjects during pedaling at three velocities (300°/s, 480°/s, and 660°/s), and maximum incremental tests were performed for each position. The maximum isokinetic muscle strength in the recumbent position was 210.0 ± 29.2 Nm at 300°/s, 158.4 ± 19.8 Nm at 480°/s, and 110.6 ± 13.2 at 660°/s. In contrast, the muscle strength in the supine position was 229.3 ± 36.7 Nm at 300°/s, 180.7 ± 20.3 Nm at 480°/s, and 129.6 ± 14.0 Nm at 660°/s. Thus, the maximum isokinetic muscle strength showed significantly higher values in the supine position than in the recumbent position at all angular velocities. The knee and hip joint angles were measured at peak torque using a goniometer; the knee joint angle was not significantly different between both positions, whereas the hip joint angle was greater in the supine position than in the recumbent position (Supine position: 137.3 ± 9.33 degree at 300°/s, 140.0 ± 11.13 degrees at 480°/s, and 141.0 ± 9.61 degrees at 660°/s. Recumbent position: 99.5 ± 12.21 degrees at 300°/s, 101.6 ± 12.29 degrees at 480°/s, and 105.8 ± 14.28 degrees at 660°/s). Peak oxygen uptake was higher in the recumbent position (50.3 ± 4.43 ml·kg<sup>-1</sup>·min<sup>-1</sup>) than in the supine position (48.7 ± 5.10 ml·kg<sup>-1</sup>·min<sup>-1</sup>). At maximum exertion, the heart rate and whole-body rate of perceived exertion (RPE) were unaffected by position, but leg muscle RPE was higher in the supine position (19.5 ± 0.53 than in the recumbent position (18.8 ± 0.71). These results suggest that the supine position is more suitable for muscle strength exertion than the recumbent position, and this may be due to different hip joint angles between the positions. On the contrary, the endurance capacity was higher in the recumbent position than in the supine position. Since leg muscle RPE was higher in the supine position than in the recumbent position, it was suggested that different burdens imposed on active muscles in both positions exerted an impact on the result of the endurance capacity.

**Key words:** Pedaling position, recumbent, supine, leg muscle strength, oxygen uptake.

### Introduction

Pedaling exercise in various positions such as upright (i.e. vertical), recumbent (i.e., seat angle from 105 to 150 degrees between the backrest and seat) or supine (i.e. horizontal) posture can be used to measure the abilities of aerobic, power and endurance performance in healthy people and cardiovascular impaired patients.

Previous studies have indicated that pedaling exercise in either the recumbent or supine position at sub-

maximal intensity is associated with lower heart rates (Bonzheim et al., 1992; Denis et al., 2006; Egana et al., 2006; 2007; 2010; Koga 1999; Quinn et al., 1995, Walsh-Riddle et al., 1989), less oxygen uptake (Bonzheim et al., 1992; Denis et al., 2006; Egana et al., 2006; 2010; Quinn et al., 1995, Saitoh et al., 2005; Jones et al; 2006) and increased ventilation (Egana et al., 2006; Saitoh et al., 2005) as well as stroke volume (Cotsamire et al., 1987; Egana et al., 2010; Leyk et al., 1994) compared to pedaling exercise on a standard bicycle-type ergometer, which is in the upright position. A few researchers compared the changes in cardiovascular responses between pedaling in the recumbent and supine positions. Some studies found that heart rate and oxygen uptake during submaximal intensity exercise is lower in the supine position than in the recumbent position (Egana et al., 2010; Quinn, et al., 1995). However, at maximum and/or near-maximum exercise intensity, some studies showed no differences in cardiovascular function, including maximum oxygen uptake, between the two positions (Quinn, et al., 1995), whereas other studies showed that maximum oxygen uptake in the recumbent position is higher than that in the supine position (Takahashi et al., 1998). Therefore, a debate remains regarding the differences in maximum exercise capacity between the two positions.

Pedaling exercise in the recumbent and supine positions was performed with the legs kept parallel to the ground. It has been reported, however, that such postures of pedaling exercise decrease blood flow to active muscles in compared to bicycle-type ergometer with legs kept vertical (Egana et al., 2006; 2007; 2010) and lowered oxygen supply to these muscles (Denis, 2006). Therefore, it is considered that pedaling exercise with the legs situated parallel to the ground may increase the burden on leg the muscles. As muscle strength exertion during pedaling in the recumbent and supine positions has not been determined, the characteristics of muscle strength exertion in the two positions are not yet clear. However, previous studies that measured changes in position and muscle strength exertion during pedaling exercise induced by changing the trunk angle or seat-tube angle using a bicycle-type ergometer found that keeping the trunk angle vertical, rather than narrowing the angle of the hip joint as in racing style, increases power efficacy (Price et al., 1997). As the angle of the hip joint is different between the recumbent and supine positions, maximum muscle strength exertion capacity is estimated to vary with a change in position.

So far, no studies have directly compared the maximum muscle strength and maximum endurance capacity between the supine and recumbent positions. However, in a study that imposed a constant load of pedaling exercise under submaximum condition, Egana et al. (2010) reported that although exhaustion time did not differ between the upright and recumbent positions, the time shortened in the supine position than in the two positions. Meanwhile, a study using a bicycle-type ergometer reported that exercise with a wider hip joint angle proved to be superior in exerting muscle strength. Based on these findings, we proposed a hypothesis that maximum exercise capacity may change depending on the position, rather than the supposition that either the supine or the recumbent position always shows the higher maximum muscle strength and maximum endurance capacity.

## Methods

### Subjects

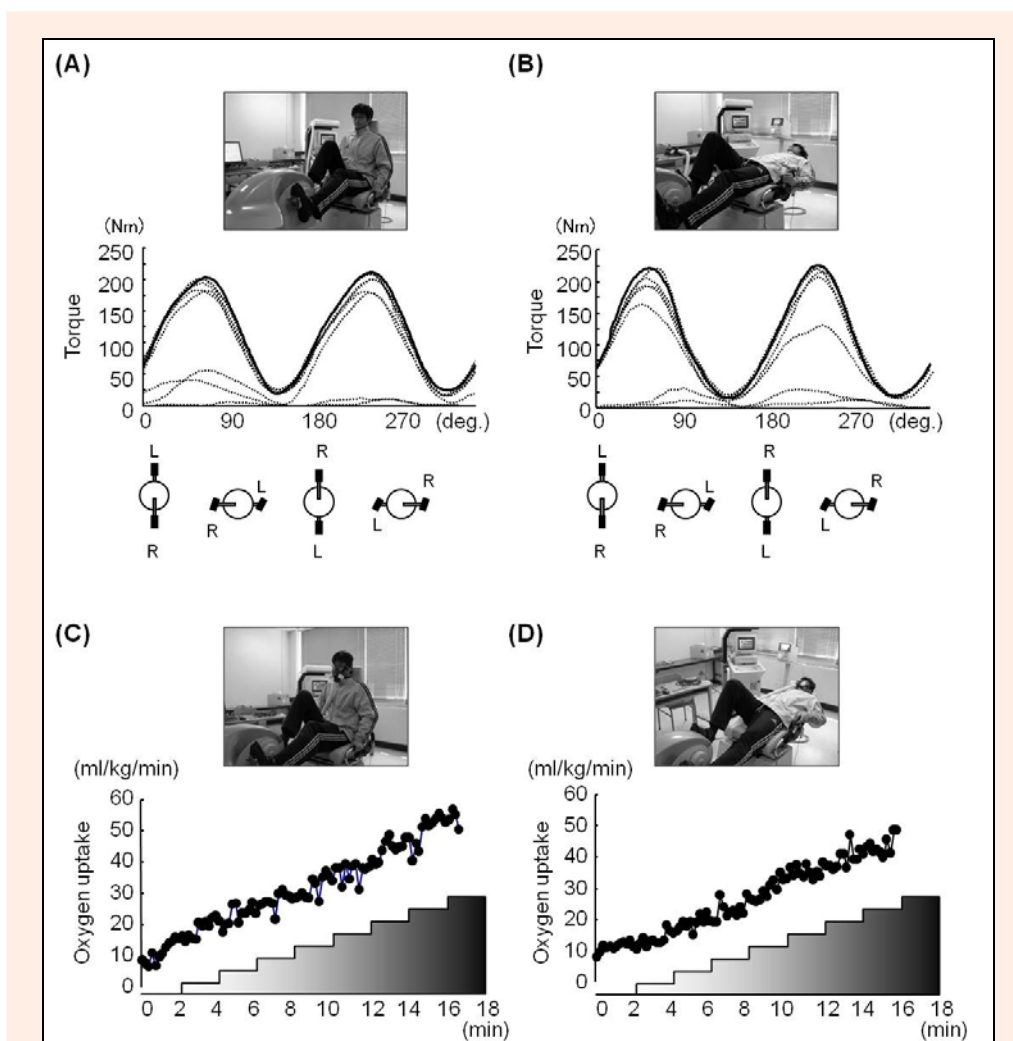
Subjects in this study were eight healthy males (height:  $1.73 \pm 0.05$  m, weight:  $66.6 \pm 6.5$  kg, BMI:  $22.2 \pm 1.3$   $\text{kg}\cdot\text{m}^{-2}$ , age:  $25.3 \pm 2.3$  years). Subjects were all normotensive without having any clinical conditions such as

neurological, cardiovascular, pulmonary, kidney, and musculoskeletal problems. Those suffering from hip, knee, ankle joint pain and taking medication were excluded. This study was approved by the ethics committee of Yonezawa Women's Junior College, and all subjects gave their informed consent to the experimental protocol.

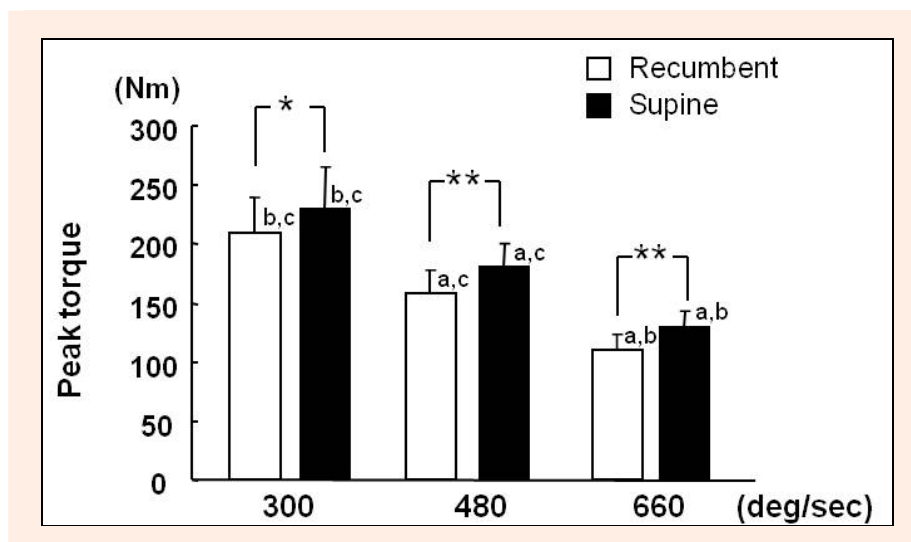
### Experimental procedure

Exercise tests were performed in the recumbent and supine positions using a position-controllable cycle ergometer (StrengthErgo; Mitsubishi Electric Co. Tokyo, Japan). This ergometer was controlled by a servo motor and can be programmed with various exercise programs by a personal computer. Each subject was measured for maximum leg muscle strength in isokinetic mode during the pedaling, and maximum oxygen uptake was measured by maximal incremental exercise test.

For the testing position, the recumbent position was set at a seat angle of 105 degrees between the backrest and seat, and the pedal shaft was set at 55 cm from ground level. In the supine position, the seat was tilted rearward to 170 degrees, and the crank axis was set the same as in the recumbent position (Figure 1).



**Figure 1.** Measurement of muscle strength and oxygen uptake in each body position (A), (B): The solid line indicates the peak torque output, and the dotted line indicates the muscle exertion other than peak torque measured for 10 cycles. (C), (D): Typical oxygen uptake data during maximum incremental exercise test.



**Figure 2.** Comparison of peak torques during pedaling exercise in the supine and recumbent positions. Values are expressed as the mean  $\pm$  SD ( $n=8$ ). a: significant difference from 300 deg/sec ( $p < 0.01$ ). b: significant difference from 480 deg/sec ( $p < 0.01$ ). c: significant difference from 660 deg/sec ( $p < 0.01$ ). \*: significant difference ( $p < 0.05$ ). \*\*: significant difference ( $p < 0.01$ ).

Each subject was given an orientation session to familiarize them with the equipment and the protocol to be used during the testing session. At the beginning of each experiment, the greater trochanter/crank center distance was adjusted for each individual so that the knees were slightly bent when the legs were maximally extended. To make the distance from the trochanter to the crank center the same for each subject, adjustments were made before every pedaling position. The feet were fixed with using a toe clip during the exercise test.

### Maximal isokinetic leg muscle strength

Isokinetic leg muscle strength was measured during pedaling at angular velocities of 300°/s, 480°/s, and 660°/s. In addition, maximum muscle strength was defined as the maximal peak torque within 10 cycles. Each subject's right leg was fitted with a goniometer in order to measure the angles of the knee and hip joints. Each measurement was set randomly, and adequate rest was allowed between measurements to ensure adequate recovery. Data of muscle strength and pedaling angle during pedaling derived from the ergometer and goniometer were digitized by 1000 Hz of sampling frequency through MacLab and recorded on a personal computer. The recorded data were analyzed later to evaluate peak torque and the angles and ranges of movement of hip and knee joints at the time of exertion of peak torque.

### Maximum incremental exercise test

All subjects underwent maximal incremental tests in both the recumbent and supine positions. The maximal tests were carried out randomly, and the interval between the tests was at least three days to ensure adequate recovery. The test was initiated at power output of 0W. Increments of 25 W were made every 2 min until exhaustion. In this test, subjects were encouraged to maintain a cadence of 50 rpm, as prompted by a metronome. Exercise test was terminated when the subjects reached volitional exhaustion and the pedal cadence could not be maintained at 45 rpm.

Oxygen consumption was measured every 10 seconds using an AE-10 (Aeromonitor, Minato Medical Science Co., Ltd., Japan). Heart rates were measured by ECG using a bipolar chest lead. To measure the overall effort sense, the rating of perceived exertion (RPE) (Borg 1973) was measured at rest and at the end of each stage.

### Statistical analysis

The numerical values were expressed as the mean  $\pm$  standard deviation. To assess the effects of body position and contraction velocity, 2 (trial)  $\times$  3 (velocity) repeated measures ANOVA was used. If significant main effects or interactions were confirmed, *Tukey post hoc test* were used to evaluate significant differences. Comparison between the recumbent and supine positions was carried out by paired t-test. The effect size of ANOVA was shown as Partial  $\eta^2$  ( $h_p^2$ ), while the effect size of t-test was indicated as Cohen's d (d). These analyses were performed with commercially available statistical software (SPSS 12.0J SPSS Inc., USA). Power was calculated with  $\alpha$ -level set at 0.05 (Origin 8.5, OriginLab Corp., USA). The significance level for all comparisons was set at  $p < 0.05$ .

## Results

### Leg muscle strength

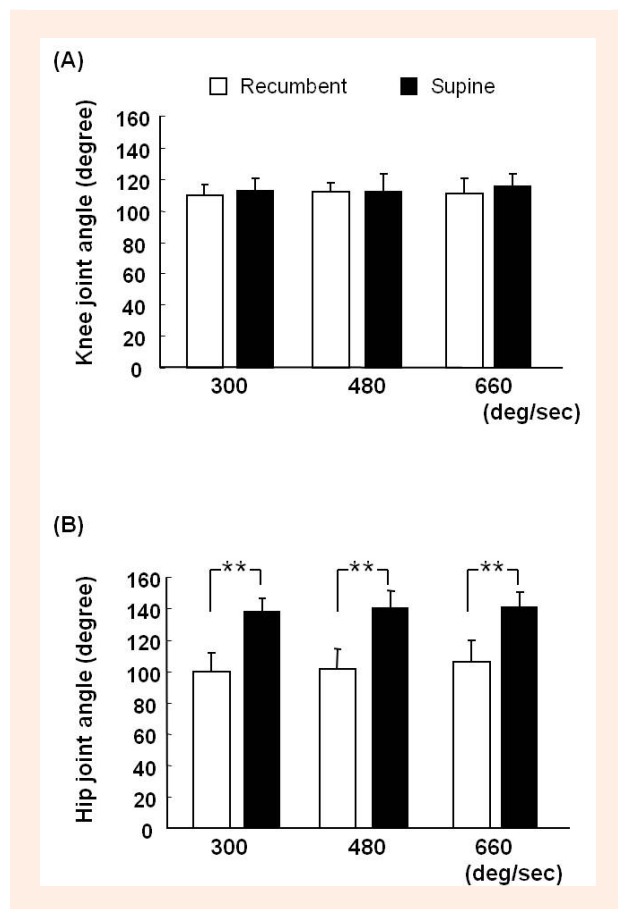
#### Peak torque

Comparison of peak torques during pedaling exercise in the supine and recumbent positions is presented at the Figure 2. Peak torque in the recumbent position and supine position decreased with increased angular velocity. Comparison of the recumbent and supine positions at each angular velocity showed significantly higher values for peak torque in the supine position than in the recumbent position at all angular velocities (300°/s = ES(d) = 0.58, power = 0.58, 480°/s = ES(d) = 1.11, power = 0.96, 660°/s = ES(d) = 1.40, power = 1). Two-way ANOVA showed that the position was ( $F(1,7) = 18.62$ ,  $p < 0.01$ ,  $ES(h_p^2) = 0.73$ , power = 0.86); the velocity was ( $F(2,14) = 206.60$ ,  $p <$

0.01,  $ES(h_p^2) = 0.97$ , power = 1); and the position  $\times$  velocity was ( $F(2,14) = 0.29$ ,  $p = 0.75$ ,  $ES(h_p^2) = 0.04$ , power = 0.06).

### Angle of knee joint and hip joint at time of peak torque

Comparison of knee and hip joint angles at peak torque is presented at the Figure 3. For knee Two-way ANOVA indicated that the position was ( $F(1,7) = 1.53$ ,  $p = 0.26$ ,  $ES(h_p^2) = 0.18$ , power = 0.21); the velocity was ( $F(2,14) = 0.61$ ,  $p = 0.56$ ,  $ES(h_p^2) = 0.08$ , power = 0.09); and the position  $\times$  velocity was ( $F(2,14) = 0.52$ ,  $p = 0.61$ ,  $ES(h_p^2) = 0.07$ , power = 0.12). A significant difference was not observed in main effects or interactions (Figure 3a).



**Figure 3.** Comparison of knee and hip joint angles at peak torque. Values are expressed as the mean  $\pm$  SD ( $n=8$ ). \*\*: significant difference ( $p < 0.01$ ).

For hip, two-way ANOVA showed that the position was ( $F(1,7) = 108.93$ ,  $p < 0.01$ ,  $ES(h_p^2) = 0.94$ , power = 1); the velocity was ( $F(2,14) = 2.56$ ,  $p = 0.11$ ,  $ES(h_p^2) = 0.27$ , power = 0.15); and the position  $\times$  velocity was ( $F(2,14) = 1.47$ ,  $p = 0.26$ ,  $ES(h_p^2) = 0.17$ , power = 0.09). The angle of the hip joint at peak torque was significantly greater in the supine position than in the recumbent position at all angular velocities (300°/s =  $ES(d) = 3.47$ , power = 1, 480°/s =  $ES(d) = 3.25$ , power = 1, 660°/s =  $ES(d) = 2.90$ , power = 1) (Figure 3b).

### Range of joint motion during pedaling

The range of joint motion, which is the maximum flexion angle of the knee, was  $60.3 \pm 8.89$  degrees in the recum-

bent position and  $60.0 \pm 7.43$  degrees in the supine position, showing no significant difference between the two positions ( $p = 0.89$ ,  $ES(d) = 0.04$ , power = 0.09). The maximum extension position of the knee joint was  $139.1 \pm 12.02$  degrees in the recumbent position and  $143.1 \pm 11.81$  degrees in the supine position, showing no significant difference between the two positions ( $p = 0.14$ ,  $ES(d) = 0.34$ , power = 0.20). The range of motion of the knee joint was  $78.8 \pm 10.83$  degrees in the recumbent position and  $83.1 \pm 6.12$  degrees in the supine position, showing no significant difference between the two positions ( $p = 0.16$ ,  $ES(d) = 0.49$ , power = 0.26).

The maximum flexed position of the hip joint was  $63.9 \pm 5.71$  degrees in the recumbent position and  $111.0 \pm 13.08$  degrees in the supine position. Thus, the supine position had a significantly greater maximum flexed position than that of the recumbent position ( $p < 0.01$ ,  $ES(d) = 4.67$ , power = 1). The maximum extension position of the hip joint was  $113.6 \pm 7.49$  degrees in the recumbent position and  $159.1 \pm 10.73$  degrees in the supine position. Thus, the supine position had a significantly greater maximum extension position than that of the recumbent position ( $p < 0.01$ ,  $ES(d) = 4.92$ , power = 1). The range of motion of the hip joint was  $49.7 \pm 7.11$  degrees in the recumbent position and  $48.1 \pm 7.26$  degrees in the supine position, showing no significant difference between the two postures ( $p = 0.600$ ,  $ES(d) = 0.22$ , power = 0.06).

### Endurance capacity

Maximum oxygen uptake was  $50.3 \pm 4.43$   $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  in the recumbent position and  $48.7 \pm 5.10$   $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  in the supine position. Thus, the recumbent position showed a significantly higher maximum oxygen uptake compared to the supine position ( $p < 0.05$ ,  $ES(d) = 0.34$ , power = 0.68). Maximum heart rate was  $192.4 \pm 9.05$  bpm in the recumbent posture and  $188.5 \pm 13.53$  bpm in the supine position, with no significant difference between the two postures ( $p = 0.38$ ,  $ES(d) = 0.34$ , power = 0.13). Overall body RPE at the point of maximum exertion was  $18.4 \pm 1.69$  in the recumbent position and  $17.5 \pm 1.77$  in the supine position, with no significant difference between the two positions ( $P = 0.09$ ,  $ES(d) = 0.51$ , power = 0.40). Leg muscle RPE was  $18.8 \pm 0.71$  in the recumbent position and  $19.5 \pm 0.53$  in the supine position ( $p < 0.05$ ,  $ES(d) = 1.20$ , power = 0.54). Thus, the supine position showed a significantly higher leg muscle RPE compared to the recumbent position.

### Discussion

The maximum value for each measured parameter did differ depending on the pedaling position. That is, the maximum torque was confirmed to be higher in the supine position than in the recumbent position at all angular velocities, whereas maximum oxygen uptake, which is an index of endurance capacity, was higher in the recumbent position than in the supine position. We speculate that these results were due to changes in hip joint angle and alteration of active muscle groups accompanying the change in pedaling position.

Isokinetic maximal peak torque measured in this



study during pedaling showed higher values in the supine position than in the recumbent position at all angular velocities. Differences during pedaling were observed between the recumbent and supine positions in the angle of peak torque, maximum flexed position, and maximum extension position of the hip joint. The difference in angle of the hip joint may have caused changes in exerted muscle strength. In the discussion by Ichinose et al. (1997) on the association between leg muscle strength and muscle lengths using ultrasound at various joint angles, it was reported that changes in muscle lengths associated with joint angles are one of the factors regulating muscle strength. Differing the hip joint angle changes the length of rectus femoris muscle, which is a bi-articular muscle, in the quadriceps femoris muscles. Previous reports have shown that the changes in the hip joint angle alter force production of knee extensor muscles, and Herzog et al. (1991) reported that the knee extensor strength decreases in the narrow hip joint angle. One of the factors of these phenomena is that it may involve in the length-tension relationship in skeletal muscle, which is explained by the sliding filament mechanism of muscle contraction. The tension is assumed to be related to number of cross-linkages between the actin and the myosin molecules, and when the muscle is shortened, the tension decreases so that the moving distance of the thin filaments is reduced (Ganong 2001). It is difficult to clarify such factor from present study. Further examination is necessary to assess or clarify that the muscle length in the leg muscles changes with the hip joint angle using ultrasound. Blazeovich et al. (1998) previously measured the angle of peak torque of exerted muscle strength in the hip joints of athletes using an isokinetic muscle strength measurement device at an angular velocity of 480°/s and reported a mean value of 51.65°, which is equivalent to a hip joint angle of about 130°. Therefore, it stands to reason that the supine position in this study was better for muscle strength exertion in the hip-joint muscle groups compared to the recumbent position. In research studying the changes in trunk angle and seat-tube angle using a bicycle ergometer, power transmission and exercise efficiency were higher at a wider hip joint angle than at a narrower hip joint angle (Price et al., 1997). In the present study, the hip joint angle was wider in the supine position than in the recumbent position. Therefore, taken the previous findings together with the results of this study, it was suggested that the supine position is superior to the recumbent position in transmission of power to the pedals.

On the other hand, maximum oxygen uptake as evaluated by maximum incremental testing showed higher values in the recumbent position than in the supine position. No differences in maximum heart rate or RPE were observed between the two positions. These results were similar to those of a previous study (Quinn et al., 1995). Various factors, including differences in oxygen kinetics, muscle blood flow, metabolism of active muscles, and muscle activities, have been suggested to the decreased peak oxygen uptake in the supine position compared to the recumbent position. Since these parameters were not measured in this study, it was difficult to discuss their effects in detail. However, based on the results of leg muscle RPE measured in the study, we confirmed that the

subjects exhibited higher effort sense in pedaling exercise in the supine position than in the recumbent position. Egana et al. (2006) reported that oxygen kinetics decreased in pedaling exercise in the supine position than in the upright position, while the oxygen kinetics did not differ between the recumbent and upright positions in a different study (Egana et al., 2010). Based on these reports, it was speculated that oxygen kinetics diminished in the supine position compared to the recumbent position. Therefore, the supine position might have promoted the accumulation of lactic and phosphoric acids in active muscles, leading to higher effort sense among the participants. In addition, such an impact on the active muscles might have affected the supraspinal via afferent nerves, thus hindering commands from the central nervous system to the active muscles (Amann et al., 2008). In another perspective, different muscle activities between pedaling exercise in the supine and recumbent positions may be the factor causing a difference in peak oxygen uptake. In pedaling exercise, the extension power of hip and knee joints is important (Ericson et al., 1986). Kato et al. (2000) examined the muscle activities of a group of muscles (gluteus maximus, biceps femoris, rectus femoris and vastus lateralis) was involved in the extension of hip and knee joints in pedaling in the supine and recumbent positions using surface electromyogram. They found no difference in the vastus lateralis activity between the two positions. However, muscle activities in the gluteus maximus and biceps femoris during pedaling showed higher values in the recumbent position than in the supine position. On the other hand, muscle activities of the rectus femoris was shown to increase in the supine position than in the recumbent position. Such differences in the group of muscles employed in pedaling might have affected endurance capacity. Further discussions are required for clear understanding of the active muscles activities.

In addition, no significant changes in the angle of peak torque for the knee joint or hip joint were observed in either the recumbent or supine position even at an increased angular velocity. These observations indicate the effectiveness of a cycle-type muscle strength assessment device for evaluating leg muscle strength (Beelen et al., 1994; Hamar et al., 1995; McCartney et al., 1983). Previous measurements of monoarticular muscle strength using isokinetic devices found that the optimal angle for maximum muscle strength exertion deviates due to a delay in reaching the peak torque angle associated with increased velocity (Kawakami et al., 2002). In the present study, no such delay in reaching the angle of peak torque was observed during isokinetic muscle strength exertion, even at increased angular velocity with a cycle ergometer. These phenomena are considered to be the characteristics of a cycle ergometer with which muscle strength can be measured even at faster angular velocities due to acceleration by rotating pedals. Because an isokinetic cycle ergometer allows muscle strength measurement and training at various velocities, it is possible to accommodate resistance at a fixed velocity throughout the range of motion which is a characteristic of isokinetic, and move multiple joints in rhythmical movements as in gaiting. This device may effectively contribute to gait rehabilitation and training as well as clarification of the level of leg muscle strength

(Beelen et al., 1994; Hamar et al., 1995; McCartney et al., 1983; Zeevi D 2004).

## Conclusion

It is clear from our results that the supine position showed higher maximum muscle strength compared to the recumbent position despite lower maximum oxygen uptake. Findings obtained from exploring the characteristics of the supine and recumbent positions can be applied to training or rehabilitation. In a previous study, Ray et al. (1991) compared pedaling exercise in the supine position with exercise on a bicycle-type ergometer, and reported that the maximum oxygen uptake by training demonstrated a high level of improvement not only in pedaling exercise in the supine position but also in exercise using a bicycle-type device. Combining the previous findings and results of the present study, it was suggested although the supine position places a greater burden on leg muscles, which is accountable for decreased endurance capacity, training in this position can contribute to improvement of leg muscle strength. Our results also demonstrate that it would be possible to exert muscle strength or conduct endurance training in a safe and comfortable manner by adjusting the widths of hip joint angles in the recumbent position in early rehabilitation of patients or initiation of exercise for those with poor physical strength. It should be noted, however, that it is necessary to make further discussions in consideration of physiological changes in active muscles accompanying shifts in position.

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### Key points

- Isokinetic maximal peak torque measured in this study during pedaling showed higher values in the supine position than in the recumbent position at all angular velocities.
- Maximum oxygen uptake as evaluated by maximum incremental testing showed higher values in the recumbent position than in the supine position.
- No significant changes in the angle of peak torque for the knee joint or hip joint were observed in either the recumbent or supine position even at an increased angular velocity. These observations indicate the effectiveness of a cycle-type muscle strength assessment device for evaluating leg muscle strength.

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