

Quadriceps muscle strength and its relationship to radiographic knee osteoarthritis in Japanese elderly

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Abstract

Background Knee osteoarthritis (OA) is a multifactorial disease and strongly affected by mechanical factors. The aims of the present study were to assess validity and reliability of a new muscle strength measuring device, the Quadriceps Training Machine (QTM) and evaluate the relationship between quadriceps strength measured by QTM and radiographic knee OA by epidemiological survey.

Methods The isometric knee extension muscle strength of QTM was compared with BIODEX in 24 healthy adults. Then, the relationship between radiographic knee OA and

quadriceps strength using QTM was investigated with 2,032 knees in 1,016 subjects by an epidemiological survey (Matsudai Knee Osteoarthritis Survey).

Results Significant correlation was observed between QTM and BIODEX ($r = 0.69, 0.82$). In the Matsudai Knee Osteoarthritis Survey, the prevalence of radiographic OA (grade II or higher upon Kellgren–Lawrence classification) was: 13, 36.9, 67.8, and 86.5 %, regarding women in their fifties, sixties, seventies, and eighties, respectively, and was 1.7, 13.4, 33.5, and 66.2 % regarding men, respectively. Quadriceps muscle strength declined following 50 years of age, and significant decline was observed in the their sixties and seventies. Quadriceps muscle strength of the OA group (grades II, III and IV) was significantly declined compared with that of the Non-OA group (grade-0 and I). Furthermore, the tendency of the muscle strength level to decline with the progression of knee OA grade was particularly observed between grade 0 and grade I in both men and women and between grade I and grade II in men.

Conclusion The relationship between radiographic knee OA and quadriceps strength was quantitatively evaluated by an epidemiological survey, and we found a correlation between knee OA and the decline in quadriceps strength. Furthermore, it was suggested that the decline in quadriceps muscle strength may be more strongly related to the incidence of knee OA than to its progression.

This study was performed in Niigata University, 2-8050, Igarashi, Nishi-ku, Niigata City 950-2181, Niigata, Japan.

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Introduction

Knee osteoarthritis (OA) is a chronic degenerative disease of the knee joint accompanying aging, causing a decline in the knee joint function while standing and walking when it has advanced and greatly affecting daily life. Regarding the prevalence of knee OA, it is reported that radiographic

knee OA is observed in 37 % of adults aged 60 years old or older and, furthermore, symptomatic knee OA is observed in 12 % in the United States [1]. Meanwhile, in Japan, Yoshimura et al. [2] reported that radiographic OA was observed in 42 % of men and 62 % of women aged 40 years or older in the ROAD (Research on Osteoarthritis/Osteoporosis Against Disability) study. Knee OA is a multifactorial disease and several previous studies have described various risk factors associated with its incidence and progression. They included age, gender, ethnicity, obesity, smoking, occupation, presence of knee injuries, metabolic diseases, quadriceps muscle strength, knee alignment, osteoporosis, hormones, genes, etc. However, there are still many factors that remain unclear [3–22].

Among these, it is believed that mechanical factors such as body weight, knee alignment, joint stability, bone mineral density, muscle strength of the lower extremity, thrust while walking, and adduction moment may have a large effect on the incidence and progression of knee OA. Among them, we focused on quadriceps strength, which is believed to be effective for prevention and suppression of the disease.

In order to clarify the relationship between knee OA and quadriceps strength, a detailed and quantitative analysis and evaluation with a large number of subjects needs to be conducted in the field of epidemiologic study. However, currently, in terms of devices that may quantitatively evaluate muscle strength of the lower limbs in detail, only large devices installed in major institutes exist such as Cybex, Biodex, etc. Therefore, we developed a new muscle strength measuring device (QTM) allowing for detailed quantitative measurement of the quadriceps strength, which is also lightweight and portable.

The first purpose of the present study was to assess validity and reliability of a new muscle strength measuring device. The second purpose was to investigate the

relationship between radiographic knee OA and quadriceps strength by an epidemiological survey with a large number of subjects using this device.

Subjects and method

Investigation of validity and reliability of QTM

The Quadriceps Training Machine (QTM) (QTM-05F, Alcare Co., Ltd. Tokyo, Japan) was developed based on the method for quadriceps setting training in a knee extension position, which is one exercise of quadriceps muscle training. The present device is 300 mm in height, 350 mm in width, and 100 mm in height with a total weight of 3.4 kg, thus making it small, lightweight and portable. This device has a knee holding part at its center corresponding to the knee joint with approximately 20° of flexion (Fig. 1).

The QTM has 3 functions including a load measuring mode, body composition mode, and training mode. Among these, the load measuring mode allows for chronological measurement of the knee extension muscle strength by a strain gauge measurement. The sampling rate of the muscular strength measurement data was 250 ms, the smallest measurement unit was 0.1 kg, and the maximum measured value was 135 kg.

The subjects carried out knee extension exercises by putting their knee joint on the knee holding part of the QTM, with the load pressure applied to the QTM in the popliteal region at this time measured and displayed as the isometric knee extension muscle strength (quadriceps strength) (Fig. 2). In order to investigate the accuracy of the measuring value of QTM, the isometric knee extension muscle strength using QTM and the Biodex system 3 (BDX-3, Biodex Medical System Inc., Shirley, New York, USA) were compared with 24 healthy adults (13 men, 11

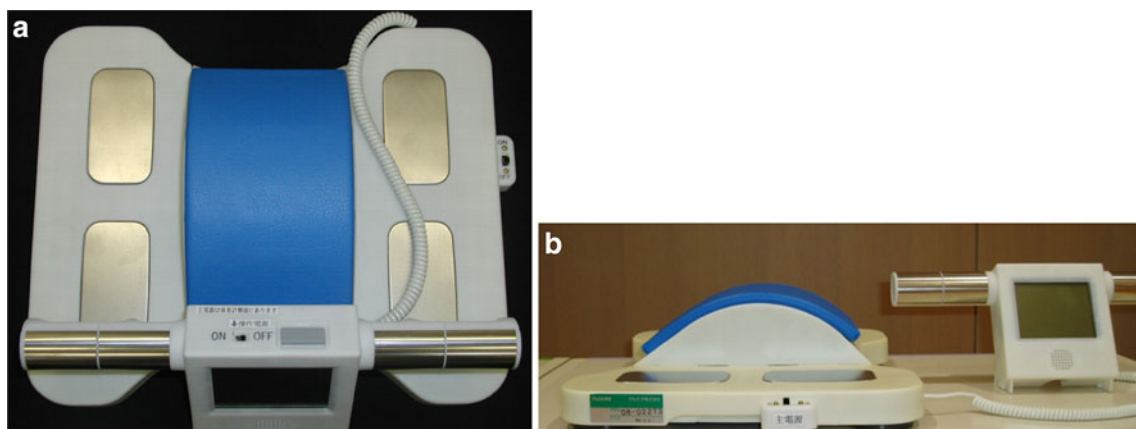


Fig. 1 Quadriceps muscle training machine (QTM). **a** Top view, **b** side view. QTM is 300 mm in height, 350 mm in width, and 100 mm in height with a total weight of 3.4 kg

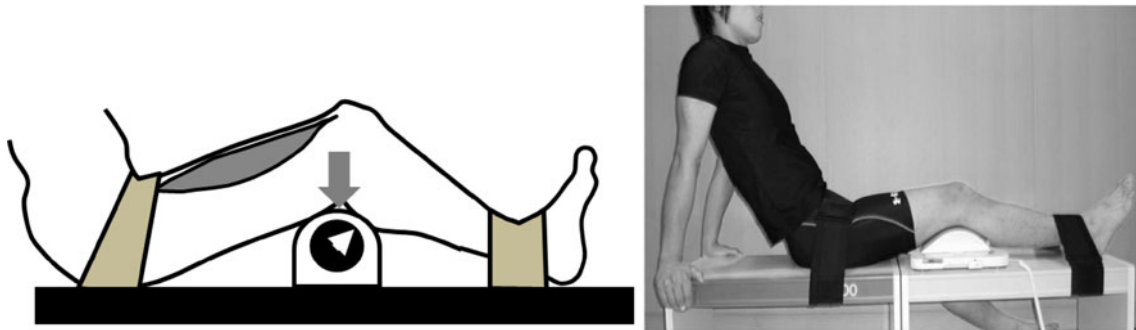


Fig. 2 Position setting of QTM. The subject extends knee on the knee holding part of the QTM. The load pressure applied to the QTM was measured and displayed as the isometric knee extension muscle strength

women, average age: 31.5 ± 8.3 years old). The right knee of all cases was evaluated and measurement was taken regarding 2 sets using both QTM and BIODEX with 5 s of measurement time, taking a break of 20 s in between, and following 5 min of warm-up with an exercise bike at 50w. Moreover, in order to investigate the reproducibility, the order of measurement of QTM and BIODEX was reversed and then the same measurement was conducted again a week following the initial measurement. The maximum measuring value was adopted for both trials, and correlation of the measuring value of QTM and BIODEX was obtained. Regarding the statistical analysis, Pearson's correlation coefficient was used and a level of significance of less than 5 % was determined to have statistical significance.

Relationship between quadriceps strength by QTM and radiographic knee osteoarthritis

The subjects were 1,037 inhabitants (492 men and 535 women) in the Matsudai district in Niigata prefecture and they all participated in an extensive survey of knee OA in 2010 (Matsudai Knee Osteoarthritis Survey). Of 1,037 participants, 21 people were excluded due to data deficiency, and 1,016 subjects (482 men and 534 women) were finally investigated.

Bilateral quadriceps strength of each subject was measured by the QTM. In order to eliminate the effect of physique, measured value was divided by body weight and we evaluated this data as muscle strength per body weight ratio (M/P ratio). Furthermore, a weight-bearing standing knee radiograph was obtained and graded according to the Kellgren–Lawrence classification [23]. Radiographic knee OA was defined if a Kellgren–Lawrence grade of II or higher was detected.

From these results, (1) the change in quadriceps muscle strength level by gender and by age, (2) comparison of the quadriceps muscle strength level between the non-OA group and OA group, and (3) the change in quadriceps muscle strength level by gender and by knee OA grades,

were investigated regarding 2,032 knees in 1,016 subjects. Regarding the statistical analysis, a *t* test without correspondence was used for the investigation by gender and a Student's *t* test without correspondence as well as analysis of covariance was used for the comparison of the non-OA group and OA group in order to eliminate any effects due to age factors. Moreover, Scheffe's method of paired comparisons was used for the investigation by age and knee OA grade. In all investigations, 5 % or less was determined as the level of significance. All statistical analyses were performed using SPSS version 19.

The study was approved by the Ethics Committee of our University School of Medicine (receipt number 978, 979).

Results

Validity and reliability of QTM

The correlation of maximum measuring value between QTM and BIODEX was $r = 0.69$ ($p < 0.01$) upon the first measurement and $r = 0.82$ ($p < 0.01$) upon the second measurement conducted the following week, with significant correlation observed at both measurements (Fig. 3). Moreover, a good correlation was also observed between the first and second measured QTM value, at $r = 0.92$ ($p < 0.01$).

Relationship between quadriceps strength by QTM and radiographic knee osteoarthritis

In the Matsudai Knee Osteoarthritis Survey, the average age of the 1,016 subjects was 65.9 ± 13.0 years old (men: 66.9 ± 13.1 years old, women: 64.9 ± 12.7 years old) with most males and females in their seventies, followed by subjects in their sixties and fifties.

Moreover, there were more women subjects in all age groups except for the forties and eighties or older, in which there were more men than women. The prevalence of

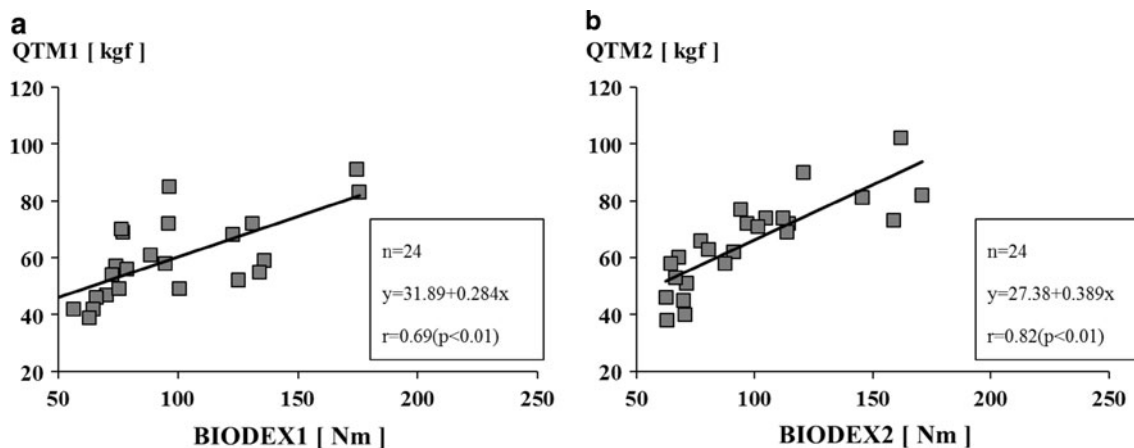


Fig. 3 Correlation of maximum measuring value between QTM and BIODEX. **a** First measurement, **b** second measurement. The correlation between QTM and BIODEX was $r = 0.69$ ($p < 0.01$) upon the

first measurement and $r = 0.82$ ($p < 0.01$) upon the second measurement, with significant correlation observed at both measurements

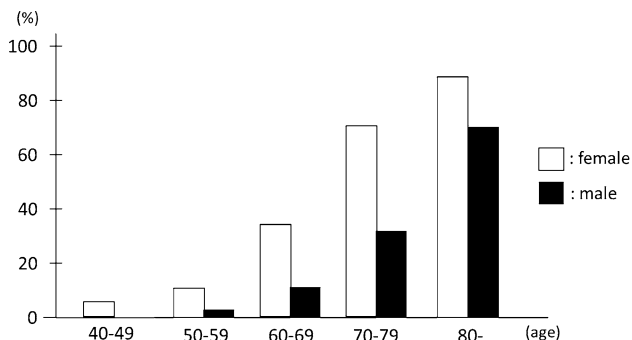
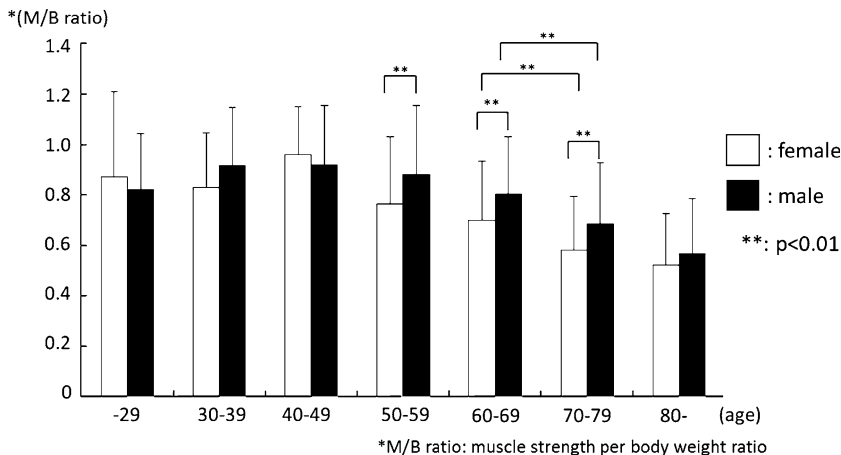


Fig. 4 Prevalence of radiographic knee OA (grade-II or higher upon Kellgren–Lawrence classification) by age

radiographic OA upon Kellgren–Lawrence classification by age when grade II or higher was: 13, 36.9, 67.8, and 86.5 %, regarding women in their fifties, sixties, seventies, and eighties, respectively, and was 1.7, 13.4, 33.5, and 66.2 % in men. The prevalence in women exceeded that of men in all age groups of 40 years old or older (Fig. 4).

Regarding the change in quadriceps muscle strength level by age, differences due to age were not observed in either men or women until the forties; however, the muscle strength level declined with age following 50 years of age, and a significant decline in the muscle strength level was observed in both men and women in their sixties and seventies. Moreover, the level of muscle strength of men in their fifties, sixties, and seventies was significantly higher than that of women (Fig. 5). Knee OA grades 0 and I were classified into the non-OA group and grades II, III, and IV were classified into the OA group by Kellgren–Lawrence classification, and when the muscle strength level was compared between these two groups, a significant decline in the muscle strength level was observed in the OA group in both men and women (Fig. 6). Furthermore, a tendency of the quadriceps muscle strength level to decline with the progression of knee OA grade was observed in both men and women, and particularly, a significant decline was observed between grade 0 and grade I in both men and women and between grade I and grade II in men (Fig. 7).

Fig. 5 Quantitative quadriceps muscle strength by age



Discussion

In the present study, we showed the clinical utility of the QTM and clarified the relationship between radiographic knee osteoarthritis and quantitatively evaluated quadriceps muscle strength.

Currently, isokinetic devices such as Cybex, Biodex, and KIN-COM (ChatteX, Hixson, TN) allow for the most detailed measurement regarding the quantitative evaluation of the muscular strength of the lower limbs; however, these are expensive, large-scale, and impossible to move. Meanwhile, the Hand Held Dynamometer (HDD) is often used as a portable muscle strength dynamometer, but problems such as a limited dynamometry value have been suggested even though credibility is obtained [24, 25]. Moreover, although there are also chair-shaped measuring training devices that apply a leg press, these have problems with portability due to their weight [26]. The QTM of the current study has higher usability compared to other devices in terms of its small size, light weight, and good portability, as well as the fact that it has good correlation with Biodex

and high credibility of measurement, and furthermore, the fact that it comprises not only the muscle strength measuring function but also muscle strength training functions and body composition evaluating functions. Accordingly, it is believed that this device may be actively used in investigational research and muscular strength training guidance with groups other than medical institutes such as sites of epidemiological surveys, nursing homes, and schools.

There are several epidemiological studies regarding the relationship between knee OA and quantitatively evaluated quadriceps muscle strength. Slemenda et al. [16] measured the quadriceps muscle strength of 342 people using KIN-COM and reported that the muscle strength to body weight ratio of women with knee OA declined by 15 % compared to that of healthy individuals. Moreover, Baker et al., evaluated quadriceps muscle strength using a chair-shaped measuring device with strain gauge in an epidemiological survey with 2,472 people as the subjects in Beijing, China, and showed that reduced quadriceps muscle strength was correlated to both tibiofemoral and patellofemoral OA in both men and women [27]. Recently, Segal et al., measured quadriceps muscle strength and hamstring muscular strength using Cybex 350 in a multi-institute knee OA study (MOST Study) in the United States and evaluated 3,865 knees in which observation regarding the change of the joint space was possible for the subsequent 30 months. As a result, it was clarified that the decline in quadriceps muscle strength was related to the joint space narrowing in women [28]. Meanwhile, in Japan, Ikeda et al. [29] measured the volume of the quadriceps muscle using CT regarding 738 young and middle-aged women and showed that there was a relationship between quadriceps muscle atrophy and radiographic knee OA. However, in the ROAD study [2], which is currently the largest cohort study in Japan related to knee OA, the relationship between quadriceps muscle strength and knee OA was not mentioned.

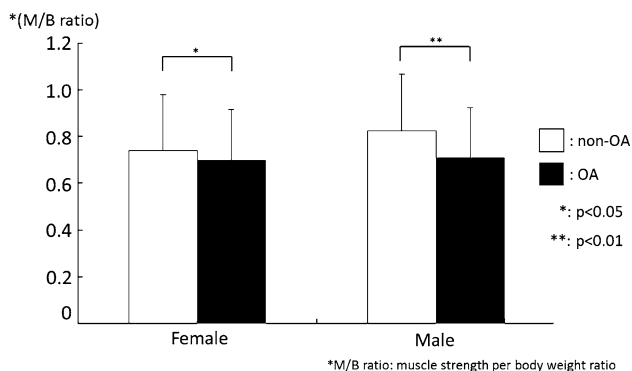
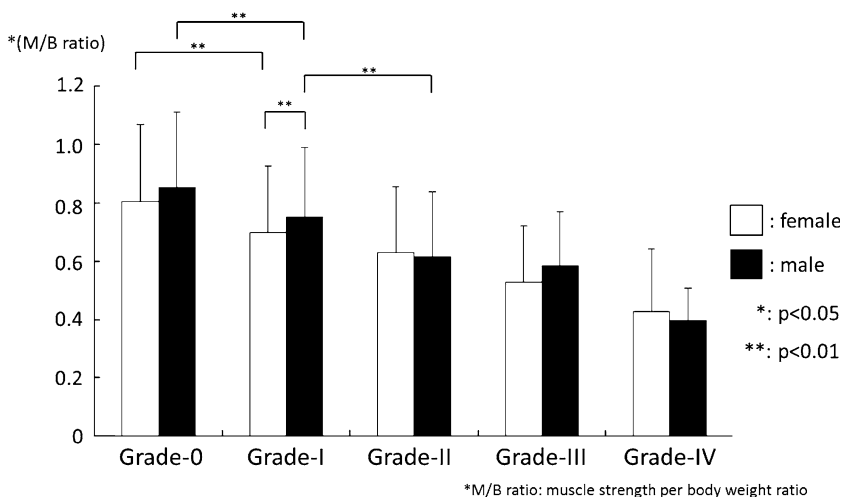


Fig. 6 Comparison of quadriceps muscle strength between non-OA group (K-L grade 0, I) and OA-group (K-L grade II, III, and IV)

Fig. 7 Change of quadriceps muscle strength by knee OA grade



In the current study, the relationship between radiographic knee OA and quantitative quadriceps muscle strength in an epidemiological survey using multiple cases was evaluated. Moreover, the prevalence of radiographic OA in the Matsudai Knee Osteoarthritis Survey was the same as that described in other reports, and from this fact, the results obtained from analysis of the present cohort are, therefore, suggested to be valid as data showing the pathophysiology of knee OA. Quadriceps muscle strength of the OA group was observed to be declining more in both men and woman compared to the non-OA group in this study. This suggests that there is a correlation between knee OA and the decline in quadriceps muscle strength; it was clarified that knee OA in Japan comprised the same pathophysiology as knee OA in other countries regarding quadriceps muscle strength. Furthermore, a significant decline in muscle strength was observed from grade 0 to I and from grade I to II, and it may be said that the fact that a significant change was not observed from grade II to III or from grade III to IV suggests that the decline in quadriceps muscle strength is more strongly related to the incidence of knee OA than to its progression. However, Segal and Glass [30] described in a recent review that reinforcement of quadriceps muscle strength is effective in decreasing the risk of symptomatic knee OA, but there is no evidence regarding whether or not it affects the onset of radiographic knee OA.

There were two limitations in the present study. First, this study was a cross-sectional study and the causal relationship between knee OA and quadriceps muscle strength has not been clarified. Second, the investigation was only conducted regarding radiographic knee OA, not for symptomatic knee OA. It is believed that longitudinally analyzing the same cohorts and investigating whether or not a decrease in quadriceps muscle strength is the cause of incidence or progression of knee OA in addition to conducting the same investigation regarding symptomatic knee OA will be necessary in the future.

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Conflict of interest The authors declare that they have no conflict of interest.

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