Aging-related changes in strength and cross-sectional area of knee flexor muscles

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Research Article

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Abstract

Background: We aimed to study the association between flexor muscle strength in the knee joint and cross-sectional area (CSA) on magnetic resonance imaging (MRI). We also evaluated aging-related changes in flexor muscle strength and CSA. We hypothesized that muscle strength is associated with muscle CSA on MRI and that such relationships would differ among the flexor muscles. Furthermore, we hypothesized that muscle strength and CSA would decline, and the reduced rate of muscle CSA would differ among the flexor muscles with aging.

Methods: A total of 252 patients (mean age, 33.6 years; range, 11–66 years) who visited the outpatient clinic with knee pain between September 2006 and August 2009 were retrospectively analyzed. The CSA of each knee joint flexor muscle (biceps femoris, sartorius, gracilis, semitendinosus, and semimembranosus) was measured on MRI axial images at the supra-patellar level. We evaluated flexor muscle strength (peak torque, N.m) using a Cybex dynamometer at 60 and 180°/s and evaluated its correlation with CSA.

Results: Mean CSA was 605.4 mm^2 for the semimembranosus, 444.7 mm^2 for the biceps femoris, 282 mm^2 for the sartorius, 55.4 mm^2 for the semitendinosus, and 34.1 mm^2 for the gracilis. Mean peak torque was 67.4 N.m and 52.7 N.m at 60°/s and 180°/s, respectively. CSA was positively correlated with flexion strengths of 60°/s ($r = 0.363$, $p = 0.000$) and 180°/s ($r = 0.354$, $p = 0.000$). Muscle strength was associated with CSA for all muscles, except the gracilis ($r = 0.056$, $p = 0.375$). Flexion strength decreased significantly with age after the third decade of life. Total CSA decreased with age ($r = -0.247$, $p = 0.000$). CSA of the biceps femoris, sartorius, semimembranosus, and semitendinosus decreased significantly, while CSA of the gracilis tended to decrease non-significantly with aging.

Conclusions: Muscle strength was associated with total muscle CSA on MRI and the CSA of every muscle but the gracilis. Flexion strength decreased significantly with aging after the third decade of life. Total CSA decreased significantly with aging. CSA of the biceps femoris, sartorius, semimembranosus, and semitendinosus decreased significantly, whereas that of the gracilis decreased slightly with aging.

Level of Evidence: Level III, retrospective comparative study

Background

A significant increase in sports activity participation has been observed across all age groups, thereby increasing the frequency of sports injuries around the knee. Thus, understanding the muscles around the knee is important for patients as well as orthopedic physicians and rehabilitation trainers. Weakening of muscle strength around the knee tends to make the knee vulnerable to damage with aging. Age-related decreases in size and strength are characteristic of the muscles of the human body [1–3]. Such a decline in muscle strength leads to decreased functional and living abilities and an increased risk of injury associated with common daily activities [4, 5]. Thus, a quantitative assessment of muscular strength around the knee joint is required. In addition, a correlation between muscle strength and muscle cross-sectional area (CSA) has been reported [6–8], and muscle size is an important determining factor of muscular strength [9, 10]. However, the proportion of bending force according to muscle type and how aging affects muscle strength are unclear.

Therefore, we hypothesized that muscle strength is associated with muscle CSA on magnetic resonance imaging (MRI) and that the relationship between muscle strength and CSA differs among the flexor muscles. Additionally, muscle strength and CSA decline with aging, and the rate of reduction in muscle CSA differs for each flexor muscle. To evaluate this hypothesis, we studied the relationship between flexor muscle strength of the knee joint and flexor muscle CSA on MRI. We also compared the strength and CSA of each flexor muscle and evaluated the changes in flexor muscle strength and CSA on MRI with aging.

Methods

Patients

A total of 252 patients who visited the outpatient clinic with acute-onset knee pain (< 1 month) were reviewed retrospectively between September 2006 and July 2009. The inclusion criteria were: (1) acute-onset knee pain within < 1 month of symptom onset; (2) use of both knee MRI and a Cybex evaluation. Patients were excluded from the study if they had chronic-onset knee pain or could not undergo the Cybex test because of persistent knee pain. A total of 204 males and 48 females (mean age, 34 years; range, 11–66 years) were included. The patients were divided into four groups by age.

MRI muscle quantification

All patients underwent an MRI study (3-T Achieva; Philips Medical Systems, Andover, MA, USA). We measured knee flexor muscle (biceps femoris, sartorius, gracilis, semitendinosus, and semimembranosus) CSA on an MRI axial view [11] at the patellar upper pole (Fig. 1) [12]. The lining along the boundary of the muscle outline was recorded for the CSA of the knee flexor muscles on the INFINITT system using a free-hand technique (Fig. 2).

Muscle power

The Cybex test was performed at the 6-month follow-up in patients without pain to rule out muscle weakness due to pain. We measured flexor muscle strength (peak torque, N.m) using a Cybex dynamometer at 60 and 180°/s for an objective evaluation of strength. Patients sat on the examination table with their upper body and thighs fixed. The Cybex workout axis coincided with the axis of knee flexion, and the lower-extremity axis was parallel to the dynamometer arm. Muscle power was recorded at 60°/s after four exercise repetitions. The test was repeated at 180°/s in the same manner.

Statistical analysis

Data are reported as means ± standard deviation. SPSS software ver. 21.0 (SPSS Inc., Chicago, IL, USA) was used for analyses. Correlations between muscle strength and CSA were analyzed using Pearson’s correlation coefficient test. Muscle strength and muscle CSA by age were assessed by one-way analysis of variance. Values of $P < 0.05$ were considered statistically significant.

Results

Muscle strength and CSA

The semimembranosus muscle had the highest CSA. The mean values were: semimembranosus, 605.4 mm^2; biceps femoris, 444.7 mm^2; sartorius, 282 mm^2; semitendinosus, 55.4 mm^2; and gracilis, 34.1 mm^2 (Table 1). Mean peak torque was 67.4 N.m at 60°/s and 52.7 N.m at 180°/s (Table 2).

Table 1
Mean cross-sectional area of the knee flexor muscles.

	SM	Biceps femoris	Sartorius	ST	Gracilis	Total
Mean CSA (mm^2)	605.4 ± 265.8	444.7 ± 162.5	282.0 ± 110.3	55.4 ± 45.7	34.1 ± 27.2	1421.7 ± 439.7

SM: semimembranosus; ST: semitendinosus; CSA: cross-sectional area

Table 2
Mean peak torque at 60°/s and 180°/s.

	60°/s	180°/s
Mean peak torque (N.m)	67.4 ± 26.9	52.7 ± 20.6

Total CSA was correlated with muscle strength at 60°/s (r = 0.363, p = 0.000) and 180°/s (r = 0.354, p = 0.000) (Fig. 3). All CSA values were correlated with muscle strength at 60°/s and 180°/s, with the exception of the gracilis muscle (r = 0.010, p = 0.877 at 60°/s; r = 0.056, p = 0.375 at 180°/s) (Figs. 4 and 5).

Muscle strength and CSA with aging

Muscle strength of the knee joint decreased significantly beginning in subjects in their 20s. Muscle strength was negatively correlated with aging at 60°/s (r = − 0.332, p = 0.000) and 180°/s (r = − 0.353, p = 0.000) (Fig. 6).

Total CSA decreased significantly with aging. Total CSA was negatively correlated with aging (r = − 0.247, p = 0.000) (Fig. 7). All CSA values decreased significantly with aging, with the exception of the gracilis (Fig. 8). The rates of reduction in muscle CSA were as follows: biceps femoris, 33.1%; sartorius, 28%; semimembranosus, 22.3%; semitendinosus, 21.9%; and gracilis, 0.6% (Table 3).

Table 3
Reduction in cross-sectional area with aging.

	Reduction rate (%)	P value
Biceps femoris	33.1	0.000*
Sartorius	28.0	0.001*
Semimembranosus	22.3	0.018*
Semitendinosus	21.9	0.023*
Gracilis	0.6	0.995
*, $p < 0.05$		

Discussion

We measured knee flexor muscle volume on MRI and determined the maximum flexion strength values. Total CSA—with the exception of that of the gracilis—and knee flexor strength decreased in older adults versus young adults. Bruce et al. [13] reported that the regression line between muscle strength and CSA cannot have a true intercept because if muscle CSA equals zero, there must be no force. Akagi et al. [6] reported that muscle volume is a major determinant of joint torque in each knee joint muscle group. Our results showed that all flexor muscle CSA values were correlated with flexion power and that CSA decreased with aging except for the gracilis. The mean CSA of the gracilis was 34.1 mm^2; therefore, a thin CSA did not affect knee flexion power and no change with aging was detected.

Aagaard et al. [11] found that training-induced changes in muscle fiber CSA differ among fiber types; i.e., type II fibers, which are recruited as the level of force increases, show more prominent hypertrophy than type I fibers. Johnson et al. [14] reported that fiber-type composition is more or less specific to the muscles and that there is a greater difference in the percentage of type II fibers between the anterior thigh and posterior muscle groups. In an animal study, Ariano et al. [15] discovered more type II muscle fibers in the semimembranosus and that the semitendinosus has almost 0% type II muscle fibers. Johnson et al. [14] reported that greater numbers of type II muscle fibers are present in the sartorius and biceps femoris in humans.

Knee flexor muscle volume and strength decreased significantly in older versus younger adults. In addition to a decline in muscle volume, other age-related neuromuscular changes that have been implicated in strength deficits include an infiltration of intramuscular fat, increased connective tissue, reduced contractile tissue, reduced neural drive, changes at the neuromuscular junction, increased antagonist muscle co-activation, decreased muscle fiber specific tension, and preferential atrophy of type II muscle fibers [16, 17]. Thus, the lack of a decrease in the volume of the gracilis can be explained by its fewer type II muscle fibers.

There are some limitations to this study. There may be concern about muscle atrophy on an MRI evaluation; however, since patients were excluded if they had chronic onset knee pain, muscle atrophy was likely minimal. Furthermore, we checked CSA on the MRI axial view at the level of the patellar upper pole and evaluated some gracilis and semitendinosus muscles at the tendinous level.

Conclusions

In summary, muscle strength was associated with total muscle CSA on MRI and the CSA of each muscle except the gracilis. Flexion strength decreased significantly with aging after the 20s. Total CSA decreased significantly with aging. CSA of the biceps femoris, sartorius, semimembranosus, and semitendinosus decreased significantly, whereas that of the gracilis tended to decrease slightly with aging. The relationship between the CSA of the gracilis and knee flexion strength was weak because of the low CSA. Thus, the reduction in muscle volume with aging could be due to the presence of fewer type II muscle fibers.

Abbreviations

CSA: cross-sectional area; MRI: magnetic resonance imaging; SM: semimembranosus; ST: semitendinosus

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the Kyung Hee University Hospital Institutional Review Board (KHUH 0845-08). All procedures were performed in accordance with relevant guidelines. Informed consent was obtained from all study participants and/or their legal guardians for study participation.

Consent for publication

Not applicable.

Availability of data and materials

Data and materials can be accessed through a request to the corresponding author, LHS.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

PSY contributed to the conception and design of the study, analysis and interpretation of data, drafting/revision of article. YKH contributed to the conception and design of the study, acquisition of data, analysis and interpretation of data, and drafting/revision of the article. KTS contributed to the acquisition and interpretation of data and revision of the article. LHS contributed to the conception and design of the study, analysis and interpretation of data, drafting/revision of article, as well as to the final approval of the article. All authors contributed to and approved the final manuscript.

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Figures

Figure 1

Measurement of flexor muscle cross-sectional area at the level of the patellar upper pole.

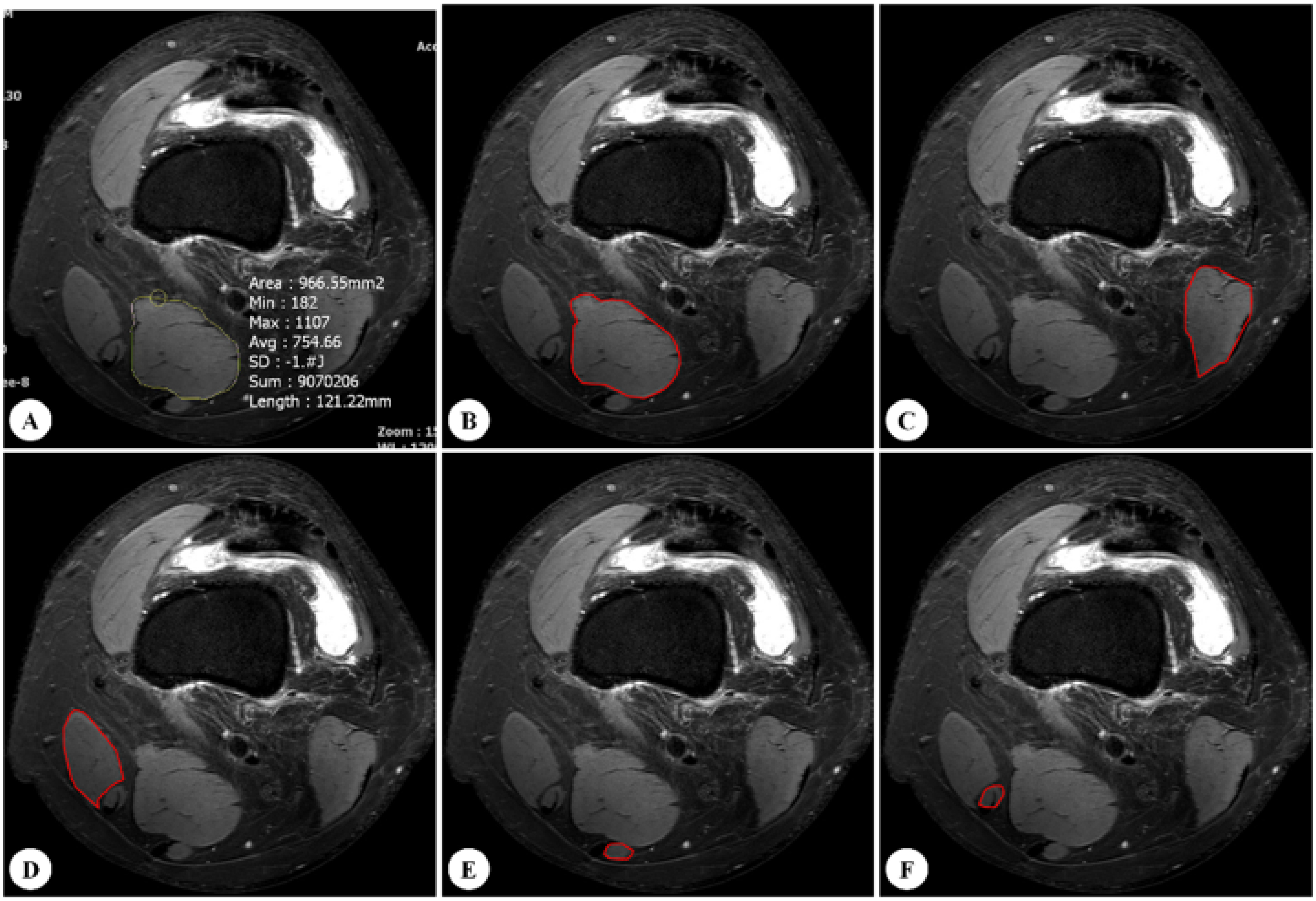

Figure 2

Cross-sectional area of the knee flexor muscles recorded using the INFINITT system. (A) The free-hand technique was used. (B) The semimembranosus, (C) biceps femoris, (D) sartorius, (E) semitendinosus, and (F) gracilis were recorded on the INFINITT system using a muscle outline.

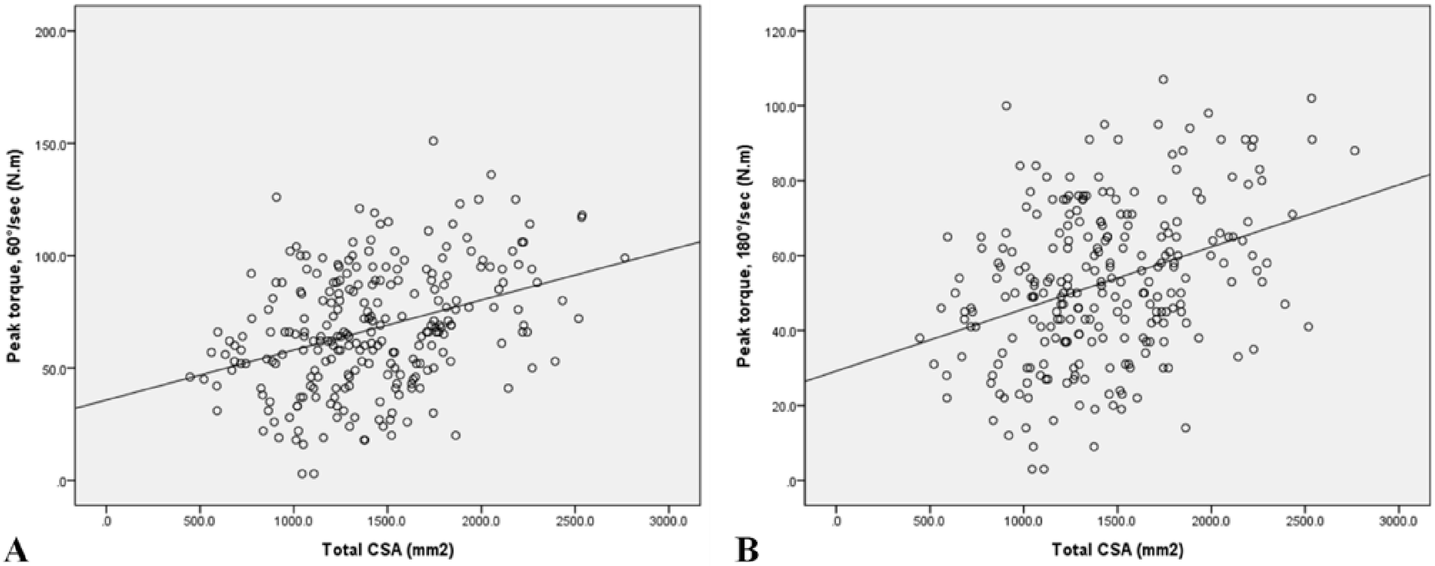

Figure 3

Relationships between muscle strength at (A) 60°/s and (B) 180°/s and total cross-sectional area of the knee flexor muscles.

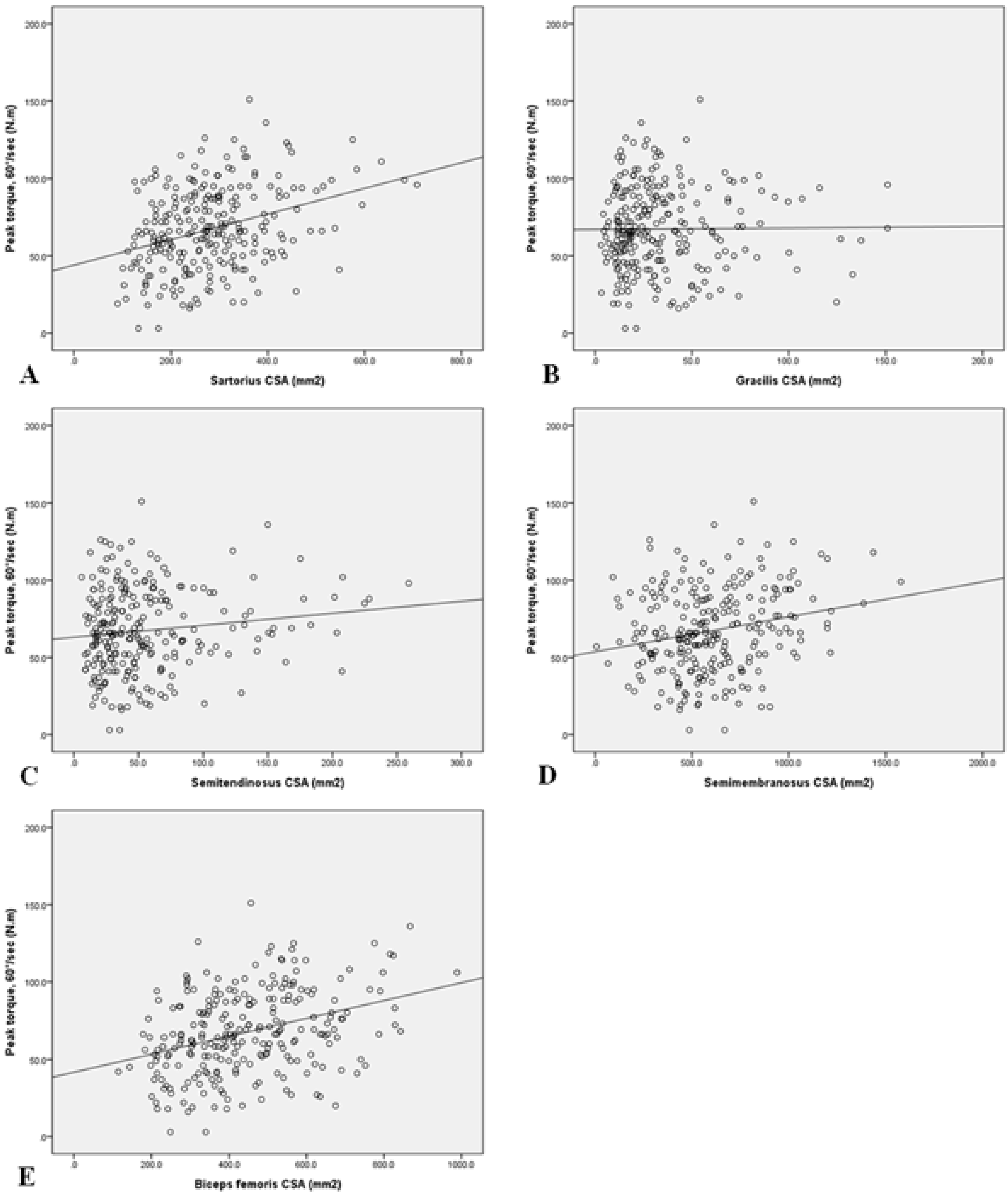

Figure 4

Relationships between muscle strength at 60°/s and cross-sectional area of the knee flexor muscles: (A) sartorius, r = 0.339, p = 0.000; (B) gracilis, r = 0.010, p = 0.877; (C) semitendinosus, r = 0.132, p = 0.037; (D) semimembranosus, r = 0.223, p = 0.000; (E) biceps femoris, r = 0.348, p = 0.000.

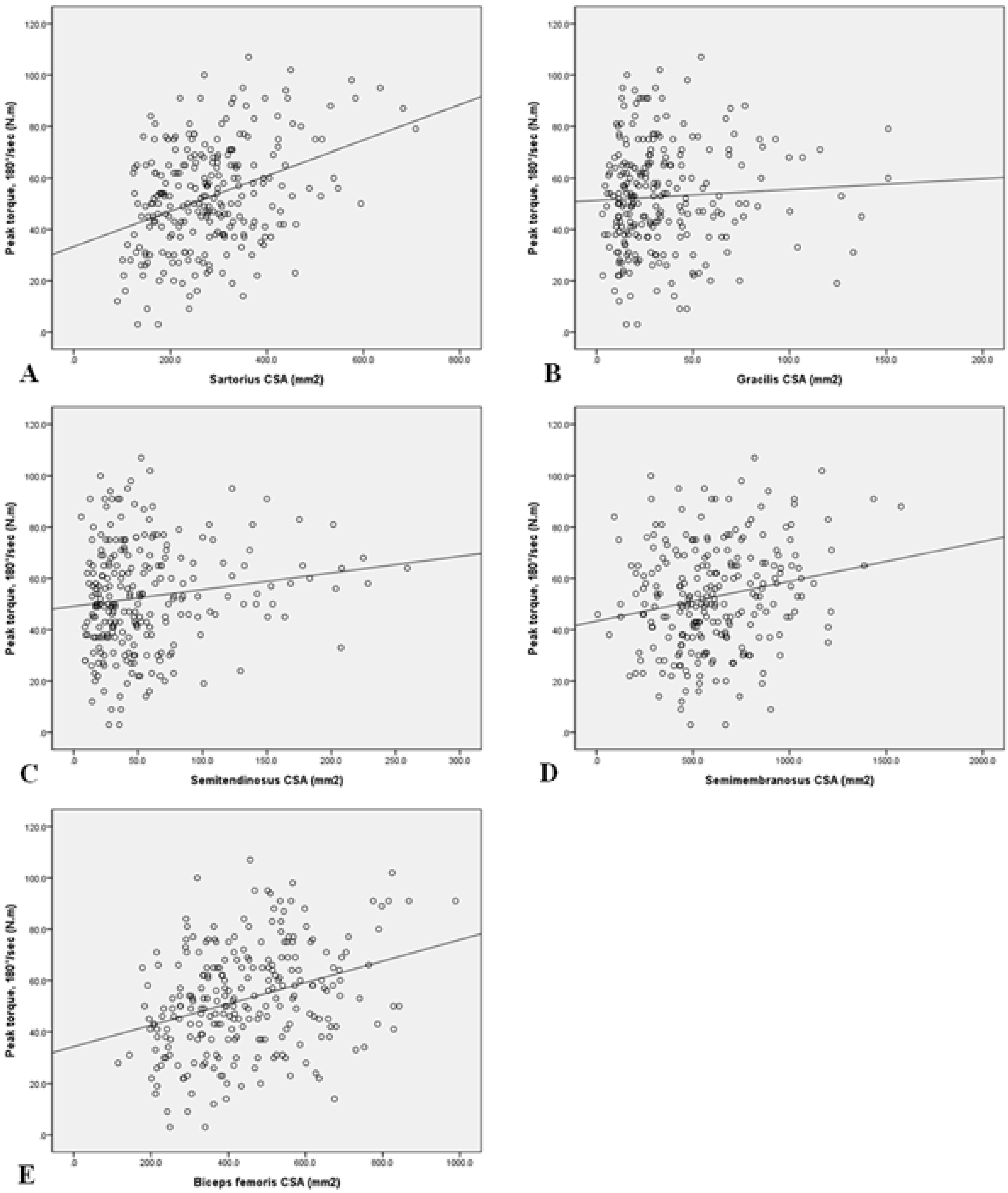

Figure 5

Relationships between muscle strength at 180°/s and cross-sectional area of the knee flexor muscles: (A) sartorius, r = 0.369, p = 0.000; (B) gracilis, r = 0.056, p = 0.375; (C) semitendinosus, r = 0.144, p = 0.022; (D) semimembranosus, r = 0.200, p = 0.001; (E) biceps femoris, r = 0.329, p = 0.000.

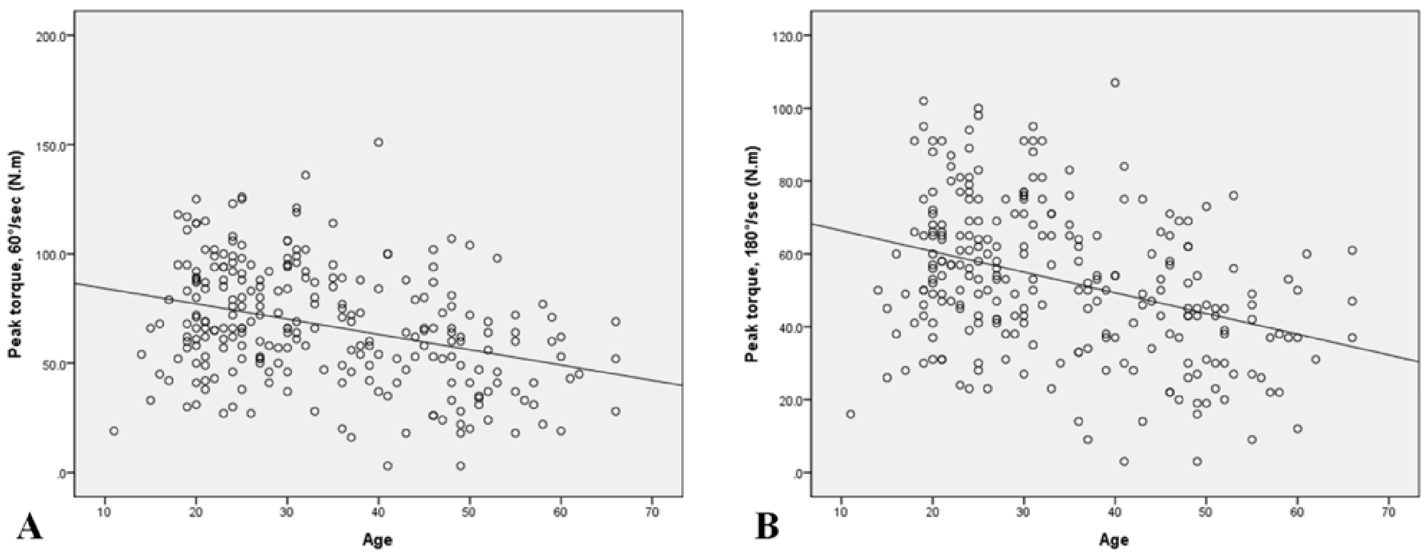

Figure 6

Relationships between muscle strength at (A) 60°/s (r = −0.332, p = 0.000) and (B) 180°/s (r = −0.353, p = 0.000) and aging.

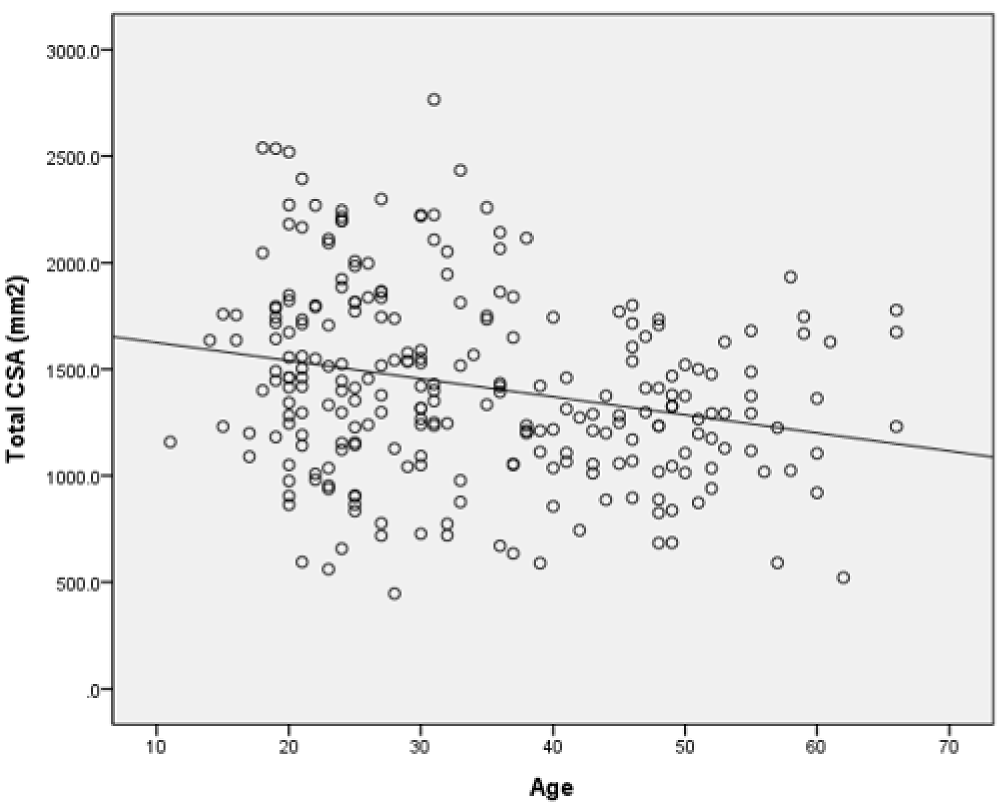

Figure 7

Relationship between total cross-sectional area and aging (r = 0.247, p = 0.000).

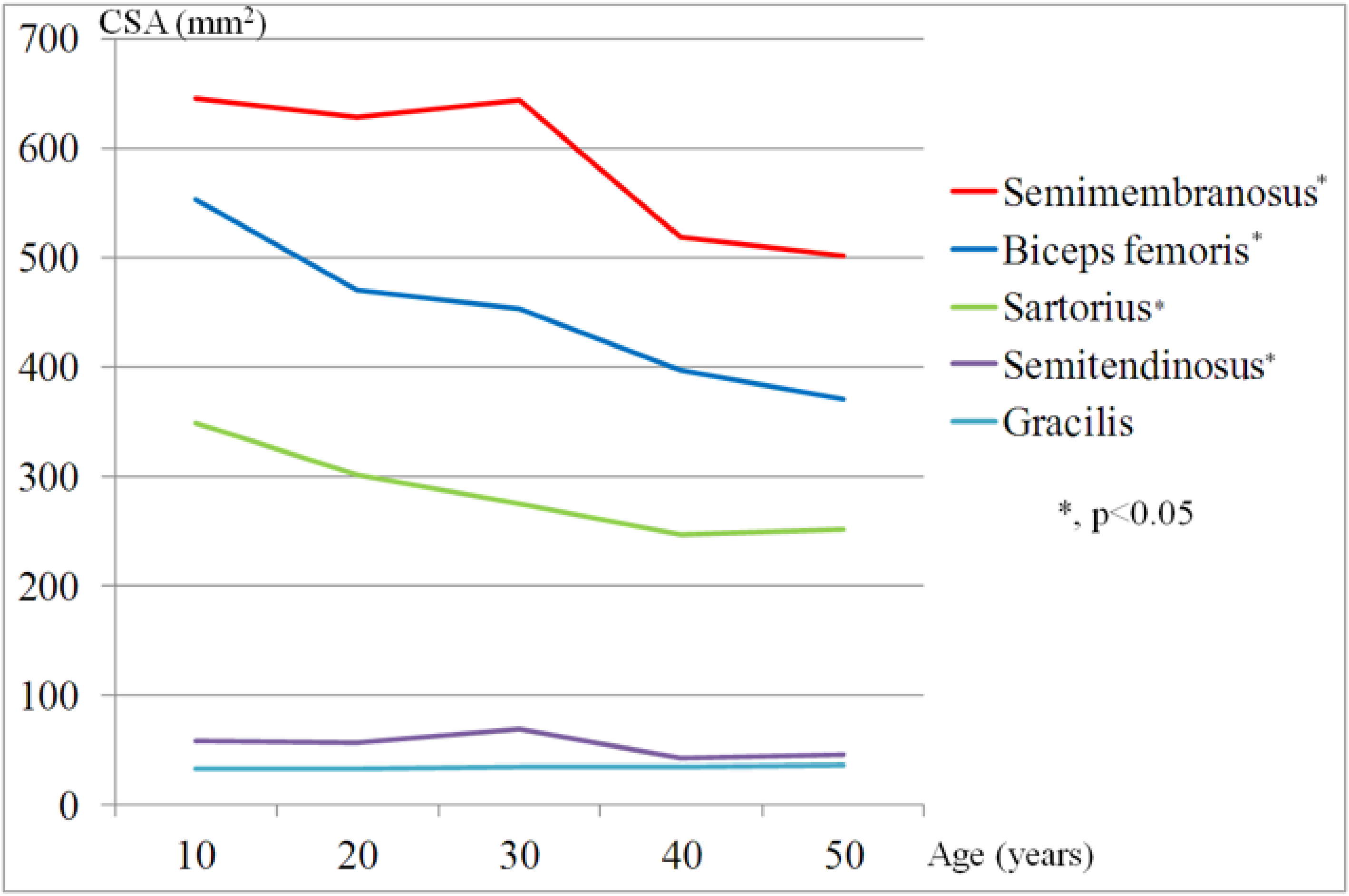

Figure 8

Relationship between cross-sectional area and aging.