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Maximal voluntary isokinetic knee flexion torque is associated with femoral shaft bone strength indices in knee replacement patients

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ABSTRACT

It is currently unknown whether knee replacement-associated bone loss is modified by rehabilitation programs. Thus, a sample of 45 (18 men and 25 women) persons with unilateral knee replacement were recruited; age 66 years (sd 6), height 169 cm (sd 8), body mass 83 kg (sd 15), time since operation 10 months (sd 4) to explore the associations between maximal torque/power in knee extension/flexion and femoral mid-shaft bone traits (Cortical cross-sectional area (CoA, mm^2), cortical volumetric bone mineral density (CoD, mg/mm^3) and bone bending strength index (SSI, mm^3)). Bone traits were calculated from a single computed tomography slice from the femoral mid-shaft. Pain in the operated knee was assessed with the WOMAC questionnaire. Stepwise regression models were built for the operated leg bone traits, with knee extension and flexion torque and power, age, height, body mass, pain score and time since operation as independent variables. CoA was 2.3% ($P=0.015$), CoD 1.2% ($P<0.001$) and SSI 1.6% ($P=0.235$) lower in the operated compared to non-operated leg. The overall proportions of the variation explained by the regression models were 50%, 29% and 55% for CoA, CoD and SSI, respectively. Body mass explained 12% of Coa, 11% of CoD and 11% of SSI ($P\leq0.003$). Maximal knee flexion torque explained 38% of Coa, 7% of CoD and 44% of SSI ($p\leq0.047$). For CoD time since operation also became a significant predictor (11%, $P=0.045$). Knee flexion torque of the operated leg was positively associated with bone strength in the operated leg. Thus, successful rehabilitation may diminish bone loss in the operated leg.

1. Introduction

Among other causes, stress-shielding-related bone loss in the immediate proximity of a knee prosthesis may lead to loosening of the prosthesis [1]. In addition, bone loss has been observed more peripherally both in the tibial and femoral diaphyses in association with total knee replacement operations [2–6]. Bone loss in the operated leg is most marked during the first post-operative year [1], while the functional performance of the operated leg remains weaker than that of the non-operated leg during the same time span [7]. Previous studies have shown that knee extensor and flexor muscle weakness continues to persist for several months, even years, post-operatively compared to the non-operated side [8–13]. Furthermore, analyses of the history of musculoskeletal injuries have indicated that the associated decreases in bone mineral density typically persist for years and are also seen on a more systemic level, e.g. on the spine following tibial and femoral fractures. Such loss is presumably related to persistent decreases in performance and hence skeletal loading [14]. In our previous report, in persons with knee replacement, the mean asymmetrical power deficit was 19–23% in the knee flexor and extensor muscles on average 10 months post surgery [7]. Factors leading to muscle weakness include loss of neural activation and muscle tissue due to long-term disuse of the affected leg prior to the operation [15], procedures related to the operation [13] and lack of post-operative (strength-increasing) rehabilitation (aimed at increasing strength) [16].

The functional performance of the operated leg may be vastly improved with successful rehabilitation based on progressive resistance training [17–19]. However, it is currently unknown whether bone loss is modified by these successful rehabilitation programs. The aim of this study, therefore, was to explore the associations between knee extension/flexion torque/power and femoral mid-shaft bone traits of the operated leg of patients who had undergone unilateral knee replacement surgery.

2. Materials and methods

All the 201 patients who, according to the physical therapy records of Kymenlaakso Central Hospital, had undergone unilateral knee replacement 4–18 months prior to the study were informed about the study.

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Eighty-six patients responded and were contacted by the research personnel and interviewed over the telephone. Patients with bilateral knee arthroplasty, revision arthroplasty, unicompartmental hemiarthroplasty, severe cardiovascular diseases, dementia, rheumatoid arthritis or any major surgery in either of the knees were excluded from the study. The patient recruitment process has been described in detail elsewhere [7]. However, due to not having completed all of the knee extension and flexion performance measurements we have excluded three patients. Thus, a sample of 45 (18 men and 27 women) eligible volunteers with unilateral knee replacement participated in this study (mean age 66 (SD 6), height 169(8) cm, body mass 83(15) kg, time since surgery 10(4) months). Before the laboratory examinations, the participants were informed about the study and gave their written informed consent. The study was conducted according to the Declaration of Helsinki and approved by the ethical committee of Kymenlaakso Central Hospital.

For all the participants the reason for the knee replacement surgery was osteoarthritis of the knee joint. Details of the knee replacement operation were collected from the hospital medical records. In all cases tri-compartmental total knee arthroplasty surgery had been performed with cement fixation. Eight of the 45 participants had diagnosed osteoarthritis in the non-operated knee. The WOMAC questionnaire (Western Ontario and McMaster University Osteoarthritis Index) [20] pain index was used to assess the level of pain (5 subscales) in the operated knee of the participants. The version based on the visual analog scale (range 0–100 mm, with 100 indicating the worst possible situation) was used. The pain index is the sum of the related subscales divided by the number of subscales used.

Operated leg performance was assessed with maximal knee extension and flexion tests. Bone traits were assessed from both the operated and the non-operated leg with quantitative computed tomography (QCT). QCT and neuromuscular measurements and analyses were conducted blinded to the knee replacement status of the leg. To ensure blinding, the subjects were asked to wear long sleeved trousers during the performance measurements.

2.1. Knee extension and flexion performance

Performance was assessed with an isokinetic dynamometer (Biodex Medical Systems Inc, 20 Ramsey Rd, Shirley, NY) as maximal torque and power in knee extension and flexion at 60°/s and 180°/s, respectively, with a sampling frequency of 100 Hz through the entire range of motion. The dynamometer was calibrated before each measurement session according to the standard procedure recommended by the manufacturer. Before the measurement session, the participants were carefully familiarized with the testing procedure. For each leg, the axis of rotation of the dynamometer was aligned with the condylus lateralis femoris. The lever arm of the dynamometer was attached around the ankle 2.5 cm above the midpoint of the malleolus lateralis. The hip and thigh were stabilized with straps. The full knee range of motion was measured. The non-operated leg was measured first. After 2 to 3 submaximal flexion extension movements, 3 maximal continuous knee extension (i.e. concentric quadriceps contraction) followed by a knee flexion (i.e. concentric hamstrings contraction) trials were performed at an angular velocity of 60°/s, and 5 trials were performed at a velocity of 180°/s, with 2 to 3 min of rest between trials. The participants were verbally encouraged to make a maximal effort throughout the whole range of motion. The highest peak torque (Nm) at an angular velocity of 60°/s was analyzed. Peak power was analyzed in extension and flexion at an angular velocity of 180°/s. The ICC of the isokinetic parameters for the operated knee in the patients with knee replacement varied between .90 and .97 [7].

2.2. Femoral mid-shaft bone traits

A single computed tomography slice (Siemens Somatom DR, Siemens AG, Erlangen, Germany) covering both legs was obtained from the femoral mid-shaft. Mid-shaft was defined as the midpoint between the level of the greatest lateral protuberance of the greater trochanter and lower edge of the patella. The Hounsfield units provided by the QCT device were converted to volumetric bone mineral density (vBMD, g/mm^3) values by scanning (K_2HPO_4) phantom liquids and calculating the linear conversion equations. As bone traits of interest, cortical cross-sectional area (CoA, mm^2), cortical vBMD (CoD, g/mm^3) and density-weighted section modulus (SSI, mm^4) were calculated from the CT slices for the operated and the non-operated femurs. Bone analysis was conducted with a custom-made Matlab (MATLAB® the language of technical computing, version 7.0.1.24704 (R14) service pack 1, The MathWorks, Inc.) script [21].

2.3. Statistical analysis

Mean, standard deviation (sd) and 95% confidence interval (95% CI) are given as descriptive statistics. The bones were compared to each other with repeated measures ANOVA with the leg as a within-subject factor. Stepwise regression models were built for the operated leg with the bone variables of the operated leg as the dependent variable (CoA, CoD and SSI), while knee extension and flexion torque and power, age, height, body mass, pain score and time since operation were offered as independent variables. Statistical analyses were conducted with SPSS 15.0.1 (SPSS Inc.) software and the significance level was set at $P \leq 0.05$.

3. Results

The mean WOMAC pain index score was 16(13) mm. The mean knee extension and flexion torques for the operated leg were 80(28) (sd) and 53 21) Nm (sd), respectively (the knee extension and flexion performance results have been reported previously in [7] (sd)). The mean respective powers were 118 (48) (sd) and 105(45) W (sd).

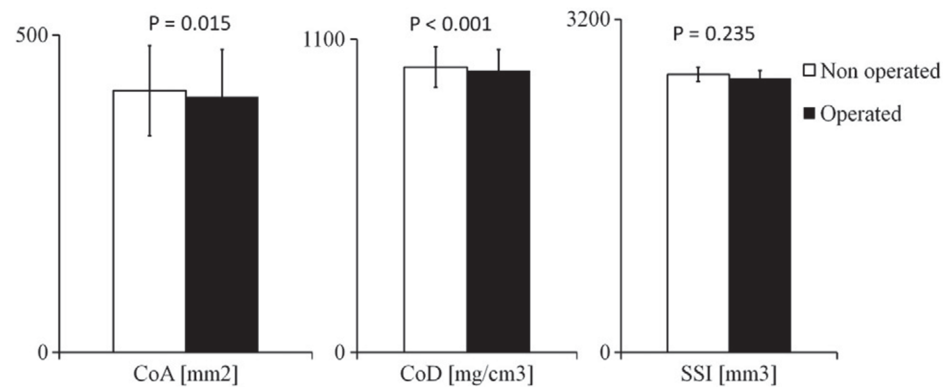

Fig. 1. Mid-femoral bone traits of the operated and non-operated leg. Mean (error bar SD) and P-value for repeated measures ANOVA with leg as the within-subject factor.

In the mid-femoral shaft, the CoA of the operated leg was 2.3% (95% CI 0.5 to 4.1%), CoD 1.2% (95% CI 0.7 to 1.7%) and SSI 1.6% (95% CI −0.6 to 3.7%) lower than the value of the non-operated leg (Fig. 1). The overall proportions of the variation explained by the regression models were 50%, 29% and 55% for CoA, CoD and SSI, respectively (Table 1). On the operated leg body mass independently explained 12% ($p=0.003$) of Coa, 11% ($p=0.001$) of CoD and 11% ($p=0.003$) of SSI. Maximal knee flexion torque independently explained 38% ($p<0.001$) of Coa, 7% ($p=0.047$) of CoD and 44% of SSI ($p<0.001$). For CoD, time since operation also became a significant independent predictor (11%, $P=0.045$) (Table 1).

4. Discussion

The primary finding of the present study was that the maximal voluntary isokinetic knee flexion torque of the operated leg is positively associated with the mid-femoral bone traits of the operated leg. The finding raises the hypothesis that successful rehabilitation may positively modify the bone loss associated with knee replacement.

The difference in bone traits observed between the operated and non-operated legs were in line with previous observations, i.e. diaphyseal bone loss is relatively modest following total knee arthroplasty [3–6]. It has been shown previously that the side of the body affected with osteoarthritis causing the knee replacement also has lower proximal femur bone mineral density and that this difference does not disappear following arthroplasty [22]. The present results were also in line with the aforementioned finding. Albeit the side-to-side differences in performance were not associated with the side-to-side differences in bone (data not shown), the difference in bone mineral density between the leg affected by osteoarthritis and the non-affected leg may be associated with differences between the operated and non-operated leg in locomotory kinetics and kinematics. Harato et al. showed that walking kinetics and kinematics may differ between legs 15 months after knee replacement [23]. In addition, after knee replacement [7] and in healthy older persons [24] knee extensor power asymmetry has been shown to be associated with slower walking speed or stair ascending. Consequently, it may be reasonable to speculate that the differences in performance between legs reflect habitual loading of the bone, thus at least partially causing the bone deficit in the leg with the replaced knee.

To date, only a few studies have investigated the effects of progressive resistance training after knee replacement surgery. Previous studies have shown favourable effects of rehabilitation in lower-limb muscle strength or in mobility in persons with knee replacement [17–19,25]. Presumably, successful rehabilitation has the potential to reduce the differences between the operated and non-operated leg, as has already been shown in persons with knee replacement [19] and with hip fracture [26,27]. Since a higher body mass index has been found to be associated with less prominent bone loss in association with total knee replacement [4], it can thus be speculated that the bone differences following knee replacement could also be modified by rehabilitation involving increased loading of the operated leg. However, one of the potential causes of implant loosening is high forces on the implant-skeletal surface [1], which somewhat undermines the rationale of the above speculation.

This study has its limitations. The study was a cross-sectional analysis without follow-up; therefore, we can only speculate on the causal relationships or the associations over time. The study population consisted of people who were relatively healthy and mobile and had undergone successful unilateral knee replacement procedures. Nevertheless, some of the participants had osteoarthritis in the non-operated knee, and this condition may have influenced the side-to-side differences in bone traits observed between the legs. The pooling of genders may also have affected the results. However, generally for diaphyseal bone, the associations between bone traits and neuromuscular performance are similar in men and women [21,28]. Furthermore, there was no gender difference in the asymmetry in bone traits in the present data. It is noteworthy that in the regression models constructed in the present study only maximal knee flexion torque of the four neuromuscular performance variables turned out to be a significant predictor of the mid-fermoral bone traits. This is probably due to the strong ($r>0.63$, data not shown) correlation between these variables. It may also be questioned whether the observed relatively modest side-to-side differences between legs bear any clinical meaning. Normal age-related bone loss is less than 1% per year, even during postmenopausal bone loss in women [29]. Permanent bone loss due to, for example, previous injury and subsequent surgery (post-traumatic osteoporosis) may be a risk factor for osteoporotic fractures in later life [14]. In our study, in 17 of the 45 subjects the operated leg had a bone bending strength index more than 5% lower than the non-operated leg and 6 of the 45 had a value more than 10% lower, which can clearly be argued to be clinically significant. Furthermore, the mean bone trait differences between legs of 1.2 and 2.3%, if interpreted as bone loss, are approximately equal to two years' worth of bone loss in the studied age group [29]. In future studies, it would be interesting to see whether similar associations are observed between performance and the bone in the immediate vicinity of the prosthesis.

In conclusion, maximal voluntary isokinetic knee flexion torque of the operated leg is positively associated with the femoral mid-shaft bone strength of the operated leg. In addition to positively modifying functional ability, improving performance may also diminish bone loss in the operated leg.

Table 1
Stepwise regression results for the operated leg. Unstandardized beta coefficients reported. Bone variables (CoA, CoD and SSI) were used as the dependent variable, while knee extension and flexion torque and power, age, height, body mass, pain score and time since operation were offered as independent variables. Variables not included as a predictor in any of the regression models (i.e. knee extension torque, knee extension and flexion power, age, height and pain score) are not reported.

	CoA [mm^2]	CoD [mg/cm^3]	SSI [mm^3]
Included variables			
Flexion torque [Nm]	$\beta=1.65$, $P<0.001$	$\beta=0.51$, $P=0.047$	$\beta=16.5$, $P<0.001$
Body mass [kg]	$\beta=1.82$, $P=0.003$	$\beta=-1.19$, $P=0.001$	$\beta=14.9$, $P=0.003$
Time since operation [months]	Not included	$\beta=2.30$, $P=0.045$	Not included
R^2 of the final model	0.50	0.29	0.55

Conflicts of interest

All authors have no conflicts of interest.

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