Effect of activity level after TKA on the relative bone mineral density measured on standard radiographs in periprosthetic tibial bone: a five-year follow-up study

Yong Liu
Sun Yat-sen University First Affiliated Hospital
Peiheng He
Sun Yat-sen University First Affiliated Hospital
Xing Li
Sun Yat-sen University First Affiliated Hospital
Yongheng Ye
Sun Yat-sen University First Affiliated Hospital
Minghao Liu
Sun Yat-sen University First Affiliated Hospital
Weizhi Chen
Sun Yat-sen University First Affiliated Hospital
Dongliang XU (dddrxu@163.com)
Sun Yat-Sen University https://orcid.org/0000-0002-0927-5778

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Abstract

Background: To suggest the best activity level to guide clinical rehabilitation by evaluating the effect of activity level on BMD in the proximal tibia 5 years after TKA.

Methods: In 121 patients, the UCLA activity rating was evaluated, and the relative BMD in periprosthetic tibial bone was measured by ImageJ software on anteroposterior X-ray images. ANOVA, chi-squared test, paired t test and nonlinear regression were used for data analysis.

Results: Activity level significantly affected rBMD in the proximal tibia, with the smallest reduction in rBMD observed with moderate activity. The difference in rBMD% between the lateral and medial metaphysis was significant. The regions with a significant difference in rBMD% between the lateral and medial metaphysis were closest to the base plate of the prosthesis. The lateral and medial regions closest to the stem of the prosthesis showed no significant difference in rBMD%.

Conclusions: Moderate-intensity functional exercise is recommended within 3 years after TKA.

Background

An increasing number of patients with end-stage osteoarthritis are receiving treatment with total knee arthroplasty (TKA), which is a successful procedure for alleviating pain, improving functional ability, and enhancing quality of life1;. Bone mineral density (BMD) is an indicator of bone quality and reflects the material properties, bone metabolism and risk of fracture2,3;. Postoperative changes in the periprosthetic bone density in the tibia are closely related to the outcomes of TKA. Several studies4-7; have reported a reduction in BMD in the proximal tibia after TKA, which can cause the subsidence of some components, especially of the tibial plateau, and increase the risk of prosthetic loosening and further revision.

Dual X-ray absorptiometry (DXA) is the gold standard clinical method used to evaluate BMD, but it is not used in routine examinations after TKA due to not only the absence of this technology in many hospitals with limited resources but also the high cost of the technology. Several studies have reported that the grayscale values measured on standard radiographs are closely related to BMD and can reflect changes in BMD2,8;. Hernandez-Vaquero et al8; revealed a method based on digital radiological densitometry to evaluate bone density using X-ray images. They measured the grayscale values as the relative BMD (rBMD) and validated that the consistency between the true BMD measured by DXA and the rBMD measured by this technique was approximately 0.72 to 0.92. Therefore, this technique could be used as an alternative to DXA to assess changes in BMD after TKA.

Physical activity is a critical part of functional recovery of the knee joint after TKA. Oktas et al9; concluded that a rehabilitation program for strengthening the muscles around the hip and knee joints was quite important to the success of TKA. However, Kilgus, DJ et al10; reported that a high level of physical activity was correlated with increased osteoporosis-related prosthetic loosening in patients after total hip replacement. Ponzio et al11; revealed that increased postoperative activity was associated with an increased risk of revision. Thus, the optimal level of physical activity for patients after TKA is unclear. There is no consensus on the intensity of rehabilitation and physical activity that should be performed after surgery. To provide a reference for guiding clinical rehabilitation exercise after TKA, the aim of this study was to determine an optimal activity level to minimize BMD loss.

Methods

Patients

A total of 121 patients who were diagnosed with severe knee osteoarthritis (Kellgren-Lawrence classification III or IV) and underwent unilateral primary TKA by the same experienced surgeon from January 2010 to December 2013 were enrolled in the research. All operations were performed in the Department of Joint Surgery of the First Affiliated Hospital of Sun Yat-Sen University. A posterior-stabilized prosthesis (DePuy Synthes, P.F.C. Sigma, Warsaw, IN, USA) was implanted for all patients. The postoperative UCLA Activity Scale scores for the participants ranged from 4 to 9. Table 1 shows the basic characteristics of the patients. This study was approved by the Medical Ethics Committee of The First Affiliated Hospital of Sun Yat-Sen University (code number [2011] 57), and all the procedures followed the principles of the Helsinki Declaration.

rBMD (calibrated grayscale value) measurements of periprosthetic tibial bone

To evaluate the relative changes in the tibial BMD, anteroposterior X-ray images collected at 5 time points (baseline (within one week) and 3 months, 1 year, 3 years, and 5 years postoperatively) were saved as JPG files with 255 (8-bit) grayscale and 300 dpi resolution. The X-ray images at the different time points were collected with the patient in the same standing position and the tibia neutral. Knee flexion was minimized by fixing the tibial tubercle at the lower end of the knee. Rotation was controlled by fixing the heel and the first and second toes. Ten regions of interest (ROIs) were chosen as the measured regions of the tibia: four lateral regions (L1, L2, L3, L4), four medial regions (M1, M2, M3, M4), and two distal regions (D1, D2) (Fig. 1). ImageJ, a public domain Java-based scientific image processing and analysis package, was used to measure the mean grayscale value in the established regions of the radiographs. For each designated region, the grayscale value of regions ‘a’ and ‘f’, representing the surrounding air (assigned ‘a’) and the femoral component (‘f’), could be regarded as the minimum and maximum grayscale measurements in each radiograph for interfilm comparison. To account for variability between follow-up radiographs, the measured grayscale value of each designated region was calibrated by software using the formula:, where $G_{C,R}$ is the calibrated grayscale value, also representing the rBMD in a given region, G_R is the mean grayscale value within an ROI, G_a is the value of air within the radiograph, and G_f is the mean grayscale value of the femoral component2;.

Clinical outcome evaluation

All patients were clinically evaluated with respect to knee function using the Knee Society Score (KSS)12,13;, the Western Ontario and McMaster University Osteoarthritis Index (WOMAC)14,13; and visual analogue scale (VAS) score preoperatively and at each follow-up time point (3 months, 1 year, 3 years, and 5 years postoperatively). The physical activity level was evaluated using the University of California Los Angeles (UCLA) Activity Rating Scale15-17;.

Statistical analysis

The Shapiro-Wilk test was used to confirm that the data were normally distributed. ANOVA and chi-squared tests were performed to explore the differences in patient age, sex, BMI, and hip-knee-ankle (HKA) angle among UCLA activity ratings and the influence of the UCLA activity rating on the percent change in rBMD. Paired t tests were used to compare the percentage change in rBMD in the lateral and medial tibia. Significance was defined as P<

0.05. Curve fitting and nonlinear regression were performed to determine the relationship between the UCLA activity rating and percent change in rBMD. All statistical analyses were performed using SPSS 21.0.

Results

Clinical and functional outcomes

The objective and subjective clinical outcomes are shown in Table 2. After TKA, a steady improvement in the clinical outcomes (WOMAC, KSS, VAS score) was observed.

Effects of UCLA activity rating on average rBMD in the proximal tibia over 5 years of follow up

The baseline rBMD was measured within 1 week after TKA. The percent change in rBMD (rBMD%) was calculated by the following equation: rBMD% =100%*[rBMD (baseline)-rBMD (each time)]/ rBMD (baseline). In brief, in this study, a UCLA activity rating of 4-5, 6-7 and 8-9 was considered to describe a low, moderate and high activity level, respectively. There were no significant differences in patient age, sex, BMI or HKA angle among the various UCLA activity ratings (Table 3). The UCLA activity rating was significantly associated with the average rBMD% in the proximal tibia at 1 year (P<0.001) and 3 years (P=0.002) but not at 5 years (P=0.239). The average rBMD% in the proximal tibia decreased with UCLA activity rating until a moderate activity level and then started to increase (Fig. 2). The smallest reduction in the average rBMD was at a moderate activity level, and the rBMD increased (0.86%, 0.43%) at a moderate activity level compared with the corresponding baseline at both 1 and 3 years.

Nonlinear regression of rBMD% in the proximal tibia and UCLA activity rating

The parabola fitted by nonlinear regression was a suitable trend curve for representing the relationship of the average rBMD% in the proximal tibia with the UCLA activity rating (Fig. 3). Regression of the average BMD% against the UCLA activity rating showed the following optimal equations:

See Formulas 1 and 2 in the supplemental files.

Where Y(1y) and Y(3y) are the average rBMD% in the proximal region at 1 and 3 years, respectively, and X is the UCLA activity rating.

Influence of UCLA activity rating on rBMD in medial, lateral and distal metaphysis at 1 and 3 years

The UCLA activity rating significantly influenced the rBMD% in the medial (P<0.001, P=0.005) and lateral (P=0.02, P=0.002) metaphysis, while the influence was not significant in the distal metaphysis at either 1 or 3 years. The change trend of the rBMD% in the medial and lateral metaphysis was generally similar to that of the average rBMD% in the proximal tibia. Compared with the rBMD in the lateral metaphysis, the rBMD in the medial metaphysis showed a significantly greater reduction at both 1 year (P=0.003) and 3 years (P=0.002). A decreased rBMD in the medial metaphysis was consistently seen at each activity level, while an increased rBMD was found in the lateral metaphysis at a moderate activity level (Table 4). The differences in rBMD% between the corresponding lateral and medial regions L1, L2, M1, and M2 were significant at both 1 year (P=0.001, P=0.026) and 3 years (P<0.001, P=0.008), while the differences in rBMD% between the corresponding lateral and medial regions L3, L4, M3, and M4 were not significant at either 1 year (P=0.053, P=0.396) or 3 years (P=0.359,

P=0.678). The greatest difference in rBMD% between corresponding lateral and medial regions was found between regions L1 and M1.

Discussion

The aim of the present study was to evaluate the effect of activity level, determined by the UCLA activity rating, on BMD in periprosthetic bone after TKA and suggest the best activity level to guide clinical rehabilitation postoperatively. Although the rBMD measured on standard X-ray images is not the true BMD, Hernandez-Vaquero et al8; have proven that the relationship between the rBMD measured on standard X-ray images and the true BMD measured by DXA is linear (Cronbach's correlation of 0.72 to 0.92), namely, rBMD could serve as an alternative to BMD.

No significant differences in factors such as sex, age, BMI and postoperative alignment were found among patients with different activity levels. We also found that different postoperative activity levels had an effect on BMD in periprosthetic bone and that a moderate activity level was most beneficial for reducing bone density loss. The significant influence on activity level on BMD after 1 and 3 years could be attributed to adaptive bone remodeling and changes in load. However, the postoperative activity level had no significant effect on BMD after 5 years. Seitz et al18; found that bone density loss demonstrated a reparation phase and a stabilization phase and that no significant BMD change was observed during the stabilization phase. Therefore, bone might be in the stabilization phase at 5 years and not be affected by activity level. An increase in BMD was seen at a moderate activity level at both 1 and 3 years. As postoperative bone loss is general and increases the risk of prosthetic loosening and revision, it makes sense to reduce bone loss in patients after TKA. Therefore, we suggest that patients should undergo rehabilitation training with a moderate activity level within 3 years after TKA.

A nonlinear (parabolic) relationship between the UCLA activity rating after TKA and rBMD% in the proximal tibia suggested that moderate physical activity was beneficial to maintain bone mass, while insufficient or excessive functional exercise aggravated bone loss. This phenomenon is consistent with Wolff's law19;, which indicates that mechanical stress stimulates bone formation, while disuse leads to bone loss. Petersen et al7; revealed that a decreased load led to rapid bone loss, while an increased load led to a small increase in BMD in the tibial condyles. This might suggest that a low activity level loads the tibia at a smaller or lower frequency than does a moderate activity level. Lubbeke20; reported that high activity led to a higher rate of femoral osteolysis and revision for aseptic loosening, which might help us understand the greater reduction in BMD at a high activity level than at a moderate activity level.

When considering the influence of load on BMD, it was unexpected that the activity level had a significant effect on the BMD in the lateral and medial metaphysis. The greater reduction in the BMD in the medial metaphysis might be the result of the typically higher medial load distribution in a varus knee preoperatively, adaptive bone remodeling and changes in the load following correction of the mechanical axis. However, it was unexpected that the activity level had no significant effect on the BMD in the distal metaphysis; the reason for this finding is unclear and merits further investigation, especially regarding load transfer and distribution. A significant difference in rBMD% between lateral and medial regions was observed in the regions closest to the base plate, and the greatest difference in BMD between proximal medial and lateral regions was found in the regions closest to the base plate and further from the stem of prosthesis. The findings are similar to those reported by S. R.

Small2;. This may be attributed to the uneven load distribution and habitual knee use. However, differences in rBMD% between the lateral and medial regions closest to the stem of the prosthesis were not significant. These results might suggest that the load is evenly distributed on both sides of the stem of the prosthesis.

There are some limitations to this study. First, only the effect of postoperative activity level on BMD was evaluated. To provide comprehensive suggestions for guiding clinical rehabilitation, more aspects should be studied, such as the effect of activity level on prosthetic loosening and osteolysis. Second, the BMD measured on standard X-ray images is a relative value, and while it can reflect the trend of the true BMD, there may be quantitative error with respect to the true BMD.

Conclusion

Physical activity is important for recovery after TKA; however, there are no consistent guidelines regarding activity intensity. In this retrospective study, we found that activity level had a significant effect on BMD at 1 and 3 years but not at 5 years. Moderate activity led to a minimal reduction in BMD and even an increased BMD. Therefore, moderate activity is the most appropriate activity intensity for patients, who should engage in activities of this intensity within 3 years after TKA.

Declarations

- Ethics approval and consent to participate

This study was approved by the Medical Ethics Committee of The First Affiliated Hospital of Sun Yat-Sen University (code number [2011] 57), and all the procedures followed the principles of the Helsinki Declaration.

- Consent for publication

Not applicable

- Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

- Competing interests

The authors declare that they have no competing interests

- Funding

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- Authors' contributions

YL and DX conceived the project, YL designed the experiment, collected and analyzed patients’ data, and wrote the manuscript, PH participated in patient follow-up and provided comments, YY, XL, ML and WC assisted in patient follow-up. All authors read and approved the final manuscript.

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Not applicable

Abbreviations

TKA: total knee arthroplasty, BMD: bone mineral density, rBMD: relative BMD, rBMD%: the percent change in rBMD, DXA: Dual X-ray absorptiometry, ROIs: regions of interest, KSS: Knee Society Score, WOMAC: Western Ontario and McMaster University Osteoarthritis Index, VAS: visual analogue scale, UCLA activity rating : University of California Los Angeles Activity Rating Scale, HKA angle: hip-knee-ankle angle, ANOVA: Analysis of Variance.

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Tables

Table 1 Patient characteristics

Characteristic*	Mean (SD, range)
Age	66.65 (7.52, 49-87)
Sex (n)	19 men/102 women
BMI (kg/m^2)	26.64 (3.24, 18.56-39.54)
HKA angle	177.42 (1.33, 175-180)
Operative duration (min)	131.00 (38.01, 60-270)
LOS (day)	11.65 (2.81, 7-22)
Kellgren-Lawrence classification	
III	47
IV	74

* BMI, body mass index; HKA, hip-knee-ankle; LOS, length of stay.

Table 2 Characteristics of 121 participants (N=121)

	Preoperative	3 months	1 year	3 years	5 years
KSS	76.43 ±24.84	121.69 ±12.62	164.97 ±8.14	170.96 ±8.70	182.47 ±8.17
WOMAC	44.50 ±12.69	26.47 ±11.20	10.30 ±3.34	5.47 ±2.67	3.27 ±1.69
VAS score	6.93±0.96	4.57±1.18	1.61±1.15	1.65±0.93	1.61±0.92

Note: Values are the mean ± SD.

Table 3 P values for age, sex, BMI and HKA angle among UCLA activity ratings

	1 year (n=97)	3 year (n=79)	5 year (n=26)	Method
Sex	0.645	0.499	0.597	Chi-squared
HKA angle	0.935	0.091	0.066	ANOVA
Age	0.278	0.957	0.436	ANOVA
BMI	0.422	0.825	0.658	ANOVA

Table 4 rBMD% in medial, lateral and distal regions

	Level	N	L1	M1	L2	M2	L3	M3	L4	M4
1y	4	10	10.55±3.50	12.23±11.45	8.55±5.86	9.30±8.60	8.84±5.51	10.17±6.14	7.96±6.19	5.33±7.50
	5	15	1.14±9.03	4.80±14.86	-0.19±9.47	0.68±14.65	0.01±9.19	1.19±9.86	-4.23±10.96	0.80±8.83
	6	19	-3.41±6.82	4.55±14.51	-4.54±8.86	2.34±12.27	-2.28±7.00	2.92±10.61	0.89±8.05	2.35±8.10
	7	12	-3.70±14.64	3.92±16.54	-2.27±14.38	1.60±10.83	-0.17±14.72	0.66±12.59	-2.59±10.42	-3.81±14.29
	8	16	3.40±10.06	6.96±14.42	1.84±9.60	2.40±9.19	5.92±9.13	2.90±8.68	4.30±8.24	2.84±7.71
	9	25	10.50±12.14	14.77±12.70	7.85±10.36	10.04±15.52	7.15±9.46	10.36±10.93	7.24±8.62	8.23±10.24
3y	4	10	6.81±9.01	15.18±13.19	11.23±10.67	12.21±9.18	13.11±9.51	10.49±10.13	10.18±11.68	9.22±10.52
	5	13	4.95±13.57	11.03±17.53	6.12±14.40	9.56±13.41	7.18±11.26	9.48±12.12	3.39±6.76	6.49±10.33
	6	17	2.07±8.28	4.16±18.31	-4.47±18.96	0.17±18.76	0.97±7.41	-1.19±14.48	2.09±11.80	-1.23±13.24
	7	12	-3.60±11.21	4.53±18.59	0.45±9.39	-1.59±12.91	0.61±8.90	-0.33±11.05	-0.08±7.81	3.14±10.73
	8	9	5.84±21.70	11.21±21.15	2.26±17.39	7.77±13.07	-0.55±15.95	4.73±13.29	0.30±12.81	0.11±14.06
	9	18	12.09±11.42	25.74±11.74	11.52±8.98	18.41±12.09	9.93±10.43	14.63±11.48	9.80±11.32	10.86±12.94

Note: Values are the mean ± SD.

Figures

Figure 1

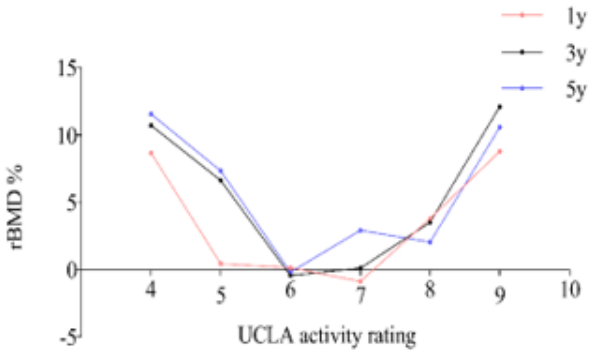

Figure 2

Relationship of UCLA activity rating with rBMD%

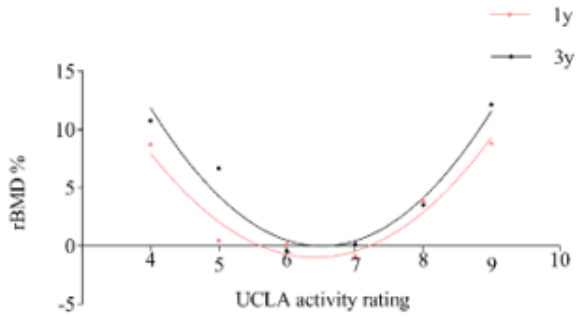

Figure 3

Nonlinear regression model of UCLA activity rating and rBMD%

Supplementary Files

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