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

Research article

Keywords: TKA, BMD, UCLA, Activity level, Rehabilitation

Posted Date: June 30th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-37186/v1

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 life[1]. Bone mineral density (BMD) is an indicator of bone quality and reflects the material properties, bone metabolism and risk of fracture[2, 3]. Postoperative changes in the periprosthetic bone density in the tibia are closely related to the outcomes of TKA. Several studies[4–7] 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 BMD[2, 8]. Hernandez-Vaquero et al[8] 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 al[9] 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 al[10] reported that a high level of physical activity was correlated with increased osteoporosis-related prosthetic loosening in patients after total hip replacement. Ponzio et al[11] 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 retrospective research. The criteria for being entered into the present study were willingness to participate and the availability of time to take X-rays of the knee after surgery for 5 years. 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 cemented TKA. Table 1 shows the basic characteristics of the patients. Postoperative rehabilitation training was carried out for all patients in accordance with progressive rehabilitation methods. 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.

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.	

rBMD (calibrated grayscale value) measurements

To measure the bone density in the proximal tibial, standardised anteroposterior (AP) radiographs were obtained 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: $G_{C,R} = [255(G_R - G_a)]/(G_f - G_a),$, 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 component[2].

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)[13, 14] 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 level of activity was evaluated using the University of California Los Angeles (UCLA) Activity Rating Scale[15–17]which has ten points: 1) wholly inactive, dependent on others; 2) mostly inactive, restricted to minimal activities of daily living; 3) sometimes participate in mild activity such as walking, limited housework or shopping; 4) regularly participate in mild activities; 5) sometimes participate in moderate activity such as swimming and unlimited housework or shopping; 6) regularly participate in moderate activities; 7) regularly participate in active events such as bicycling; 8) regularly participate in very active events such as bowling or golf; 9) sometimes participate in impact sport such as jogging, tennis, skiing, heavy labour; 10) regularly participate in impact sport.

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

121 patients with 121 TKAs had complete clinical and radiological information and were included in the final analysis. Some basic information of patients was shown in Table 2. The mean age of those included in the study at the time of operation was 66.65 years (49 to 87); 102 (84%) were women; their mean pre-operative BMI was 26.64 kg/m2 (18.56–39.54); 74 knees (61%) were in patients with an ASA grade of 4. Their activity levels range from 4 to 9.

Table 2
Characteristics of 121 participants (N = 121)

	Preoperative	**3 months**	**1 year**	**3 years**	**5 years**	***P***
KSS score	76.43 ± 24.84	121.69 ± 12.62	164.97 ± 8.14	170.96 ± 8.70	182.47 ± 8.17	< 0.001
WOMAC score	44.50 ± 12.69	26.47 ± 11.20	10.30 ± 3.34	5.47 ± 2.67	3.27 ± 1.69	< 0.001
VAS score	6.93 ± 0.96	4.57 ± 1.18	1.61 ± 1.15	1.65 ± 0.93	1.61 ± 0.92	< 0.001

Note: Values are the mean ± SD. P value is compared between 5 years after surgery and preoperative by t test.

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

During the 5-years follow-up period, the bone density in the medial, lateral and distal areas after TKA decreased compared with that before surgery. As shown in Fig. 2, the mean rBMD of the medial side, lateral side and distal side decreased by 3.04%, 0.96% and 2.17% respectively at 3 months after surgery compared with the baseline. At 1 year after surgery, the mean rBMD of the medial side, lateral side and distal side decreased by 5.64%, 3.23% and 2.93%, respectively. At 3 years after surgery, the values were 7.25%, 4.67% and 1.80%, respectively. At 5 years after surgery, they were 5.37%, 3.77% and 1.67%, respectively.

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. 3). 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.

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

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. 4). Regression of the average BMD% against the UCLA activity rating showed the following optimal equations:

$$Y(1y) = 61.95 - 19.60X + 1.53X^2 \qquad (4 \le X \le 9,\ R^2=0.95) \qquad (1)$$

$$Y(3y) = 78.25 - 24.01X + 1.85X^2 \qquad (4 \le X \le 9,\ R^2=0.94) \qquad (2)$$

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.

The UCLA activity rating significantly influenced the rBMD% in the medial (1year, $P < 0.001$, 3 years, $P = 0.005$) and lateral (1 year, $P = 0.02$, 3 years, $P = 0.002$) 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.

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.

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 al[8] 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 al[18] 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 law[19], which indicates that mechanical stress stimulates bone formation, while disuse leads to bone loss. Petersen et al[7] 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. Lubbeke[20] 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. Small[2]. 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.

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.

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

This work was supported by the 5010 Clinical Research Project of Sun Yat-sen University (2010005).

- 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.

- Acknowledgements

Not applicable

References

1. Carr AJ, Robertsson O, Graves S, Price AJ, Arden NK, Judge A, Beard DJ. Knee replacement. The Lancet. 2012;379(9823):1331–40.
2. Small SR, Ritter MA, Merchun JG, Davis KE, Rogge RD: **Changes in tibial bone density measured from standard radiographs in cemented and uncemented total knee replacements after ten years' follow-up**. *Bone & Joint Surgery* 2013, **95-B**:911–916.
3. Sessa G, Costarella L, Puma Pagliarello C, Di Stefano A, Sessa A, Testa G, Pavone V. Bone mineral density as a marker of hip implant longevity: a prospective assessment of a cementless stem with dual-energy X-ray absorptiometry at twenty years. International orthopaedics. 2019;43(1):71–5.
4. Ritter MA, Davis KE, Small SR, Merchun JG, Farris A: **Trabecular bone density of the proximal tibia as it relates to failure of a total knee replacement**. *Bone Joint J* 2014, **96b**(11):1503–1509.
5. Winther N, Jensen C, Petersen M, Lind T, Schroder H, Petersen M. Changes in bone mineral density of the proximal tibia after uncemented total knee arthroplasty. A prospective randomized study. International orthopaedics. 2016;40(2):285–94.
6. Jaroma A, Soininvaara T, Kroger H. Periprosthetic tibial bone mineral density changes after total knee arthroplasty. Acta Orthop. 2016;87(3):268–73.
7. Petersen MM, Nielsen PT, Lauritzen JB, Lund B. Changes in bone mineral density of the proximal tibia after uncemented total knee arthroplasty. A 3-year follow-up of 25 knees. Acta Orthop Scand. 1995;66(6):513–6.
8. Hernandez-Vaquero D, Garcia-Sandoval MA, Fernandez-Carreira JM, Suarez-Vazquez A, Perez-Hernandez D. Measurement of bone mineral density is possible with standard radiographs - A study involving total knee replacement. Acta Orthop. 2005;76(6):791–5.
9. Oktas B, Vergili O. The effect of intensive exercise program and kinesiotaping following total knee arthroplasty on functional recovery of patients. J Orthop Surg Res. 2018;13(1):233.

10. Kilgus DJ, Dorey FJ, Finerman GA, Amstutz HC. **Patient activity, sports participation, and impact loading on the durability of cemented total hip replacements**. *Clin Orthop Relat Res* 1991(269):25–31.
11. Ponzio DY, Chiu Y-F, Salvatore A, Lee Y-Y, Lyman S, Windsor RE. An Analysis of the Influence of Physical Activity Level on Total Knee Arthroplasty Expectations, Satisfaction, and Outcomes. J Bone Joint Surg. 2018;100(18):1539–48.
12. Insall JN, Dorr LD, Scott RD, Scott WN. **Rationale of the Knee Society clinical rating system**. *Clin Orthop Relat Res* 1989(248):13–14.
13. Giesinger JM, Hamilton DF, Jost B, Behrend H, Giesinger K. WOMAC, EQ-5D and Knee Society Score Thresholds for Treatment Success After Total Knee Arthroplasty. J Arthroplast. 2015;30(12):2154–8.
14. Walker LC, Clement ND, Deehan DJ. **Predicting the Outcome of Total Knee Arthroplasty Using the WOMAC Score: A Review of the Literature**. *J Knee Surg* 2018.
15. Lavernia CJ, Sierra RJ, Hungerford DS, Krackow K. Activity level and wear in total knee arthroplasty. J Arthroplast. 2001;16(4):446–53.
16. Low AHL, Xin X, Law WG, Teng GG, Santosa A, Lim A, Chan G, Ng SC, Thumboo J. Validation of the UCLA Scleroderma Clinical Trial Consortium Gastrointestinal Tract Instrument 2.0 in English- and Chinese-speaking patients in a multi-ethnic Singapore systemic sclerosis cohort. Clin Rheumatol. 2017;36(7):1643–8.
17. Zahiri CA, Schmalzried TP, Szuszczewicz ES, Amstutz HC. Assessing activity in joint replacement patients. J Arthroplast. 1998;13(8):890–5.
18. P S, P R: **CT bone densitometry of the anchorage of artificial knee joints**. *J Comput Assit Tomogr* 1985(9):607–608.
19. Enlow DH. Wolff's law and the factor of architectonic circumstance. Am J Orthod. 1968;54(11):803–22.
20. Lubbeke A, Garavaglia G, Barea C, Stern R, Peter R, Hoffmeyer P: **Influence of patient activity on femoral osteolysis at five and ten years following hybrid total hip replacement**. *J Bone Joint Surg Br* 2011, **93b**(4):456–463.

Figures

Figure 1

The rBMD was measured at 10 regions of interest around the tibial component on X-ray film, with 4 medial measurement areas: M1, M2, M3 and M4; 4 lateral measurement areas: L1, L2, L3 and L4; and 2 distal measurement areas: D1 and D2. In the figure above region A and F measure gray values of air and metal of femoral prosthesis respectively to adjust bone density. The measured area avoided cement, cortical bone, and fibula head. The mean value of rBMD around the tibial component was defined as (M1+M2+M3+M4+L1+L2+L3+L4+D1+D2) /10. The medial mean rBMD was defined as (M1+M2+M3+M4) /4. The lateral mean rBMD is defined as (L1+L2+L3+L4) /4.

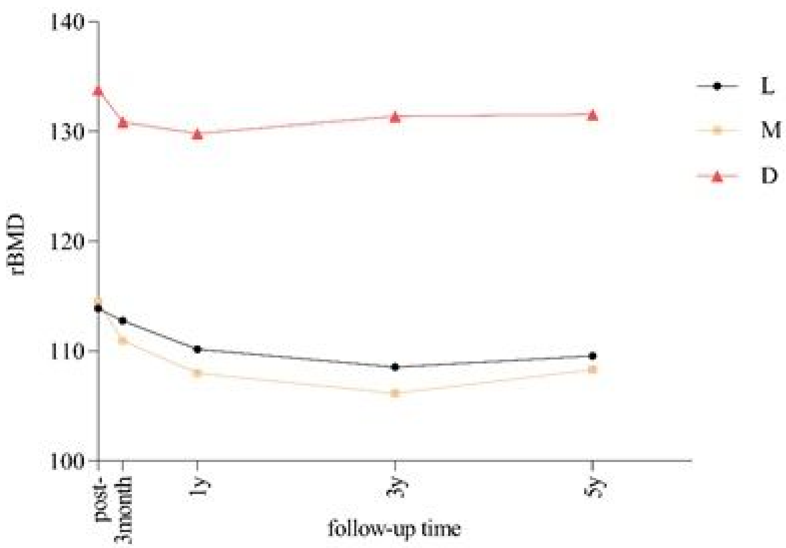

Figure 2

Curves of mean rBMD in medial, lateral and distal regions. rBMD decreased at all time points after surgery compared with baseline. The distal average rBMD of prosthesis was higher than that of medial and lateral average rBMD, while the medial average BMD decreased more than that of lateral average BMD.

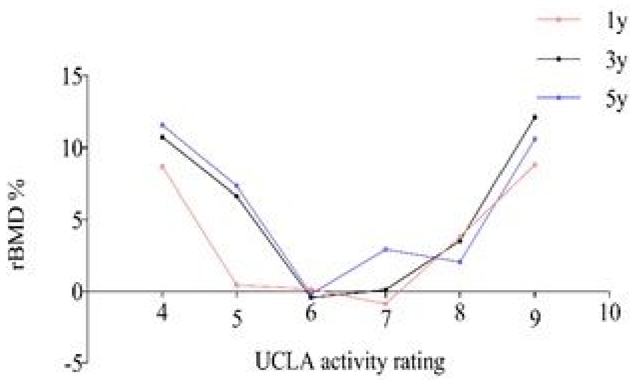

Figure 3

Relationship of UCLA activity rating with rBMD%. The rBMD measured at 1 week after surgery was defined as baseline. rBMD%=(rBMD baseline -rBMD)/rBMD baseline *100%, indicating the percentage change of rBMD measured after surgery relative to baseline. rBMD % represents the percentage decrease of rBMD, since the bone density basically showed a decreasing trend after surgery. This graph shows the percentage decrease in bone mineral density at different activity levels at 1, 3, and 5 years after surgery. It can be seen from the figure that when UCLA was 6 and 7, the rBMD% was the smallest; when UCLA was 4-6, the rBMD% decrease with the increase of UCLA; when UCLA was 7-9, the rBMD% increase with the increase of UCLA.

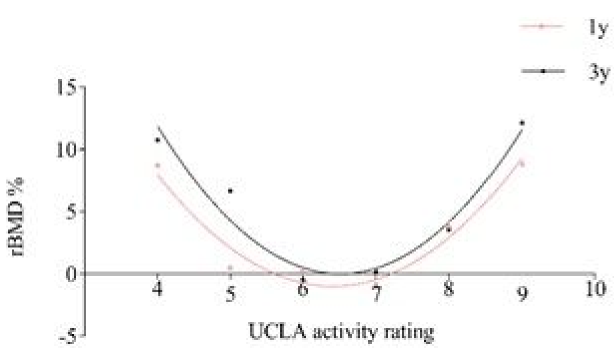

Figure 4

Nonlinear regression model of UCLA activity rating and rBMD%. The curve fitting of UCLA activity level and rBMD% showed a parabolic relationship between UCLA activity level and rBMD% at 1 and 3 years after surgery (P<0.001, P=0.02), while there was no significant relationship between UCLA activity level and rBMD% at 5 years after surgery (P=0.239).This figure showed that postoperative activity level was an important influencing factor of bone density around the prosthesis, and we further discover that the activity level had an effect on the bone around the prosthesis in the early postoperative period, but not in the late postoperative period . Bone density loss around the prosthesis was minimal at activity levels of 6 and 7.