Excised host tissues weight: New Indicators of Total Knee Arthroplasty Worthy of Attention

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Research article

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Abstract

Background: Knee osteoarthritis (KOA) is a crippling disease and affects many people around the world. Total knee arthroplasty (TKA) is an effective way to treat this disease. The objectaives of this study to compare the weight of the total knee arthroplasty implants and the weight of the natural knee in different groups and also to analyze facts which may affect the weight of surgical host excision.

Methods: In total, 105 consecutive TKAs were enrolled in this prospective cohort study with three different brands of knee prostheses. Patients meeting the criterion were divided into the normal bone mass group, the osteopenia group or the osteoporosis group according to the results of preoperative bone density examination. The removal of bone and soft tissues that were collected during TKA operations of each group were weighed and compared with the total weight of the knee prosthesis (including implanted bone cement). Multivariate logistic stepwise regression analysis was conducted to identify indicators affecting host removal weight.

Results: The average host removal weight was (132.56±36.88)g for normal bone mass group, (112.86±23.65)g for osteopenia group and (103.74±20.66)g for osteoporosis group. There were statically differences among the three groups. There was a significant difference between the normal bone mass group and the osteopenia group (P=0.003), while no difference between the osteopenia group and the osteoporosis group (P=0.154). No differences were found in the TKA components weight, bone cement weight and knee joint weight gained after TKA among all groups. Stepwise multiple regression analysis using the weight of excised host tissues as a dependent variable and BMD level, gender, age and other available indicators as independent variables revealed that BMD level(B=9.057, p=0.008), gender(B=21.692, p<0.001), Kellgren-Lawrence grade(B=13.790, p=0.003) are significant factors affecting excised host tissues weight.

Conclusion: There is a positive correlation between the weight of the host removals of TKA and the patient's bone density. BMD level, gender and K-L stage of KOA were the main factors affecting the weight of the host removal.

Introduction

Knee osteoarthritis (KOA) is a highly prevalent and crippling disease, affecting nearly 10 million adults in the US[1]. Total knee arthroplasty (TKA) is effective in relieving pain and improving patient-reported physical function in patients with advanced knee osteoarthritis. Currently, it is estimated that nearly 1.8‰- 2.4‰ patients are treated with TKA in developed countries every year[2, 3] .What's more, the demand for TKA will increase to 3.48 million in the US by 2030 according to a previous statistic[4].

The development and manufacturing of medical implants that replace failed knee joint is of great importance for an aging population. Previous studies have shown that the influence of the implant design on functional outcomes found no significant difference, while, few reports focused on knee prosthesis weight [5–7]. It has been reported that changes in the weight of the knee joint are related to the

prognosis [7]. The excessive weight of the implant directly corresponds with the type of the material that is used in its manufacture. However, it becomes mandatory on many occasions to use some available implant materials, which may not be of lightweight. Patients with different excised host tissue weight use different weight prosthesis, which is supposed to be more in line with the purpose of precision medicine. A previous study was conducted to ascertain OA patients' understanding of their perception of the amount of bone and soft tissue excised, and the true weight of their implanted prostheses and bone cement. The result showed that patients' perception of their operation varied widely, mostly, in a negative way. By overestimation of the weight of implant, they believed that they had undergone greater bone resection and subsequently gained more weight than they actually had. This may negatively affect their postoperative recovery[5]. To the best of our knowledge, the weight of the implants for the knee has not been reported in Asians. Given that patients of different races responded differently to the same orthopedic surgery, we conducted this study [8]. We hypothesized that the weights of the excised host tissues in patients with different bone mineral densities are different, so that preoperative bone mineral density examination can provide a reference for selecting suitable prosthesis for patients with different bone density.

Materials And Methods

Following approval from our institutional review board, the patients undergoing a unilateral primary TKA for osteoarthritis from October 2015 to June 2019 were eligible for enrolment in this prospective trial. Informed consent for participation was obtained from each patient before surgery. The patients who meet the following criteria will be included: (i)Initial TKA treatment; (ii)No patella replacement; (iii) No history of surgery on the affected knee (such as high tibial osteotomy); (vi)No osteoporotic fracture; (v)No severe varus or valgus knee deformity (Deformity angle 25°); (vi) No rheumatoid arthritis;(vii) No serious basal metabolic diseases. The patients' characteristics and surgical data details were shown in Table 1.

The patients who met the inclusion criteria underwent dual-energy X-ray bone density screening(GE Lunar, America) to evaluate bone mineral density (BMD) before surgery. They were divided into the normal bone mass group, the osteopenia group or the osteoporosis group according to the T score[9] (The basis for grouping was detailed in Table 2).

Table 1
Patients' Characteristics and Surgical Data in Different Groups

Parameter	normal bone mass group	osteopenia group	osteoporosis group	P value
n	23	57	25	
Age	65.6 ± 5.0	68.4 ± 6.9	65.9 ± 9.5	0.174
Gender(M/F)	16/7	41/16	23/2	0.102
Average BMI	25.00 ± 3.65	25.94 ± 3.65	24.25 ± 3.38	0.135
Preoperative VAS score	3.17 ± 1.34	3.32 ± 1.58	2.96 ± 1.51	0.600
Duration (year)	7.0 ± 4.0	9.4 ± 6.8	8.0 ± 6.3	0.234
Preoperative HSS score	55.91 ± 9.05	55.82 ± 13.62	53.48 ± 2.69	0.726
* P□0.05				

Table 2
Bone mineral density classification criteria based on DXA

Classification	T-score
Normal bone mass group	T-score≥-1.0
Osteopenia group	-2.5□T-score□-1.0
Osteoporosis group	T-score≤-2.5
Osteoporotic fracture group	T-score≤-2.5 & osteoporotic fracture

T-score = (measured value- peak bone mineral density in normal young people of the same race and the same sex)/ the standard deviation of peak bone mineral density in normal young people of the same race and the same sex. Patients with osteoporotic fractures were excluded on the preliminary screening of this study, because osteoporotic fractures are a contraindication to TKA.

Operating Procedure

Three different brands of posterior-stabilized knee prosthesis were used according to the surgeon’s preference or patient’s choice: Gemini MKII® (LINK, Germany), sigma PFC® (DePuy, America) and AK-JPX® (AK medical, China). The femoral and tibial parts of the prosthesis were Co-Cr-Mo alloy, and the spacer was made of highly cross-linked polyethylene. All cases involved were not treated with patellar replacement.

The surgeries were performed by the same senior surgeon under general anesthesia. Tourniquets were not routinely used unless patients were expected to suffer a prolonged surgery time or with mild coagulation disorder (pressure: 60 kPa). An anterior midline skin incision was made with a medial parapatellar approach. We removed the hyperplastic synovium and part of the infrapatellar fat pad, using intramedullary guides for the femur and using extramedullary guides for the tibia. After the osteotomy was completed, high-pressure pulsatile lavage was used to clean the bone surfaces and soft tissues. We then pressurised the cement into the cancellous bone to ensure better cement interdigitation and then cement-type knee joint prostheses were installed. The excised host bone and tissues and residual polymerized cement were collected by two specimen bags and then weighed by a precision electronic balance with an accuracy of 0.01 g. The weight of specimen bags, prostheses and one full bottle of cement were provided by manufacturers.

Statistical Analysis

Data analysis was performed by SPSS version 19.0 (SPSS Inc, Armonk, NY). Quantitative data are presented as the mean and standard deviation (SD). Differences in continuous variables between groups were evaluated with Student's t test. Chi-square test or Fisher exact test for difference in proportions was used to test independence between categorical variables. The average excised tissue weight, TKA component weight, bone cement weight and knee joint altered weight were compared among all groups. All quantitative data closely follow normal distribution. The weight of host removal during TKA was used as the dependent variable and BMD level, age, gender, course of disease and other factors were used as independent variables for multivariate stepwise regression analysis. (Assignment of the stepwise regression analysis was detailed in Table 3). Statistical significance was set at $P < 0.05$.

Table 3
Assignment of stepwise regression analysis

Factors	Assignment
Gender	Male = 0,Female = 1
K-L stage	Stage III = 0,stage IV = 1
BMD	Osteoporosis group = 0 Osteopenia group = 1 Normal bone mass group = 2

Results

1.The weight indicators of TKA in different bone density groups

105 patients were included. Patients' demographics, comorbid conditions, and surgical data were shown in Table 1. There was no significant difference among the groups with regard to the majority of the patients' characteristics and surgical data. The weight of removed issues and the weight of implants of

patients undergoing total knee arthroplasty (TKA) included in this study were all respectively analyzed, and the average weight of implants was (416.67 ± 42.32)g, which was significantly higher than that of removed bone and soft tissues of 115.01 ± 28.08 g, almost three times the weight of the latter, with the (301.30 ± 47.40)g weight gained on the knee. Patients were divided into groups according to different bone mineral densities. The results were compared among groups and showed that the weight of removed tissues was lighter of patients with lower BMD during the procedure ($p < 0.01$), and the ratio of the weight gained on the knee to the patient weight was also significantly different ($p = 0.002$). Among different BMD groups, there was no statistical difference comparing the following indicators: the weight of knee joint prosthesis components and bone cement, weight gained on the knee and the ratio of the weight gained on the knee to the patient weight.

Table 4
Results of each weight parameter

Average Weight	**normal bone mass group**	**osteopenia group**	**osteoporosis group**	**F**	**p**
TKA component (g)	407.99 ± 40.97	405.85 ± 41.50	393.29 ± 45.88	0.938	0.395
Cement (g)	13.34 ± 5.53	12.63 ± 5.37	15.00 ± 8.17	1.286	0.281
Excised host tissue (g)	132.56 ± 36.88	112.86 ± 23.65	103.74 ± 20.66	7.507	0.001*
(TKA componen + cement)/excised host tissue	3.44 ± 1.16	3.87 ± 0.98	4.08 ± 0.93	2.574	0.081
Gained weight (g)	287.10 ± 54.38	305.61 ± 47.48	304.55 ± 50.65	1.335	0.268
(TKA components + cement)/patient's weight (%)	(066 ± 0.13)%	(0.62 ± 0.09)%	(0.66 ± 0.10)%	1.801	0.17
excised host tissue /patient's weight(%)	(0.20 ± 0.06)%	(0.17 ± 0.04)%	(0.17 ± 0.04)%	6.67	0.002*
gained weight/patient's weight (%)	(0.45 ± 0.126)%	(0.45 ± 0.09)%	(0.49 ± 0.09)%	1.666	0.194
* P□0.05					

2. Multivariate stepwise regression analysis affecting the weight of excised host tissues in TKA surgery

The multivariate analysis which was used for these available factors showed that only BMD($B = 9.057$, $p = 0.008$), gender($B = 21.692$, $p < 0.001$) and the osteoarthritis Kellgren-Lawrence stage of affected side knee($B = 21.692$, $p < 0.001$) were entered the equation. Male patients with high BMD level and high K-L level have heavier host removel.

Table 5
Multivariate stepwise regression analysis of host removal weight in TKA surgery

variables	partial regression coefficent	Standard error	Standard partial regression coefficient	t	P
Constant	94.694	4.183		22.640	< 0.001
BMD	9.057	3.352	0.231	2.702	0.008
Gender	21.692	5.334	0.347	4.067	< 0.001
K-L stage of the affected knee joint	13.790	4.556	0.257	3.027	0.003

Discussion

For now, the study targeting at Europeans showed that the weight gained on the knee ranged from 266.7 g to 380 g of patients after TKA, and for some patients, the weight of implants was six times higher than that of removed tissues during the procedure[10, 11]. The large increase of knee joint weight after the procedure brought great challenges to the postoperative rehabilitation of patients. The data indicate that the strength of quadriceps femoris muscles and hamstring muscles on the affected side of patients was significantly lower than that on the healthy side in the short-term after TKA. In addition ,deficits in muscle torque and power and in the extensor muscle cross-sectional area were present 10 months after knee replacement[12]. Poor muscle strength may not support the unexplained weight gained, which may be one of the reasons for active activity limitation of the lower extremities of patients after TKA. Secondly, for most patients with KOA, the proprioceptive function of the knee joint had decreased in different levels[13, 14], and it would inevitably cause injury to the joint capsule, muscle tendon and ligament which contain knee joint proprioceptors after the procedure[15]. Therefore, some patients may present pathological gait patterns and have difficulty in performing basic functional tasks and in maintaining balance and postural control, even one year after surgery. While the weight gained on the knee joint after TKA would possibly deepen the impact caused by the proprioceptive change: that the tibia's forward and backward mobility in the joint was increased due to the removal of cruciate ligaments and the decrease of knee muscles strength, and the weight gained would increase this mobility inertia, which would not only accelerate the fretting wear of joint prosthesis, but also increase the risk of postoperative joint dislocation[16]. Besides, for some patients undergoing patellar resurfacing, the weight change on the femural condylar and patella could cause the change of stress load of patellofemoral joint: the increased femoral weight would directly increase patellofemoral joint shear force, which may be one of the causes of patellar trajectory changes and persistent anterior knee pain[17].

It has crucial meaning to properly reduce the weight of prosthesis components. At present, there are mainly three schemes to reduce the weight of prosthesis components. Firstly, lighter materials with the same size and volume of the knee joint prosthesis should be used. Polyethylene tibial components prosthesis has been applied to clinical practice, which can significantly reduce the weight of the prosthesis on the tibial plateau, but some studies have shown that all-polyethylene prosthesis is poor in hardness and may generate higher stress and micromotions than metal-backed tibial components[18]. Secondly, the volume of the non-load-bearing part of the prosthesis should be reduced. Some scholars assume that the weight of the femoral prosthesis can be greatly reduced by drilling holes on the non-load-bearing surface of the femoral prosthesis without affecting the load-bearing performance of the prosthesis. Sudesh et al.[11] used finite element modelling (FEM) technique to carry out the simulation study on the radius and length of the drill hole in the prosthesis. It has shown that using drills on implants can reduce the implant weight of approximately 25 g. The new type of prosthesis still have better performance under 2000N load. Thirdly, part of the uncemented prosthesis has been applied to clinical practice that can reduce the weight of cement, but the weight of the uncemented prosthesis has not been studied yet. There was no significant difference in the short-term usage life, joint function recovery and complications between the uncemented prosthesis and cemented prosthesis after the procedure, but the long-term follow-up is still needed to evaluate the long-term outcome of the uncemented prosthesis[19].

Our study first involves the new parameter of BMD, related to the weight of the knee joint prosthesis and the weight of removed host tissues when studying the outcomes of TKA. Given that weight is inextricably linked to density, we hypothesized that the lower BMD, the lighter weight of removed host tissues. We test this hypothesis with three different brands of prostheses, and our results show that the weight of removed host tissues is lower for the patients with lower BMD, while the weight change of prosthesis components and the knee joint are not statistically different. Nevertheless, we suggest that patients with lower BMD should choose the lighter prosthesis to replace. The severity of knee osteoarthritis is always negatively correlated with the BMD[20, 21], that is, compared with patients with the normal BMD, patients with lower BMD may experience more pain and have poor strength of muscles and tendons around the affected knee. According to the research, the proximal tibial BMD will reduce after TKA, and joint load capacity will also decrease in the short-term after the procedure, so the unreasonable weight gained on the knee will have a negative impact on the postoperative recovery of patients[22].

This study has some limitations. Firstly, the BMD in our study was synthetically calculated by the hip joint Ward's triangle BMD and lumbar spine L1-L4 BMD, rather than directly calculating the local knee joint BMD on the affected side, and the knee joint BMD on the affected side is always lower than that on the healthy side, so our BMD results may be higher than the real one. Secondly, the prosthesis type included in this study was posterior-stabilized knee prosthesis, which has additional gasket central column and requires osteotomy in the intercondylar fossa compared to posterior cruciate knee prosthesis, so the weight of the knee joint with this type of prosthesis may change more after the procedure, and it needs to be further studied when more prosthetic types are included. In addition, our preliminary studies have shown that the weight of host removals of patients with rheumatoid arthritis is significantly lower than normal patients with KOA. The aim of the study was to provide a standardized TKA data for reference in

the future studies. Therefore patients with Rheumatoid arthritis (RA), with severe bone defects, or with special types of prostheses (e.g., prostheses including tibial extension stem) had been excluded in our study.

Conclusion

The knee joint on the affected side of patients could be significantly heavier after treating with TKA, the gained weight varies in the range of 301.30 ± 47.40 g, and the total weight of implants is approximately 3.6 times of the weight of removed bone and soft tissue. The weight of host removal is lower for patients with lower BMD. BMD level, gender and K-L stage of KOA were the main factors affecting the weight of the host removal. Long-term follow-up and various types of prostheses are needed to be verified that how the weight change on the knee joint affects the prognosis.

Abbreviations

KOA: Knee osteoarthritis; TKA: Total knee arthroplasty; BMD: Bone mineral density; OA: Osteoarthritis; SD: Standard deviation; FEM: Finite element modelling; RA: Rheumatoid arthritis

Declarations

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Authors' contributions

XZ and KG designed the study. ZZ wrote the first draft of the manuscript. RR, CB and LY performed the procedure. LZ, SP and CH collected the data. ZS helped perform the analysis. ZZ and RR revised the manuscript. The author(s) read and approved the final manuscript.

Ethics approval and consent to participate

The research plan was approved by the ethics committee of our hospital and all the participants singed informed consent.

Consent for publication

All the patients in this study have given their informed consent for the article to be published.

Availability of data and materials

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

Competing interests

The authors declare that they have no conflicts of interest.

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