Article

J. Biol. Regul. Homeost. Agents. 2025; 39(1): 97–105
https://doi.org/10.23812/j.biol.regul.homeost.agents.20253901.12

Obesity Factors in Failure Analysis of Cemented Total Hip Replacement

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Submitted: 3 November 2022 Revised: 12 December 2022 Accepted: 15 December 2022 Published: 16 January 2025

Background: This article mainly analyzed the influence of obesity constitution on the failure of cemented total hip replacement.
Methods: By collecting body mass index (BMI) data of patients with hip joint and bone mineral density (BMD) of femur, the age, gender and number of patients were statistically analyzed, and the influence of body weight on postoperative implant force was analyzed by finite element method modeling analysis.
Results: Studies have found that obesity and BMI reaching overweight or obesity standards will aggravate the symptoms of hip patients, and the effects will be different between different genders. The effects of body weight on hip replacement, fracture of bone cement stem, sinking of prosthesis stem and loosening of bone cement-stem interface were analyzed in detail.
Conclusions: It was proved that BMI had a great correlation with postoperative failure. In addition, the effect of weight loss drugs on postoperative rehabilitation immune system was discussed.

Keywords: obesity; failure; total hip replacement; immune system

Introduction

Since hip prostheses replacement has been applied in clinic, a large number of studies have analyzed the main reasons for the failure of implanted prostheses. Many factors were interrelated and influenced each other, forming a complex organic whole. After research, obesity was one of the main factors affecting the replacement failure of patients [1].

Existing studies have shown that the factors affecting the increase of dislocation rate, liner fracture and wear in hip prosthesis replacement include body mass index (BMI), age and gender. Surgical factors affecting these risks include operator experience, prosthesis components, acetabular cup fixation method and direction, etc., [1]. Among them, obese patients were more prone to dislocation, leg length discrepancy, fracture, implant loosening, infection and pulmonary embolism. Compared with other patients, the revision rate of obese patients was significantly higher, and obesity had become an independent risk factor leading to early revision [2]. The complications caused by obesity, such as diabetes, congestive heart failure, chronic obstructive pulmonary disease (COPD), etc., have brought great limitations to researches [3]. In addition, the risk of prosthetic joint infection among obese smokers was also on the rise [4], untreated anemia or poor blood sugar control will also become risk factors [5], and BMI also interacted with age and gender [6].

To sum up, the main factors of hip revision were unclear, and the main objective factors leading to the changes of these factors were not clear. Through clinical practice, the author found that besides the failure of surgical replacement, the results of loosening failure after several years the successful initial replacement for patients were mainly related to themselves. Through analysis, it was found that the above factors could be classified as the patient's weight bearing (body weight/obesity). At present, the methods of artificial hip replacement mainly include biological type and bone cement type, among which biological type is mainly aimed at young and middle-aged patients with good physique. However, most patients were sick due to bone tissue loss in clinic, and their ages were mostly between 50 and 60 years old, and there were more female patients. Therefore, in practice, most of these patients use bone cement hip replacement.

In this study, patients were classified in terms of age and gender, and so as to adjust according to the initial operation time, aiming at studying the root cause of obesity on the failure of bone cemented hip joint. This study is helpful to improve the service life of hip replacement and reduce

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the probability of multiple operations, which has high scientific research significance and research value.

Methods and Design

Design

BMI, muscle/fat ratio, femoral neck anteversion (FNA) and bone mineral density measurements results of patients with effective hip joints were collected and statistically analyzed. In the experiment, a large number of data were treated by linear regression and the method of the minimum squares. According to the theory of mathematical statistics, the correlation coefficients were calculated and tested by Student method. The statistical analysis software SPSS.7.0 (IBM Corp., Armonk, NY, USA) and ANOVA were used to analyze the significance, and the significance difference was set as $p < 0.05$.

Participants

In this paper, 478 surgical patients admitted to The Hospital from 2016 to 2021 were collected. There were 413 joint replacement patients (about 86.5%), including 149 patients with artificial hip joint, 83 patients with knee joint, 59 patients with spine, 75 patients with ankle joint and 49 patients with shoulder joint. Among them, hip replacement accounted for 36%, which was the most common joint replacement surgery. The proportion of each class is shown in Fig. 1.

Inclusion criteria: (1) Patients who underwent joint replacement. (2) Informed consent, ability to cooperate with the investigation and research, and complete follow-up information. Exclusion criteria: (1) Exclude patients who are unable to walk and stay in bed for a long time. (2) Exclude patients with bone tumors, prosthetic site infections, and autoimmune diseases.

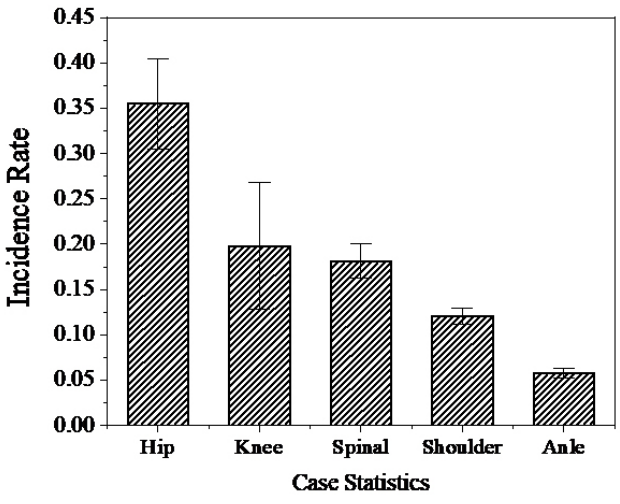

Fig. 1. Joints disease rates.

Measures

In this paper, the body mass and height of all patients at admission were calculated. The body mass index (BMI) was calculated as the ratio of body mass (kg) to height square (m^2). The BMI was calculated using the standard formula of weight in kilograms divided by 84 height in meters squared. Due to the differences between Chinese and European and American, BMI classification is different. According to the classification of BMI selected in this paper, BMI <18.5 kg/m^2 is low weight. 18.5~22.9 kg/m^2 is normal. 23.0~24.9 kg/m^2 is overweight. BMI ≥ 25 kg/m^2 is obesity.

In addition, this paper needs to collect bone mineral density of hip patients. The hospital used dual energy X-ray absorption measuring instrument (DEXA) to collect bone mineral density in different were as of the left femur (femoral neck, wards triangle, greater trochanter and shaft of femur). From Fig. 1, we can see that hip replacement cases were the primary diseases, including 2195 cases of initial replacement and 355 cases of revision surgery.

Patients with hip joint included 205 male patients (49.8%) and 208 female patients (50.2%). It can be seen from Fig. 2 that there were gender differences in the proportion of artificial hip replacement at different ages. At ages 10–50, the proportion of male patients with hip replacement is much higher than that of female patients. At the age of 50 to 60 years, the proportion of joint replacement in female patients increases, which may be related to the fact that women are in menopause during this period, the hormone secretion changes, resulting in bone loss, and the amount of surgery increases. This situation is most obvious at the age of 70–80, the number of operations for women is much higher than that for men, and after the age of 80, the number of operations for both parties decreases, which may be affected by the average life expectancy of the population.

Finite Element Mechanical Analysis

The assembled three-dimensional model of femur-bone cement-prosthetic stem was imported into the finite element analysis software ABAQUS 6.14. The Boolean operation of each assembly component was performed and the corresponding interfacial interaction was definite as contact model. Respectively set the interaction surfaces of the bone cement with the prosthesis stem and femur as tie contact. The bone cement, femur and prosthesis were set as continuous, homogeneous and isotropic materials. Each component was given corresponding material properties and element types. And then the finite element model was generated. The elastic modulus of cortical bone, prosthesis stem and bone cement were set to 16 GPa, 110 GPa and 2.08 GPa respectively. Their Poisson's ratio was set to 0.3 and C3D10 element type was used to divide the grid cells of each components.

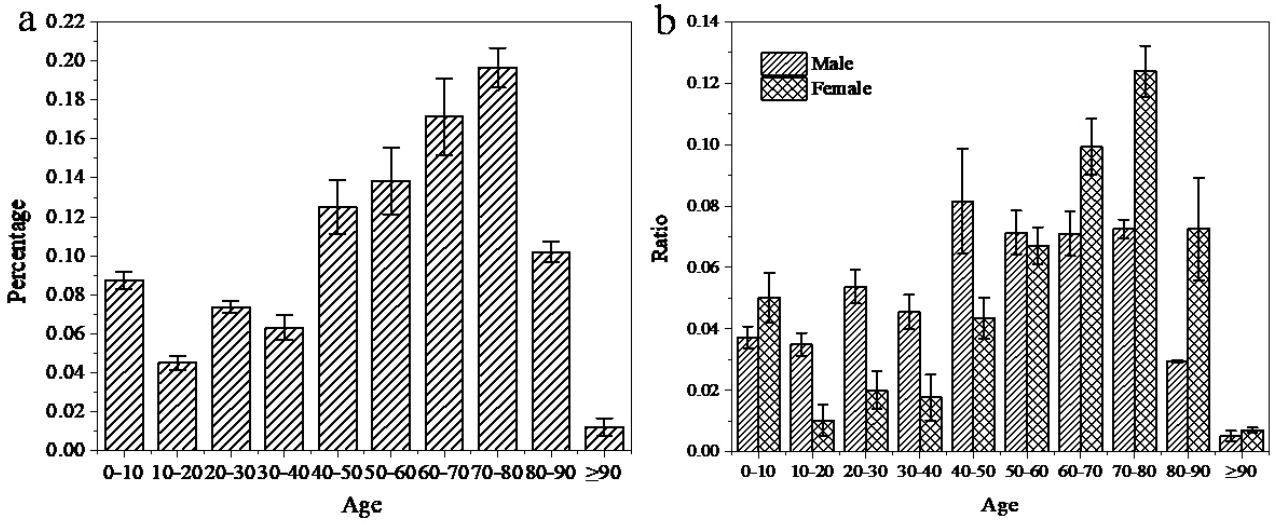

Fig. 2. Patients' percentage of total hip arthroplasty (THA). (a) Age, (b) Gender.

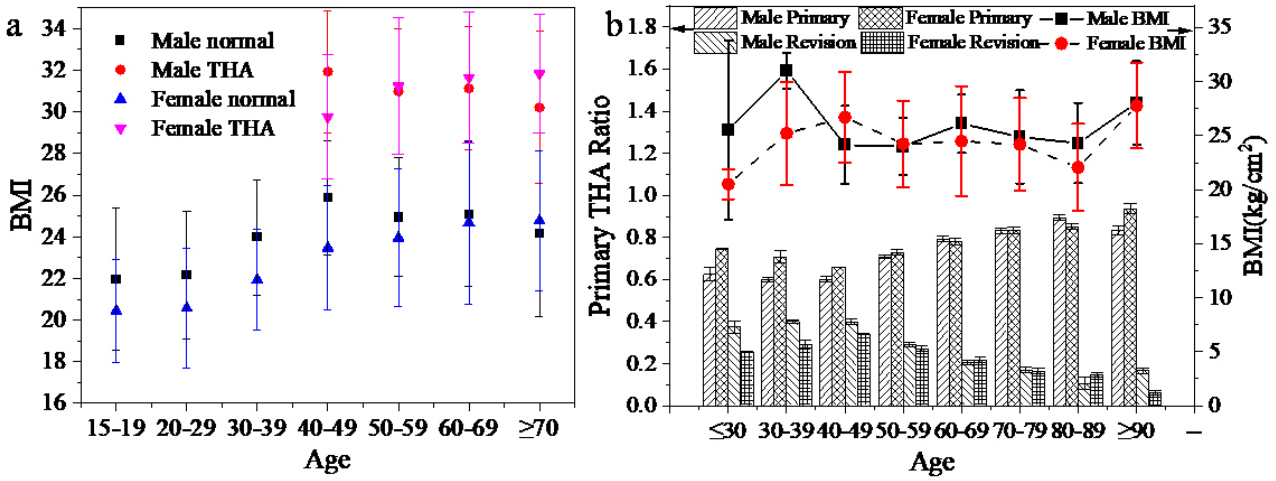

Fig. 3. Body mass index (BMI)-THA statistics diagram. (a) Comparison between THA patients and normal; (b) BMI-THA relationship.

Statistical Analysis

The collected data were analyzed using SPSS 22.0 software (IBM Corporation, USA). Continuous variables were expressed as mean ± standard deviation and range, categorical variables as proportions. The normality of continuous variables was evaluated and normalization was applied for those not normally distributed. Continuous variables were compared between groups using the Student *t*-test for independent data, analysis of variance by using the ANOVA for measurements. A p-value < 0.05 was considered significant for all groups.

Results and Analysis

Effect of Body Weight on Hip Replacement

In this paper, the body weight changes of hip patients were followed up and counted, as shown in Table 1. After 40 years old, joint replacement occurred and weight increased significantly. In the same BMI, the odds rate ratio of male OR is higher than that of female, so the increase of male BMI is closer with hip replacement than that of female, as shown in Fig. 3a. There was significant difference in BMI between 23.0 to 24.9 kg/m^2 and above in OR ($p < 0.05$). After operations of correlation between postoperative complications and BMI index, there were 24 patients with different degrees of complications, and the complication rate was 16.13%.

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Table 1. Different BMI of Age and Sex in Patients.

Ages	Male		Female	
(Year)	Normal	preoperative	Normal	preoperative
15–19	21.97 ± 3.41*	—	20.45 ± 2.47	—
20–29	22.14 ± 3.06*	—	20.57 ± 2.87	—
30–39	23.97 ± 2.78*	—	21.93 ± 2.42	—
40–49	25.88 ± 2.74*	31.93 ± 2.92	23.47 ± 2.97	29.75 ± 2.98
50–59	24.93 ± 2.85*	30.98 ± 3.02	23.95 ± 3.31	31.23 ± 3.28
60–69	25.08 ± 3.46*	31.13 ± 2.95	24.68 ± 3.92	31.64 ± 3.13
≥70	24.15 ± 3.97*	30.21 ± 3.65	24.76 ± 3.36	31.83 ± 2.84
Total	24.02 ± 3.18*	31.06 ± 3.14	22.83 ± 3.04	31.11 ± 3.06

* means $p < 0.05$, with significant difference between groups.

Initial and Revision Rates of Total Hip Arthroplasty (THA) Patients at Different Ages and BMI Values of Different Genders were Counted

For THA initial replacement patients (Fig. 3b), the rate of female patients before 60 years old is higher, the incidence rate of male patients aged 60 to 89 is slightly higher than that of female patients, and the initial replacement rate of female patients over 90 years old is higher than that of male patients. The revision rate of male is generally higher than that of female, and it rises first and then falls at the age of 50. In the early stage, the BMI growth rate of male patients was higher than that of female patients. At the age of 40, the BMI of female patients increased slightly, entered the peak of BMI index at the age of 40 to 50, and then gradually decreased and stabilized, which was consistent with that of male patients. The correlation results of BMI-THA incidence rate showed that the correlation coefficient of BMI-THA incidence rate in male was 0.524 ($p = 0.034 < 0.05$), while that in female was 0.691 ($p = 0.009 < 0.05$), which was less significant and more correlated (Table 2), and the correlation of female was greater than that of male.

Effect of Body Weight on Fracture of Bone Cement Stem

The results of cemented revision were screened and counted. The results showed that there were 11 males of fracture of bone cement stem with an average age of 72.8 years, 7 ± 1.2 years after initial replacement, and 6 females with an average age of 74.6 years, 5 ± 1.5 years after initial replacement. The fracture rate of male prosthesis accounted for 5.3% of revision, while that of female prosthesis was 3.2%. About 70% of the textured surface of the proximal end was covered with bone cement, while less than 20% of the smooth stem was covered with bone cement. The results showed that the average thickness of bone cement layer at the proximal end of the revised failed bone cement stem was about 1.2 ± 0.5 mm, which was much lower than that of the average normal bone cement thickness of 2.8 ± 0.8 mm at the proximal end and 3.5 ± 1.2 mm at the distal end. Most of the bone cement in the proximal end of canal was broken or fragmented.

In this paper, the extract of a male patient with revision due to stem fracture was selected for analysis, as shown in Fig. 4. During the revision operation, it was found that the proximal bone cement in the proximal end of canal was broken or fragmented and easy to be removed, while the distal prosthesis was firmly fixed and could not be taken out from the proximal end of canal. Moreover, the fracture part of the femoral bone marrow cavity prosthesis stem was repeatedly rubbed and stimulated, and the femoral cortex was often bulged.

Weight, Prosthesis Selection and Fracture of Cemented Femoral Prosthesis

Vincent *et al*. [7] found that the fracture time of bone cement stem is related to the patient's body weight, and the greater the body weight, the earlier the fracture time. Fatigue fracture of femoral bone cement stem occurred in 12 patients 19 to 78 months after operation, and the fracture sites were all located in the middle and distal end of 1/3 of femoral prosthesis. The fracture time of 5 cases was 3 to 7 years, which indicated that the large body weight and the small choice of prosthesis were directly related to the fracture of prosthesis, suggesting that the use of small stem cement prosthesis in joint replacement of obese patients should be avoided as much as possible.

Bone Cement Installation Technique and Femoral Prosthesis Fracture

This study found that bone cement has less protection to bone at the proximal end, and the proximal end of canal is also affected by stress concentration effect from stalk after operation. Therefore, the bone around the proximal prosthesis stem will be adaptively absorbed, which will lead to the decrease of bone rigidity of bone mineral density and bone cortical thickness of proximal bone, so as to the gradual weakening of load force transfer mechanism and the significant increase of stress on the proximal prosthesis stem, and finally leading to the fracture of proximal end or neck.

Table 2. Correlation of different factors and THA.

Variables		BMI		Muscle/Fat		FRA-BMD		Neck-BMD		Wards-BMD	
		M	F	M	F	M	F	M	F	M	F
THA	Correlation	0.42*	0.69	0.53*	0.91	0.04*	0.24	0.36*	0.13	0.22*	0.62
	Significance	0.34*	0.09	0.23*	0.00	0.94*	0.60	0.44*	0.78	0.64*	0.14
Primary	Correlation	0.46*	0.04	0.31*	0.93	0.07*	0.02	0.42*	0.83	0.09*	0.72
	Significance	0.31*	0.93	0.50*	0.00	0.88*	0.97	0.35*	0.02	0.85*	0.07
Revision	Correlation	0.46*	0.04	0.31*	0.93	0.07*	0.02	0.42*	0.83	0.09*	0.72
	Significance	0.31*	0.93	0.50*	0.00	0.88*	0.97	0.35*	0.02	0.85*	0.07
Variables		Trochanter-BMD		Shaft-BMD		Femur-BMD					
		M	F	M	F	M	F				
THA	Correlation	0.11*	0.58	0.35*	0.09	0.46*	0.28				
	Significance	0.81*	0.18	0.44*	0.86	0.29*	0.54				
Primary	Correlation	0.03*	0.22	0.33*	0.65	0.42*	0.69				
	Significance	0.96*	0.64	0.47*	0.11	0.35*	0.09				
Revision	Correlation	0.03*	0.22	0.33*	0.65	0.42*	0.69				
	Significance	0.96*	0.64	0.47*	0.11	0.35*	0.01				

Note: M, Male; F, Female; BMI, body mass index; BMD, bone mineral density; FRA-BMD, Femoral front rake angle bone density; Neck-BMD, Femoral neck bone mineral density; Wards-BMD, bone mineral density; Trochanter-BMD, Trochanter bone density; Shaft-BMD, Femoral bone density; Femur-BMD, Total femoral bone density; Statistically significant ($p < 0.05$). * means $p < 0.05$, with significant difference between groups.

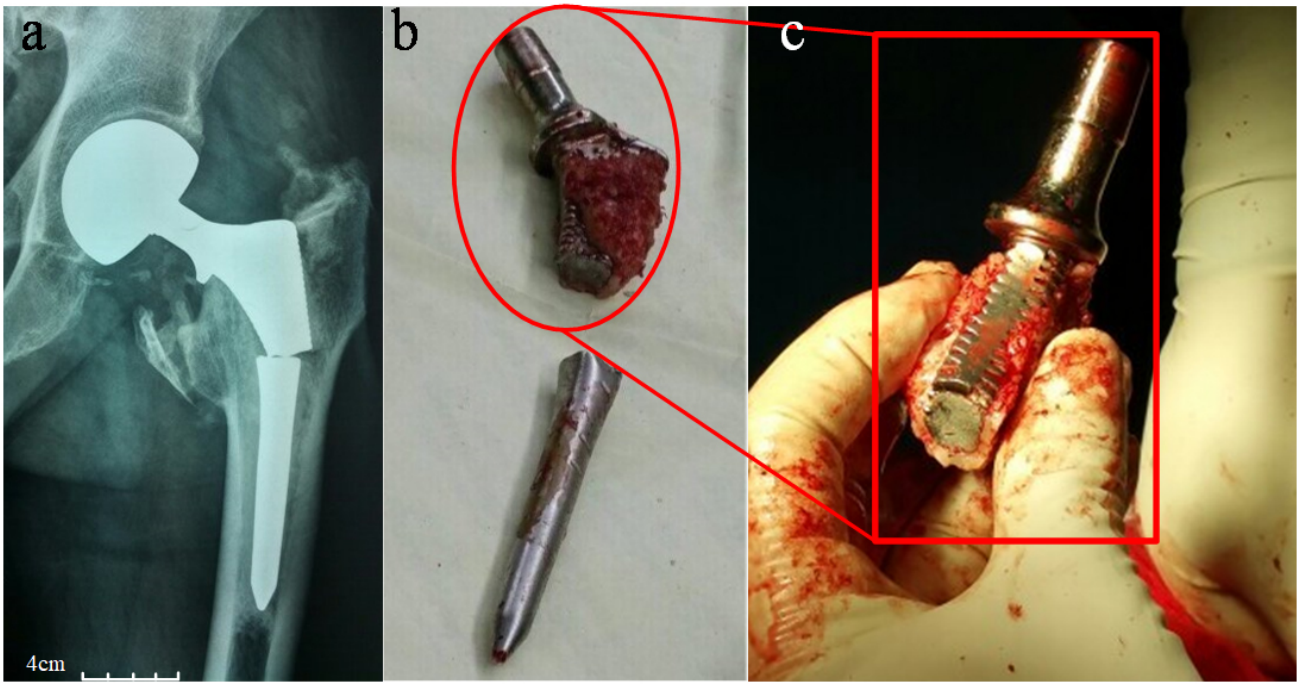

Fig. 4. Cemented stem fracture.

Effect of Body Weight on Sinking of Prosthesis Stem

No matter after cemented or biological type hip replacement, the prosthesis stem will sink. Clinical medicine prescribes that the stem sinking 2 mm is the obvious feature. At present, the stem sinking is mainly measured according to X-ray film and D'Antonio *et al.* [8] method. In this paper, 25 male and 18 female revision patients with obvious stem sinking were screened and X-ray films were extracted. According to D'Antonio *et al.* [8] method, the statistics of prosthesis stem sinking-BMI showed that the larger the BMI value, the more significant the stem sinking, as shown in Fig. 5.

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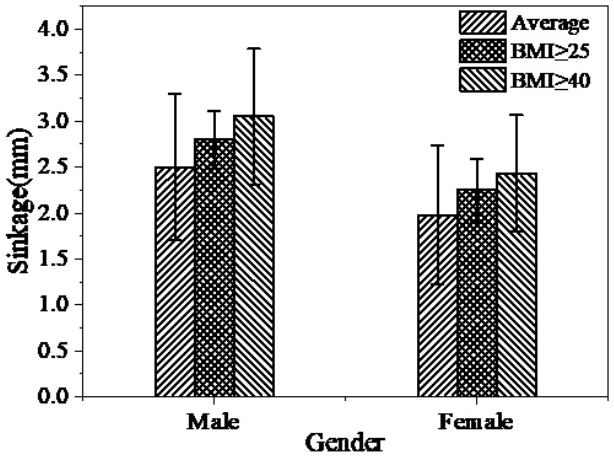

Fig. 5. Prosthesis sinking statistics in different genders patients.

Effect of Body Weight on Loosening of Bone Cement-Stem Interface

Interface loosening and stem sinking were associated with processes. Among them, aseptic loosening accounts for about 31.2% to 50% of the failure factors of artificial hip replacement, and weight gain will aggravate the risk of mechanical loosening. The loosening after cemented total hip replacement is mainly reflected in three aspects: microstructure of interface between artificial prosthesis stem and bone cement, the interface between bone cement and bone cavity, and interfaces [9], among which the loosening of the interface between prosthesis handle and cemented bone is the main failure reason. According to the statistics of this paper, about 15.3% of overweight and obese patients in 25.71% of loosening patients have imaging translucent lines <1 mm in the medial femur, and 8% of them have speckle imaging translucent areas caused by focal osteolysis in the proximal medial femur (Gruen I area) and the posterior lateral femur (VII area), as shown in Fig. 6.

Some studies [10] found that the debonding and disconnection of the interface between prosthesis stem and bone cement is mainly due to excessive shearing force or tensile stress at the interface between prosthesis stem and bone cement, which leads to interface dislocation or sliding. The increase of body weight causes the increase of external load on the prosthesis stem, the increase of medial shearing force and lateral tensile stress, and the increase of interfacial strain dislocation momentum is more and more obvious, and the prosthesis fixation enters the loosening stage earlier. Therefore, it is of great significance to study the influence of body weight on the initial debonding of bone cement-stem interface for analyzing the loosening failure of bone cement hip replacement.

The loosening process of cement-stem interface is long-term accumulation, which leads to fatigue and loosening failure of bone cement, while overweight easily accelerates the debonding and loosening process of interface and damage of bone cement layer. Through finite element gait mechanics analysis (Table 3), the maximum load of male (60 kg) foot following the ground was 3637.76 N, and the maximum load of prosthesis stem at 12 mm from proximal end was 1055 N. The force line increased first, then declined, and then slightly increased and then decreased during the process from apex to tail end, while the anterior and posterior segments of bone cement showed a peak-valley shape with high stress at apex and tail end and depression in the middle. In the femoral canal, the maximum stress is 45 N at 92 mm away from the proximal end, and it drops sharply from 150 mm to 200 mm, while the stress rises and then drops at 230 mm, while the latter part rises first and then drops in twists and turns, which proves that the interfacial shearing force is the main reason for failure, as shown in Fig. 7.

The lower limbs of human body support about 2/3 of the body weight for activities. After operation, the stress structure of the cantilever beam of femoral calcar changed, and the acetabulum center moved up, accompanied by the sinking of prosthesis stem and the loosening between host bone and prosthesis, which affected the rehabilitation of other normal muscles and bones and increased the degree or frequency of pain [6]. The BMI was found to be overweight or obese in 72% of patients, normal in 23% and low in simply 5%. BMI was associated with hip replacement in both groups and higher in male than in female. Therefore, the relationship between BMI increase in male and hip replacement is closer than that in female. Obesity can affect physiological indexes of patients, such as triglyceride and low and high concentrated fat protein cholesterol, which can induce complications such as osteoporosis and bone degeneration [11].

Discussion

Artificial hip replacement methods were divided into biological type and cemented type. Owning to biological femoral stem can promote regenerated bone tissue embedded in metal surface. Biological replacement was widely used for young and middle-aged patients who have bone quality and bone cell activity constitution. For those who were over 65 years old with osteoporosis, bone defects, bone growth dysfunction, bone cement technology was mainly used for them. However, the load bearing of the hip biomechanical system after surgery has always affected its reliability [1].

Obesity has been recognized as a risk factor for complications after initial total hip arthroplasty [12]. Some studies have shown that obese patients were more prone to dislocation, leg length discrepancy, fracture, implant loosening, infection and pulmonary embolism. The revision rate of obese group was significantly higher [2,3]. Smith *et al.* [6] found that BMI was too high to affect hip revision. While DeMik *et al.* [5] confirmed that it would ag-

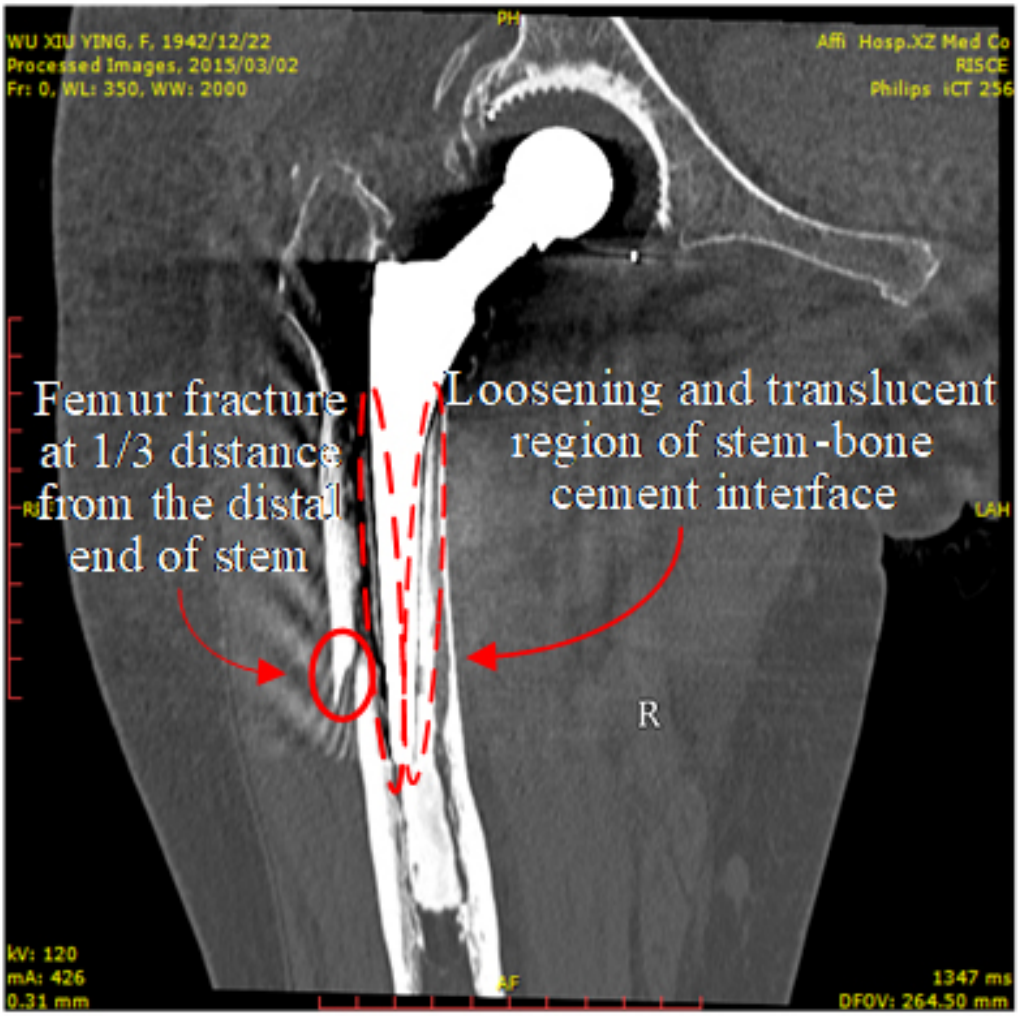

Fig. 6. Loosening and fracture region of stem-cement interface.

Table 3. Joint bearing forces in gait process.

Gait phase	Peak stress	Quantity/N	Unit vector		
			X	Y	Z
Foot followed phase	4.64 BM	3637.76	–0.36	0.10	0.93
Single-legged standing phase	3.51 BM	2751.84	–0.35	–0.05	0.93
Tiptoe off phase	4.33 BM	3394.72	–0.48	0.10	0.95

BMI, body weight: The vector is positive in the inward, backward and upward directions through the center of the femoral head.

gravate meniscus injury of knee joint. Wong *et al*. [11] and Vincent *et al*. [7] discovered that long-term obesity can hinder the functional rehabilitation of hip joint. Yu *et al*. [9] and Johnson *et al*. [12] observed that obesity increased the risk of femoral re-fracture after replacement. The other researches have shown that obese patients receiving revised THA were more likely to have reinfection rate and long-term stay in hospital than non-obese patients [13,14]. To improve the impact of obesity on joint replacement, some patients would be advised to take appropriate medication to treat obesity. Such as Naltrexone-bupropion (Contrave) sustained-release tablets and Orlistat and sibutramine. The former was prone to hypertension, type-II diabetes mellitus or dyslipidemia and liver damage liver injury and other phenomena [16]. The two latter would reduce cholesterol and affect the gastrointestinal motility of patients [17]. Xu *et al*. [18] witnessed tripterine can activate the leptin receptor-signal transducer and transcription activator to reduce obesity index. It provided a new treatment for obesity without damaging the immune system. Additionally, this study through clinical statistical analysis of obese patients increased the risk of revision, finite element simulation analysis in patients with gait prosthesis stem and bone cement between the shear stress increases with load increases. In

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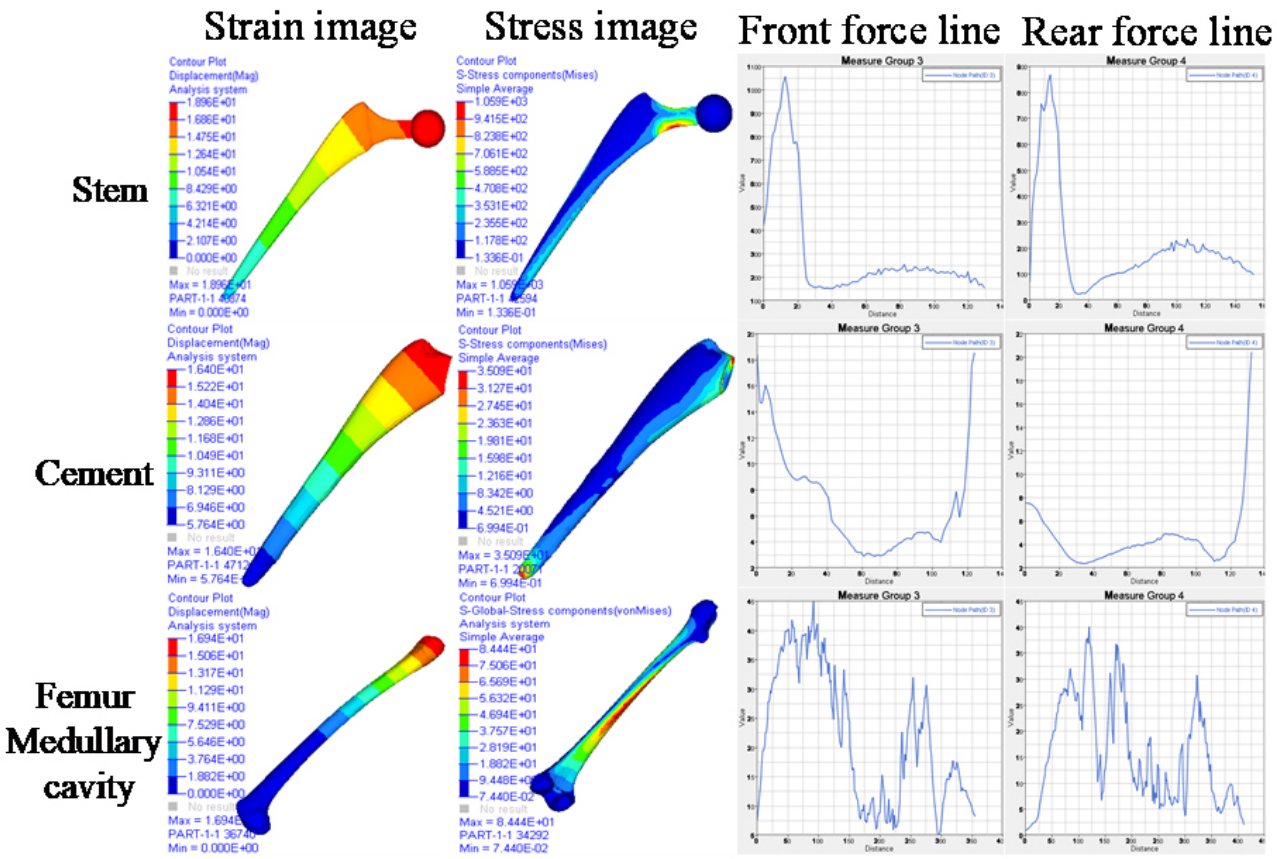

Fig. 7. Maximum load for cemented CoCrMo Prosthetic in gait process.

particular, overweight obese patients will increase the loosening risk of the femoral-stem-cement components, which was confirmed by relevant literature [19–23].

By collecting BMI data of hip joint patients and bone mineral density values of each part of femur, the age, gender and number of diseases of patients were statistically analyzed, and the influence of body weight on the stress of postoperative implants was analyzed by finite element mechanical modeling. This paper mainly analyzes the influence of obesity on the failure of hip joint replacement with bone cement. Studies have found that obesity and BMI reaching the overweight or obese standard will aggravate the disease of hip joint patients, and the impact of different genders will also be different, which proves that BMI has a greater correlation with postoperative failure. It provides a scientific basis for prolonging the service life of hip joint and reducing The Times of revision.

Conclusions

In conclusion, this work reported that BMI was statistically correlated with genders and age and primary and revision rates in total hip replacement patients. Additionally, it was analyzed that the effects of BMI on femur fracture, stem subsidence and components loosening failure of cemented hip replacement. Further Finite element analysis simulation studies have witnessed that the increased body weight of patients would inevitably lead to the interface loosening failure of cemented hip replacement joint.

Availability of Data and Materials

The data used to support the findings of this study were included within the article.

Author Contributions

LFZ: Conceptualization, Methodology, Writing - Review & Editing, Supervision. HTL: Software, Validation. FY: Resources, Investigation. YQ: Investigation, Formal analysis. LX: Data Curation, Writing - Original Draft. JMW: Data Curation, Writing - Original Draft. YCW: Data Curation, Writing - Original Draft. ZYT: Data Curation, Writing - Original Draft.

Ethics Approval and Consent to Participate

The study was approved by the Ethics Committee (Research Ethics Committee of Suqian Hospital of Nanjing Gulou Hospital Group, number code: 2022010, on 4th January 2022). Patients were informed and gave their written consent to participate in the study.

Funding

This work was supported by a grant from the Project supported by National Natural Science Foundation of China (No.51905238), and supported by Natural Science Fund for Colleges and Universities in Jiangsu Province (No.19KJB460017), and supported by Special Research Foundation of Young Teachers Scholars Program of Jiangsu Normal University (No. 18XLRS010), and supported by Key Research and Design projects of Jiangsu Provincial Department of Science and Technology (No. BE2022708).

Conflict of Interest

The authors declare no conflict of interest.

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