The Influence of the Posterior Slope Angle and Posterior Condylar Offset in Posterior-Stabilized Total Knee Arthroplasty Was Analyzed From the Way of Constructing Flexion Gap

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Abstract

Introduction

The purpose of this study was to compare the effects of two ways of establishing the flexion gap on the flexion angle and flexion-extension motion after posterior-stabilized （PS） prosthesis. A way for the posterior slope angle（PSA）and posterior condylar offset（PCO）were greater than preoperative, another for less than preoperative.

Materials and Methods

They are grouped according to the way flexion gaps are constructed. Data from 28 total knee arthroplasty （TKA）patients treated with propensity score match (PSM) were included. The difference of flexion angle and flexion-extension motion between the two groups was compared, and the influence of PCO and PSA on the flexion angle in the two ways was analyzed.

Results

Postoperative flexion degree of the two groups was 115.50±14.64° and 112.29±10.64° (P =0.553), and there was no statistical significance. Postoperative flexion-extension motion grade data of the decrease group was better than that of the increased group (P =0.031). Postoperative flexion angle was negatively correlated with PCO change in the increase group (r^2=0.574 b '=-0.758 p=0.002).

Conclusions

Increasing the PSA and PCO to construct flexion gaps in PS TKA will cause problems with flexion-extension movements. It may be more reasonable to avoid excessive PSA and select appropriate PCO to reconstruct the flexion gap in PS prosthetic.

Introduction

The establishment of flexion gap in TKA not only affects the stability of knee joint after surgery, but also affects the range of motion. The establishment of flexion gap bony structure is mainly the construction of PSA and PCO. Studies[1] have proved that there is an anatomical correlation between them. In order to construct a good flexion gap during the operation, it is also necessary to balance the relationship between them. More and more studies [2-4] analyze their influence on flexion together.

At present, prosthesis designers recommend conservative 3° low PSA osteotomy for PS prosthesis, but there is a lack of individualized treatment and systematic explanation, and clinical selection has been controversial[5,6].The studies[7,8] proved that the increase or decrease of PSA would lead to the increase or decrease of the flexion gap.When the central osteotomy volume of the tibial plateau is consistent, the flexion gap is not only related to the postoperative PSA, but also affected by the preoperative PSA. In other words, the increase or decrease of the postoperative PSA relative to the initial PSA will also lead to the increase or decrease of the reconstructed flexion gap.When the extension gap has been established and the PSA has been determined, it is common to ensure that there is no fracture of the anterior femoral cortex. Moving the osteotomy plate back and forth appropriately or adjusting the size of the prosthesis are common management methods, but the principle is to balance the flexion gap by adjusting the PCO. The flexion gap can also be affected by soft tissue, but as a complement to good bone remodeling, osteotomy design is obviously more important. In theory, the simultaneous increase or decrease of PSA and PCO both can achieve a good bony balance in the flexion gap. But which makes more reasonable? What is the interaction between PSA and PCO in these two cases? This can also answer the question of whether unified low PSA osteotomy is reasonable at the present stage and whether individualized osteotomy should be established. Previous studies [9,10]generally only considered the single factor of PSA or PCO, and most did not consider the preoperative effect of both. With the deepening of cognition, it is more scientific and rigorous to include the PCO and PSA of flexion gap construction into the experiment and calculate the change amount to reflect the influence on flexion gap.

Materials And Methods

Patient inclusion criteria

From January 2019 to July 2019,patients with primary TKA were retrospectively examined by preoperative and postoperative lateral radiographs, and the values and changes of PSA and PCO were measured. Inclusion criteria were patients diagnosed with osteoarthritis, neutral or varus deformity less than 15°, and cartilage wear and pain requiring replacement. Patients with a history of knee surgery, fracture trauma, rheumatoid rheumatism, post-traumatic or suppurative arthritis of the knee, and abnormal muscle strength due to neurological diseases were excluded. A total of 36 cases of knee joints were enrolled, and 14 pairs were successfully matched after PSM treatment. The mean follow-up time was more than 1 year. None of the patients received revision surgery, and no serious complications required hospitalization.

Surgical and rehabilitation programs

The surgery was performed by a number of experienced surgeons. All knee surgeries were performed using PS knee prostheses(China, Ai-Kang, A3GT). The approach methods were median and patellar pararthrotomy, PSA lowering or raising standard osteotomy, and standard osteotomy of distal femur to establish expansion space. The posterior reference osteotomy was used and the flexion gap was tested in the mold trial. According to the test results, the osteotomy plate was adjusted to establish the flexion gap. After satisfactory remodeling of bony structure, the soft tissue should be fine-tuned, the articular surface of patella hyperplasia should be treated and denervated. The balance of flexion and extension, force line establishment and patella trajectory were satisfactory. During hospitalization, passive functional exercise of knee joint was carried out uniformly. After discharge, the doctor instructed functional exercise and regular review.

Collected data

The data of age, gender, body mass index (BMI), preoperative flexion and extension activity were collected. The postoperative recovery was obtained through outpatient reexamination and follow-up. Postoperative flexion angle was measured with protractor. Inspect whether there is patellofemoral joint bouncing, delayed knee extension weakness, pain in front of knee joint during exercise. The lateral radiographs of the knee were measured before and after the surgery, where the condyles and the prosthesis overlapped well. The PSA was assessed using the mean angles of the posterior tibial cortex (PTC) and the anterior tibial cortex (ATC) to the tibial plane (Fig.1). This plain radiograph measurement proved to be well correlated with CT [11]. The measurement was completed by two professionals at an interval of 3 times within 1 week to take the average value. The data involved in this study were collected retrospectively and did not require the approval of an ethical statement.

Statistical analysis

Patients in the two groups were matched 1:1, the nearest neighbor method was used, and PSM were calculated according to age, gender, BMI and preoperative flexion angle. The measurement data were tested by K-S to see if they were in line with normal distribution, and expressed as mean and standard deviation (SD). Counting data after pairing were analyzed by the McNemar test and expressed as percentage. Paired t test was used to analyze whether there was statistical difference in postoperative flexion angle between groups. Wilcoxon signed rank sum test was used to analyze whether there was statistical difference in the grade data of flexion and extension motion status between groups. In addition, univariate and multivariate linear regression analyses were performed for age, BMI, preoperative flexion activity, PSA change, PCO change, and postoperative flexion angle. The different effects of PSA change and PCO changes on knee flexion angle were examined by considering the interaction between the variables. If there is no multivariate effect, the main effect is analyzed. The significance level for all analyses was set to P-0.05(bilateral). IBM SPSS 23 was used for all statistical analyses.

Table1 Demographic characteristics and clinical data of the patients after PSM

Variables	PSA PCO increase group (n=14)	PSA PCO decrease group (n=14）	P value
Demographics			
Age (y, Mean ± SD)	66.88±7.41	65.50±8.21	0.485
Gender(%male)	3（21.43）	3（21.43）	1.000
BMI (kg/m^2,Mean ± SD）)	24.87±3.21	24.97±2.34	0.904
Operative variables			
PrePSA（°,Mean ± SD）	5.16±3.00	8.13±2.89	0.024
PostPSA（°,Mean ± SD）	9.61±2.42	5.08±1.94	0.000
Change PSA（°,Mean ± SD）	4.45±2.78	-3.05±2.67	0.000
PrePCO（mm, Mean ± SD）	30.53±4.02	33.80±5.22	0.046
PostPCO（mm, Mean ± SD）	32.84±4.13	31.68±5.27	0.452
Change PCO（mm, Mean± SD）	2.18±1.05	-2.11±1.22	0.000
Functional evaluations			
PreROM（°,Mean ± SD）	81.57±23.49	91.93±17.85	0.262
PostROM（°,Mean ± SD）	115.50±14.64	112.29±10.64	0.553
Grading of flexion-extension motion			0.031
0	6（42.86）	12（85.72）	
□	4（28.57）	1（7.14）	
□	3（21.43）	1（7.14）	
□	1（7.14）	0（0）	

Abbreviations: BMI, body mass index; Pre, preoperative; PSA, posterior tibial slope;

Post, p postoperative; PCO, posterior condylar offset; ROM, range of motion;

Results

Baseline data of patients after PSM are shown in Table 1. Age, gender, BMI, and preoperative flexion angle of patients in the two groups are well balanced. The changes of PSA and PCO in the increase group were (4.45±2.78° and 2.18±1.05mm), while those in the decrease group were (-3.05±2.67° and -2.11±1.22mm). There was no statistical difference in the postoperative flexion angle between the groups. However, in the linear regression in the increase group, the postoperative flexion angle was negatively correlated with the increase in PCO (r^2= 0.574B '=-0.758 P =0.002), as shown in Fig2, while in the decrease group, the postoperative flexion angle was negatively correlated with the decrease in PCO (r^2= 0.405B' =-0.620 P =0.80), as shown in Fig3. Among them, only the change value of PCO was statistically significant in the multivariate step analysis of the increase group. The correlation of PCO change value in the decrease group was significantly higher than that of other factors, but there was no statistical significance, which may be related to the sample size, and further study is needed. The number of patellofemoral joint bounce, delayed knee joint extension weakness and knee joint pain during postoperative flexion and extension exercise was more in the decrease groups. Postoperative flexion and extension motion grade data of the decrease group was better than the increased group (P =0.031)

Discussion

This experiment found that although the two construction methods recommended to retain the initial PCO, the two groups were different from each other in terms of the tightness of the flexion gap. If the negative correlation between the increase of PCO and the flexion angle is due to the tension of the flexion gap, then why does the decrease of PCO become a negative effect when PSA decreases? This may be because the increase of PSA has an adverse effect on rollback, which weakens the advantage of PCO in delaying impact, and causes more tension in the flexion gap and more pressure on the contralateral collateral ligament. The good rollback when PSA is reduced gives full play to the advantages of PCO retention. To better explain, we introduced cruciate-retaining（CR）prosthesis, which contrasted with PS rollback mechanism.

PSA, PCO and rollback in CR

In previous studies[12], the advantages of PCO recovery and PSA enhancement focus on the delay of impact. This theory has been widely recognized in CR prosthesis. Bellemans[13,9] found in their study that increasing PSA did indeed result in greater maximum flexion before the tibial gasket impacted the posterior femur, with a 1.7° flexion gain per degree of backward inclination. At the same time, PCO recovery was important because it also allowed greater flexion before impact. However, the rollback of CR is better due to the presence of the posterior cruciate ligament (PCL), which amplifies the effects of PCO and PSA. PCL effectively prevents posterior dislocation of the tibial plateau and optimizes rollback without excessive release. Research[14] proved that the increase of PSA in Cr was conducive to rollback, so that the increasing advantages of PCO and PSA at this time could be better reflected, and the two were complementary in the flexion gap. However, in PS, backward rolling is not as ideal as in CR, Banks[15] reported that CR had a greater posterior translation of the femur than PS during progressively increased activity.

PSA, PCO and rollback in PS

In PS prosthesis, the protective effect of PCL is lost and only depends on the interaction between the cam and the column to cause the backward roll. The increase of PSA not only cannot optimize the backward roll, but also has been proved many times to lead to abnormal forward roll. Piazza[16] show that the backward tilt of the tibial component shifts the interaction between the cam and the spine to a higher bending angle. As a result, the buckling angle increases and the range of action decreases, resulting in delay and shortage of backward roll. After computer simulation, Wang Zhi Wei [17] found that the increase of PSA delayed the cam binding by 38°, even much more than Piazza's delayed binding by 18°. Satoshi Hamai[18] directly compared the motion of PS and Cr when climbing stairs, and found that Cr showed good stability in the medium degree of flexion due to the presence of PCL. In PS, there was abnormal femoral forward roll and posterior impact of the tibial column, and PSA was significantly larger in the cases that appeared. It is worth mentioning that the cam and the column are not engaged when rolling forward at medium flexion angle. Piazza demonstrated that forward rolling occurred by simulating the change in cam-column contact with a high PSA. This may mean that anomalous forward roll caused by high PSA can occur in both cases when the cam is unengaged at a medium buckling angle and when the cam is engaged at a larger buckling angle. Ephrat Most[19] noted that reduced femoral rollback may be a limiting factor in knee reconstruction, and that the timing of cam post engagement must be combined with the joint geometry after TKA to enhance femoral rollback and increase the flexion range of the knee. The increased PCO during insufficient rollback exerts additional pressure on the collateral ligaments and affects flexion. In his study, Eisaku Fujimoto[20] raised the concern that too large PCO would make the flexion gap too tight and affect the flexion angle, and PCO should be properly repaired to achieve a better balance of the collateral ligament. In addition, it is necessary to consider that the flexion gap after PCL removal is larger [7]. A larger PSA means a larger PCO to balance the flexion gap, so the choice needs to be more careful. However, for the PSA decreasing group, the performance of backward roll would be better than that of the increasing group. In this case, the influence of PCO was similar to the delayed impact in CR, and PCO retention became a favorable factor. Therefore, the opposite effect of PCO was caused in the two groups.

To sum up, in the PS prosthesis, the selection of PSA may require the first guarantee of backward rolling, and then, according to the selected PSA, build a PCO that can delay the impact as much as possible without putting too much pressure on the collateral ligament. Roll-back optimization of PS is worthy of further study. From the practical point of view, conservative low PSA is suitable for most people. For a small number of individuals with small initial PSA, choosing 3° can avoid the occurrence of forward tilt. At the present stage, conservative low osteotomy may have optimization space, but it is relatively reasonable.

Differences in flexion-extension movement

In addition, we also found that the patellofemoral joint bouncing, delayed knee extension weakness, pain in front of knee joint were more common in the increased groups than in the decrease group. We think this is related to increased pressure on the patellofemoral joint and a decrease in the extensor arm.

Reviewing previous mechanical studies[21-23], good rollback can directly reduce the pressure of femur on patella, increase the angle between the extensor arm and the action line between quadriceps and patella ligament, and reduce the pressure on patellofemoral joint. This can effectively relieve muscle weakness and preoperative knee pain after joint replacement and reduce wear and tear of the prosthesis. However, the increase of PSA leads to poor backward roll, and the reduction of moment arm is difficult to achieve. Meanwhile, the complementary increase of PCO in the flexion gap is an adverse factor in patella pressure.[24] This may explain the higher incidence of patellofemoral joint bouncing, delayed knee extension weakness, and anterior knee pain in the increase group. At the same time, the increase of PSA has also been shown to lead to the excessive extension of the knee joint in the extension position, causing the femoral cam to impact the front of the tibial column, leading to the wear and deformation of the front column.[25] Hanjunlee[26] also suggests that care should be taken to match the tilt angle of the femur and tibia, as excessive extension could have a negative impact on the stability of the knee and quadriceps or hamstring fatigue. Therefore, from the perspective of flexion and extension movement, it is not recommended to increase PSA and PCO to reconstruct the flexion gap.

Limitations of the experiment

There are some limitations in this experiment. Firstly, the sample size of our study lost a lot due to the strict requirements on the type of prosthesis, lateral imaging data and PSM, but it was worth it for the scientific nature of the experiment and the comparability of grouped samples. The regression analysis of the reduction group showed that PCO was the biggest influencing factor of buckling angle, but it was limited by the sample size. The results were not statistically significant and require further study. Secondly, the retrospectively studied subjects were all Asian with PS prosthesis, which was not retroflexed and had non-single radial fixation platform. Whether the conclusions can be applied to other ethnic groups and prosthesis needs further study. Finally, there are bilateral operations in the data, and the flexion angle may be affected by the operation on the other side.

Conclusion

Increasing the PSA and PCO to reconstruct the flexion gap will cause problems with flexion and extension motion. With regard to increasing the PSA expanded flexion gap, increasing the PCO to make up will bring about the loss of flexion angle, which may be due to the poor rollback caused by increasing the PSA. For the reconstruction method with reduced PSA, it may be more advantageous to keep the original PCO, which needs further study. It is suggested that it may be more reasonable to avoid excessive PSA and select appropriate PCO to reconstruct the flexion gap in PS prosthesis.

Declarations

Conflict of interest statement

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Conflicts of interest/Competing interests: Not applicable

Availability of data and material: Data and statistical results have been uploaded in supplementary materials

Code availability: Not applicable

Ethics approval: The data involved in this study were collected retrospectively and did not require the approval of an ethical statement.

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Figures

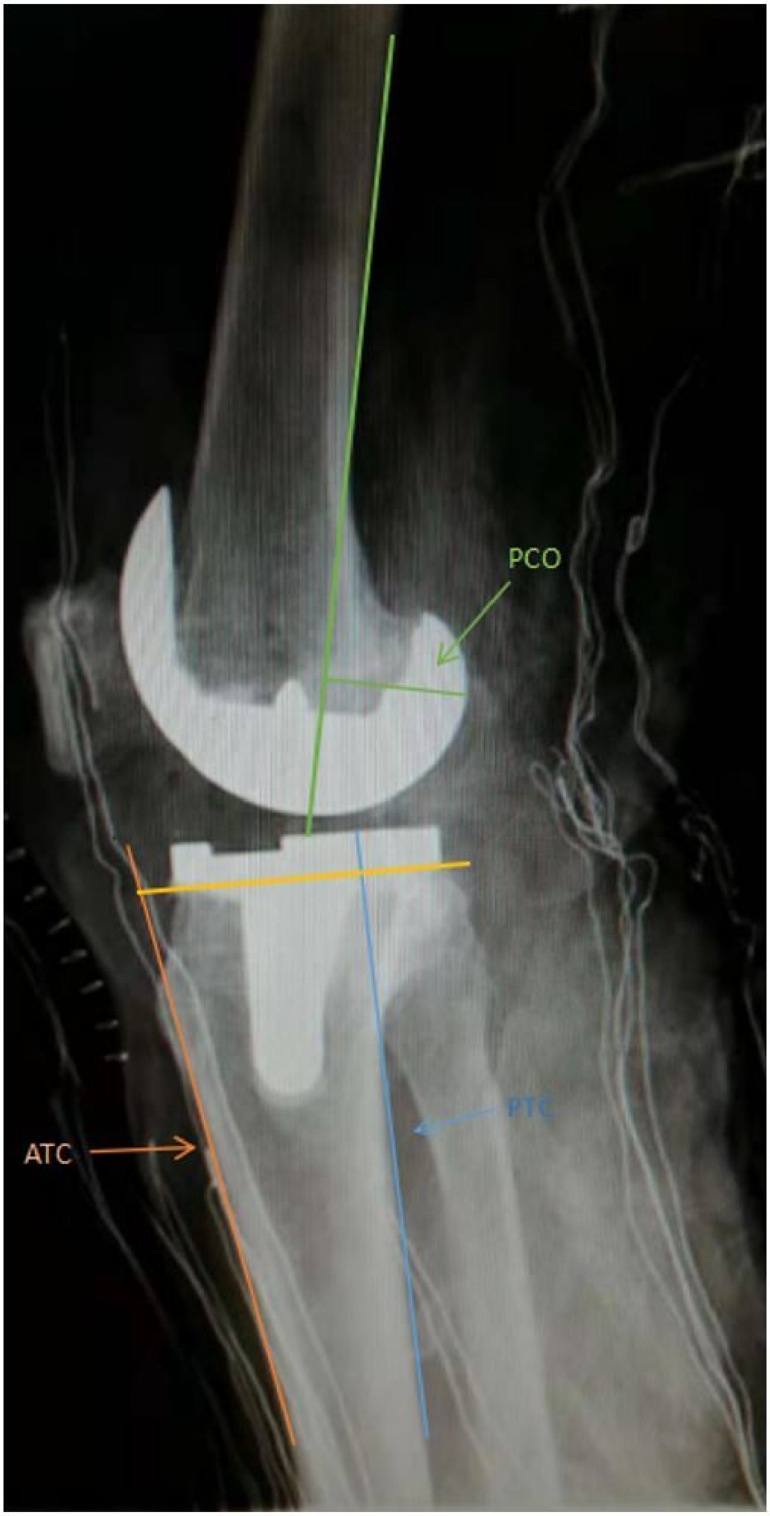

Figure 1

Measurement methods of graphic. ATC: anterior tibial cortex, PTC: posterior tibial cortex. PSA= (ATC+PTC) /2

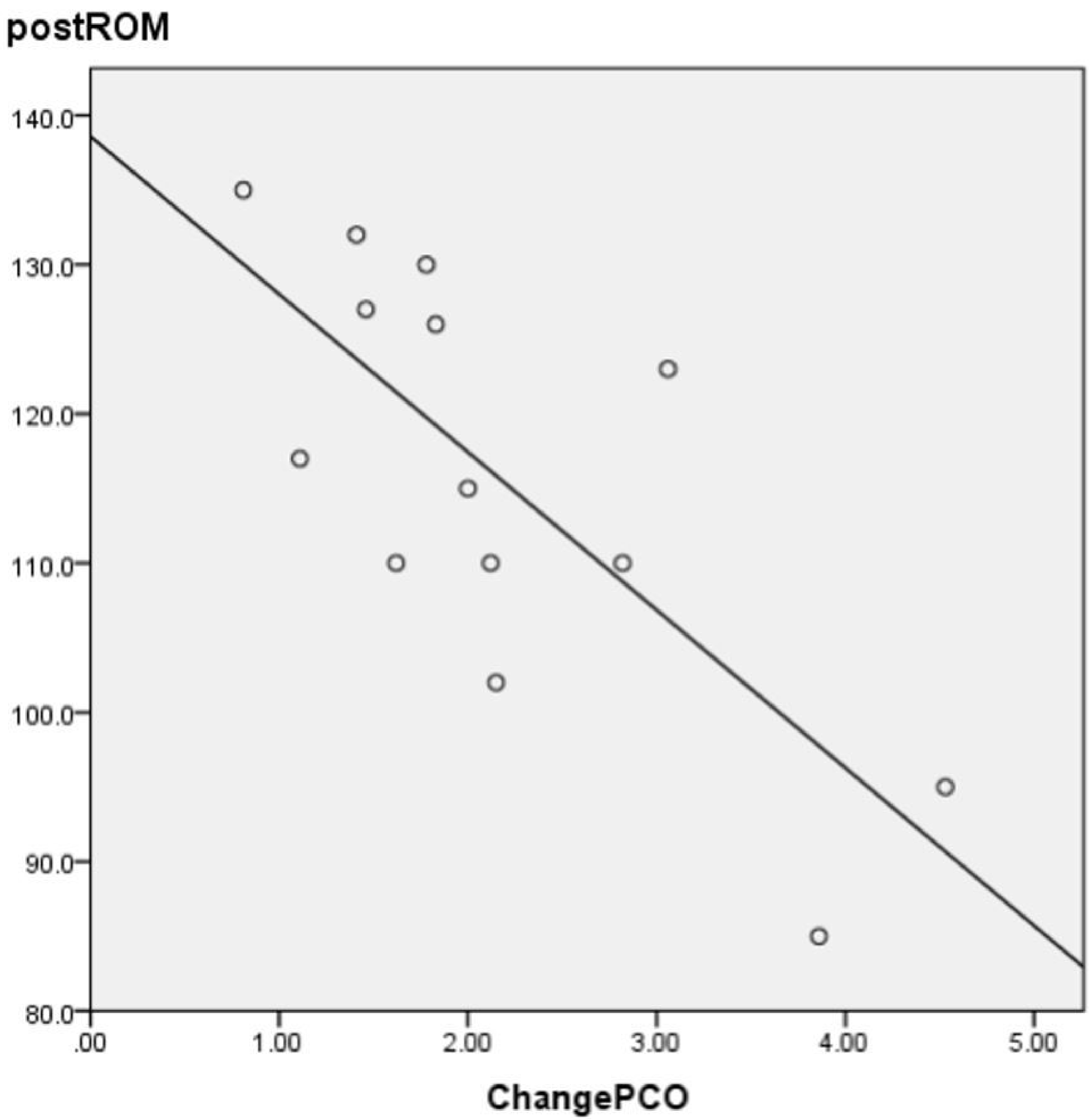

Figure 2

In the case of PSA increase, the increase of PCO was negatively correlated with the postoperative flexion angle.

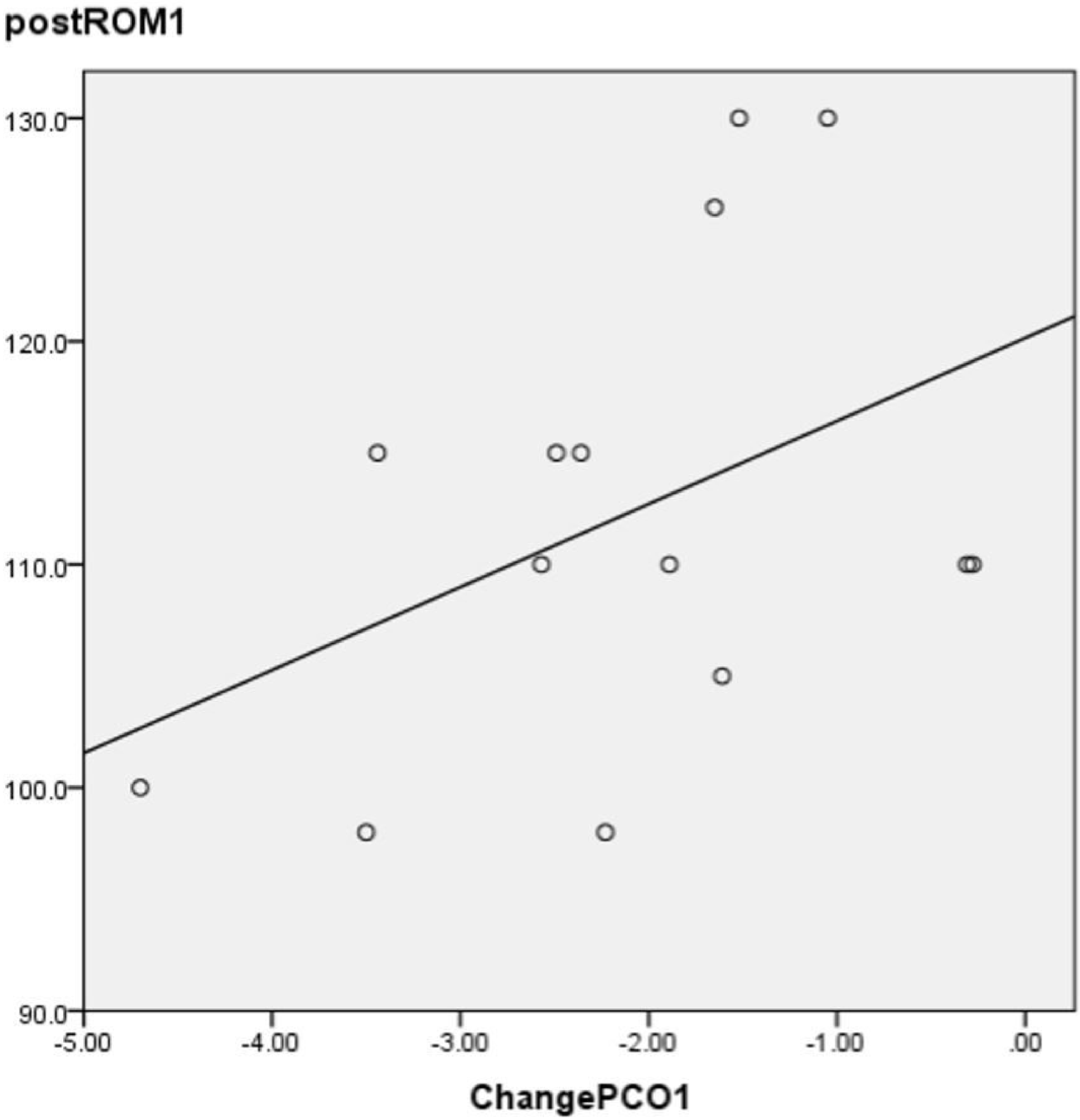

Figure 3

In the case of reduced PSA, the decrease of PCO was positively correlated with postoperative flexion angle.

Supplementary Files

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