Association of knee flexion angle after posterior-stabilized total knee arthroplasty with postoperative tibial external position relative to the femur and the extent of tibial internal rotation from knee extension to flexion

Abstract

Background

This study evaluated the relationship between preoperative and postoperative knee kinematics, moreover, investigated tibial rotational position and the extent of tibial internal rotation from knee extension to flexion as factors to obtain significant knee flexion after total knee arthroplasty (TKA).

Methods

Fifty-four patients (60 knees total; 15 males, 16 knees; 39 females, 44 knees) who underwent posterior-stabilized TKA using a navigation system were included. Intraoperative knee kinematics involving tibial rotational position relative to the femur and the extent of tibial internal rotation were examined at 2 time points; 1) after landmarks registration (pre-TKA), and 2) after skin closure (post-TKA). The relationship between the knee flexion angle at 1 year postoperatively and intraoperative tibial rotational position, or the extent of tibial rotation among several knee flexion angles calculated with a navigation system were investigated.

Results

The postoperative knee flexion angle was positively associated with the preoperative flexion angle and intraoperative knee kinematics at post-TKA involving tibial external position relative to the femur at knee extension and the extent of tibial internal rotation from extension to 90° of flexion or to maximum flexion. There was a positive relationship between the extent of tibial internal rotation at pre-TKA and that at post-TKA.

Conclusions

The intraoperative kinematics of the extent of tibial internal rotation at post-TKA was influenced by that at pre-TKA. The greater external position of the tibia relative to the femur at knee extension and the greater extent of tibial internal rotation at post-TKA might lead to good knee flexion angle.

Keywords: total knee arthroplasty; tibial internal rotation; knee kinematics; knee flexion angle

1 Introduction

Total knee arthroplasty (TKA) is an established surgical procedure used to treat osteoarthritis of the knee. Although positive results in terms of pain relief have been achieved after TKA, patient satisfaction scores after TKA have been lower than those after total hip arthroplasty [1, 2, 3]. The range of motion of the knee is an important factor that affects the postoperative clinical results of TKA, and the postoperative range of motion of the knee is strongly influenced by the preoperative range of motion [4, 5, 6, 7]. However, patient-reported outcomes after TKA may also be related to preoperative patient demographics [2]. Furthermore, it has been shown that internal rotation of the tibia from extension to flexion of the knee contributes to a better range of motion after TKA, and that tibial external rotation reduces the flexion angle [8, 9, 10, 11]. However, in normal knees, dynamic kinematics include the medial pivot motion, which is defined as femoral external rotation relative to the tibia (equivalent to tibial internal rotation relative to the femur) from extension to 120° of flexion of the knee and femoral bicondylar rollback motion from 120° to maximum flexion [12, 13, 14, 15, 16, 17]. Patient-reported outcomes after TKA might be associated with abnormalities of knee kinematics compared to conditions before osteoarthritis [18, 19, 20]. Therefore, to evaluate TKA kinematics, several studies analyzed intraoperative kinematics using a TKA navigation system [8, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30]. When the medial pivot motion of the knee was reproduced after TKA, good range of motion of the knee and high patient satisfaction scores were reported [8, 25, 26]. Therefore, the TKA surgical technique used to obtain the medial pivot motion is important. It was hypothesized that the internal rotation of the tibia has favorable effects on the postoperative range of motion of the knee. Thus, the aim of the present study was to investigate the relationship between the range of motion of the knee after TKA and the intraoperative rotational position of the tibia relative to the femur, and to calculate the extent of tibial internal rotation required to obtain a better range of motion.

2 Materials and Methods

The study was performed retrospectively and was approved by the ethics committee of the Hamamatsu University School of Medicine. From 2014 to 2017, consecutive patients who underwent primary TKA for severe varus osteoarthritis of the knee, which corresponded to grade 2 or more according to the Kellgren-Lawrence classification, were included in the study. Patients with valgus osteoarthritis, inflammatory arthritis such as infection and rheumatoid arthritis, and patients who underwent revision surgery were excluded. Patients who were performed patellar replacement were also excluded. The study population included 54 patients (60 knees) with an average age of 74.9 years (range, 52–91 years) who underwent follow-up for a minimum of 1 year.

2.1 Surgical procedures for TKA

All TKA procedures were performed using a computed tomography (CT)-free navigation system (Stryker Knee Navigation System version 4.0; Stryker Leibinger, Freiburg, Germany). The medial parapatellar approach (45 knees) or the mid-vastus approach (15 knees) was used to expose the knee joint. Minimal release of the medial collateral ligament and soft tissue was performed for osteotomy. The measured resection technique was used for femoral and tibial osteotomy. The anterior cruciate ligament and posterior cruciate ligament were sacrificed, and posterior-stabilized (PS) implants (Triathlon; Stryker Kalamazoo, MI, USA) were used for TKA. The navigation system included several anatomical landmarks. The femoral rotational axis was defined using the surgical epicondylar axis, which was based on the sulcus behind the femoral medial condyle and the tip of the femoral lateral condyle. The anteroposterior axis of the tibia was defined as the line that ran from the medial border of the tibial tubercle to the middle of the tibial insertion of the posterior cruciate ligament to confirm the rotational position when making a keel hole [31]. Following these steps, the navigation system was used for all cases during osteotomy of the femur (distal, anterior, posterior, and chamfers) and tibial plateau. The femoral and tibial components were aimed to exact vertical relative to mechanical axis in coronal plane. In sagittal plane, the femoral and tibial components were aimed to 0 to 5° of flexion. The CT-free navigation system was used during cementing to confirm the rotational position of the tibial component [32]. The patellar replacement was not performed in this series despite the osteoarthritis grade of the patellofemoral joint.

2.2 Intraoperative measurements of tibial rotation

Intraoperative kinematics, including rotational position of the tibia and the extent of tibial internal rotation relative to the femoral anteroposterior axis, were examined. Intraoperative measurements of knee kinematics were performed at two time points using the navigation system: 1) when registration was completed before osteotomy (pre-TKA) and 2) when the skin incision was closed after femoral and tibial components were cemented (post-TKA). The patella had reposition and only the medial retinaculum was sutured at pre-TKA measurement. The condition of anterior cruciate ligament was differed among each patient and the posterior cruciate ligament was remained in all patients at pre-TKA measurement. The surgeon held the patient's thighs and flexed the knee from the extension position while the patient's heel was placed on the palm of the assistant and held slightly to avoid tibial rotation, which was in accordance with the method used by Wada [33]. The navigation system automatically recorded the angle of tibial rotation at maximum extension (mean -10.5 ± 6.8°), 30°, 60°, 90°, and maximum flexion (mean 132.5 ± 10.8°) during passive knee motion. In this study, internal rotation of the tibia relative to the femur was represented as a positive value, and external rotation of the tibia was represented as a negative value. Two surgeons performed the TKAs procedures in this series. Kinematic measurements were performed one time for each patient by one of the two surgeons. Finally, the extent of tibial internal rotation between each angle of knee flexion was calculated at pre-TKA and post-TKA.

2.3 Postoperative procedure and evaluation

Patients were hospitalized the day before surgery. On the first day after surgery, the suction drain was removed, and patients were allowed to start range of motion rehabilitation and ambulation. Exercises were performed for approximately 3 weeks during hospitalization. After discharge, all patients were followed-up monthly during outpatient visits. The range of motion of the knee was examined using a goniometer for 1 year postoperatively, although the knee flexion angle measured with a goniometer which shows bone axis reference was differed from intraoperative kinematics measured with a navigation system which shows mechanical axis reference. The new Knee Society score (KSS) [34, 35] was also evaluated at 1 year after surgery.

3 Theory/calculation

The correlation between the angle of knee extension or flexion at 1 year after surgery and each intraoperative kinematics parameter, including the intraoperative rotational position of the tibia relative to the femur and the extent of tibial internal rotation, was calculated with Pearson's correlation coefficient test. In addition, the multiple regression analysis was performed as a dependent variable was knee flexion angle at 1 year after TKA. The relationship between the KSS at

1 year after surgery and each intraoperative parameter was also calculated with Pearson's correlation coefficient test. Comparison between intraoperative knee kinematics at pre-TKA and that at post-TKA was calculated with the paired t-test. The correlations between the extent of intraoperative tibial rotation from knee extension to flexion at pre-TKA and that at post-TKA were also calculated using Pearson's correlation coefficient test.

Each intraoperative parameter was compared between the group with a knee flexion angle of 120° or less at 1 year after surgery and the group with a knee flexion angle more than 120° using the parametric t-test. Furthermore, receiver-operating characteristic (ROC) curves for the knee flexion angles between the groups were calculated using the extent of intraoperative tibial internal rotation at post-TKA. The cutoff value was determined by the Youden index, which maximizes the overall rate of correct classification (sum of sensitivity and specificity). SPSS version 21 (IBM Corporation, Armonk, NY) was used for all statistical analyses; $p = 0.05$ was considered statistically significant.

4 Results

The demographic data of patients are shown in Table 1. Age, body height, body weight, and body mass index were not significantly correlated with the preoperative or postoperative range of motion of the knee or any intraoperative parameters.

The extension angle of the knee at 1 year after TKA was significantly correlated with the preoperative extension angle with Pearson's correlation coefficient test (correlation coefficient, 0.541; $p<0.001$). Intraoperative kinematics including the intraoperative rotational position of the tibia relative to the femur and the intraoperative extent of tibial internal rotation from knee extension to flexion at pre-TKA and at post-TKA were not associated with the extension angle of the knee at 1 year after surgery.

The flexion angle of the knee at 1 year after TKA was significantly associated with the preoperative flexion angle (correlation coefficient, 0.592; $p<0.001$), rotational position of the tibia at maximum knee extension (correlation coefficient, 0.249; $p=0.048$), the extent of intraoperative tibial internal rotation from knee extension to 90° of flexion (correlation coefficient, 0.332; $p=0.012$), and the intraoperative extent of tibial internal rotation from knee extension to maximum flexion (correlation coefficient, 0.325; $p=0.014$) with Pearson's correlation coefficient test. However, the knee flexion angle at 1 year after TKA was associated with only preoperative knee flexion angle with the multiple regression analysis (correlation coefficient, 0.570; $p<0.001$). The flexion angle of the knee at 1 year after surgery was not associated with intraoperative kinematics at pre-TKA.

KSS scores at 1 year after surgery for patient symptoms, satisfaction, and expectations were not associated with any intraoperative parameters or preoperative KSS scores. The KSS score for patient activity was significantly associated with the preoperative KSS score for patient activity (correlation coefficient, 0.472; $p=0006$) and the postoperative flexion angle of the knee (correlation coefficient, 0.398; p=0022).

When intraoperative rotational position of the tibia and the extent of tibial internal rotation at pre-TKA were compared with those at post-TKA, there were significant differences in the tibial rotational position at maximum extension and the extent of tibial internal rotation from maximum extension to 30°, the extent of tibial internal rotation from 30° to 60°, the extent of tibial internal rotation from maximum extension to 90°, and the extent of tibial rotation from maximum extension to maximum flexion (Table 2). Generally, the extent of intraoperative tibial internal rotation decreased at post-TKA compared that at pre-TKA.

There was a significant relationship between the extent of tibial internal rotation from maximum extension to 90° flexion at pre-TKA and that at post-TKA (correlation coefficient, 0.473; p<0.001) (Fig. 1A). Furthermore, the extent of tibial internal rotation from maximum extension to maximum flexion at pre-TKA was significantly correlated with that at post-TKA (correlation coefficient, 0.592; p<0.001) (Fig. 1B). It should be noted that 87.5% of cases had negative values for the extent of tibial internal rotation from maximum extension to 90° flexion at post-TKA if the values of the extent of tibial internal rotation were negative at pre-TKA, and the negative values of the extent of tibial internal rotation meant the external tibial rotation (Fig. 1A). Furthermore, 83.3% of cases had negative values for the extent of tibial internal rotation from maximum extension to maximum flexion at post-TKA if the values of the extent of tibial internal rotation were negative at pre-TKA

(Fig. 1B).

When patients who had a knee flexion angle of 120° or less at 1 year after surgery and patients who had a knee flexion angle more than 120° were compared with respect to intraoperative kinematics at post-TKA, there were not significant differences in the demographic data. There were significant differences in the preoperative knee flexion angle (p<0.001), intraoperative rotational position of the tibia at maximum extension of the knee (p=0.011), the intraoperative extent of tibial internal rotation from knee extension to 90° flexion (p=0.007), and that from knee extension to maximum flexion (p=0.017) between the groups (Table 3).

A cutoff value of the extent of intraoperative tibial internal rotation at post-TKA from maximum extension to 90° flexion was calculated using the ROC curve to determine whether the postoperative knee flexion angle exceeded 120° at 1 year after TKA. When a cutoff value of the extent of tibial internal rotation from maximum extension to 90° flexion was 1.25°, the sensitivity was 80.0% and the specificity was 86.4% (Fig. 2A). Furthermore, a cutoff value of the extent of tibial internal rotation at post-TKA from maximum extension to maximum flexion was calculated. When a cutoff value of the extent of tibial internal rotation from maximum extension to maximum flexion was 5.25°, the sensitivity was 66.7% and the specificity was 86.4% (Fig. 2B).

5 Discussion

The most important finding of the present study was that the extent of tibial internal rotation at post-TKA was positively associated with the range of motion of the knee at 1 year after TKA. Additionally, the extent of tibial internal rotation at post-TKA was positively related to that at pre-TKA, although the extent of tibial internal rotation at post-TKA was significantly decreased compared to that at pre-TKA. It should also be noted that most patients with preoperative tibial external rotation also had postoperative tibial external rotation.

Several reports indicated that the preoperative knee range of motion positively affected the postoperative knee range of motion [5, 4, 6, 7]. The present results moderately suggested that preoperative extension and flexion angles of the knee also positively affected postoperative extension and flexion angles, respectively. Although there is no doubt that the range of motion of the knee after TKA is significantly associated with the preoperative range of motion, it was interesting that the results of this study indicated that the external rotation of the tibia at knee extension and the extent of tibial internal rotation positively affected the postoperative flexion angle of the knee. Knee kinematics at pre-TKA involving rotational position of the tibia and the extent of tibial internal rotation was not correlated with knee flexion angle at 1 year after TKA, but knee kinematics at post-TKA was associated with that at pre-TKA. It was considered that knee kinematics at pre-TKA might be affected by preoperative varus deformity of lower extremity or posterior slope of tibial plateau. Furthermore, direction and length of the medial and lateral collateral ligaments, and iliotibial tract might be deferent from pre-TKA due to the osteophyte removal and deformity correction at post-TKA. However, based on the present results, the knee kinematics at post-TKA was considered to be affected by remained structures after TKA.

Previous studies of knee kinematics focused on the postoperative status [36, 37]. However, to our knowledge, several reports have compared the differences in knee kinematics before and after TKA. The tibial rotation in deep knee flexion relative to the femur was approximately 28° in a normal knee [12, 38]. Siston et al. reported that the rotational motion of osteoarthritic knees was significantly reduced after PS TKA [29]. Seon et al. reported that femoral external rotation after cruciate-retaining TKA was significantly decreased compared to that of the preoperative knee, although the extent of femoral external rotation after TKA was significantly positively related to that measured preoperatively [28]. These reports are similar to our results in that tibial internal rotation after TKA was related to that before TKA and decreased after TKA. Dennis et al. reported that the tibial internal rotation was less than 4° after TKA with most types of implants [12], and Cates et al. reported that 2.9° of axial rotation in PS TKA [36]. In the present study, the extent of internal rotation of the tibia around mid-flexion range, such as approximately 30° to 60° of knee flexion, did not affect the postoperative flexion angle of the knee. For patients with postoperative knee flexion of more than 120°, rotational position of the tibia at knee extension had more external rotation, and the extent of tibial internal rotation from extension to 90° and that from extension to maximum flexion were greater. However, results in this study indicated that the extent of tibial internal rotation at pre-TKA was less than that of the normal knee, and the extent of tibial internal rotation at post-TKA was further declined compared to that at pre-TKA, hence the cutoff value due to the evaluation of the ROC curve was relatively low. Therefore, it was suggested that it may be possible to only evaluate by measurement of tibial internal rotation using the navigation system in TKA. Furthermore, these results by evaluation of the navigation system suggested that screw-home movement and medial pivot motion might be critical for the knee flexion angle, even for PS TKA that involves sacrifice of the anterior and posterior cruciate ligaments. Wada et al. performed a cadaver study and reported that tibial internal rotation during knee flexion was improved by increasing the tightness of the medial collateral ligament [39]. For PS TKA involving sacrifice of the anterior and posterior cruciate ligaments, appropriate tension in the medial collateral ligament may be important for tibial internal rotation and medial pivot motion. However, postoperative tibial internal rotation is significantly affected by preoperative tibial rotation, and most patients with preoperative tibial external rotation also had postoperative tibial external rotation. Only PS TKA was used for all cases of tibial internal rotation, which limited the observable outcomes. Therefore, medial pivot, bicruciate-retaining, and bicruciate-stabilized implants should be studied, especially in patients with tibial external rotation at pre-TKA.

There were several limitations to this study. First, intraoperative measurements of the knee kinematics might have been different from the measurements evaluated during outpatient examinations due to general anesthesia, use of an air tourniquet, or non-weight-bearing conditions. However, it was reported that knee kinematics measured intraoperatively were strongly correlated with postoperative kinematics [26,40]. Therefore, it was considered that intraoperative measurements of the knee kinematics in this study were significantly associated with postoperative kinematics. However, the current method that we measured intraoperative kinematics by the surgeon and assistant was slightly differed from Wada's procedures [33], and the reliability assessment of this procedure was not performed. Second, the follow-up time of 1 year was relatively short. Longer follow-up might be required to evaluate patients' satisfaction, expectations, and activity using the KSS score, although it was reported that a follow-up period of 1 year was sufficient for predicting the range of motion of the knee after TKA [41]. Third, the actual rotational position of the implant has not been evaluated by postoperative CT examinations. In particular, abnormal rotational alignment of the femoral and tibial components can affect knee kinematics. Furthermore, several reports showed that rotational alignment of femoral component was improved by using navigation [42,43]. Fourth, the anterior to posterior translation from knee extension to flexion was not evaluated. The anterior or posterior translation might be associated with knee kinematics and range of motion.

The present findings confirm that preoperative knee range of motion significantly affects postoperative knee range of motion. Postoperative passive knee kinematics was significantly associated with preoperative knee kinematics with regard to tibial rotation from knee extension to flexion. The extent of tibial internal rotation was so small that it could only be detected by using the navigation system. Therefore, the present results suggested that the extent of tibial internal rotation measured using the navigation system will help to predict the postoperative knee flexion angle after TKA.

6 Conclusion

The extent of tibial internal rotation at post-TKA affected the knee flexion angle after surgery, although the detected value was relatively small enough to be measured using navigation system.

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Ethical approval: All procedures performed during studies involving human participants were in accordance with the ethical standards of the institution (Hamamatsu University School of Medicine) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Figure captions

Fig. 1

A: The contribution of the extent of pre-tibial rotation (TR) movement and post-TR movement from maximum extension to 90° flexion. B: The contribution of the extent of pre-TR movement and post-TR movement from maximum extension to maximum flexion. There was a significant relationship between the extent of movement pre-TR from maximum extension to 90° flexion and that post-TR from maximum extension to 90° of flexion (correlation coefficient, 0.473; $p<0.001$) (A). The pre-TR extent of movement from maximum extension to maximum flexion was significantly correlated with the post-TR extent of movement from maximum extension to maximum flexion (correlation coefficient, 0.592; $p<0.001$) (B).

Fig. 2

A: The receiver-operating characteristic (ROC) curve for the postoperative knee flexion angle of 120°, which was calculated for the extent of post-tibial rotation (TR) movement from maximum extension to 90° of flexion using cutoff values.

B: The ROC curve for the postoperative knee flexion angle of 120°, which was calculated for the extent of pre-TR movement from maximum extension to maximum flexion using cutoff values.

Table 1

The demographics data of patients

Gender (male / female)	15 (16 knees) / 39 (44 knees)
Age (yr)	74.9 ± 7.9
Body height (cm)	152.0 ± 8.9
Body weight (kg)	62.1 ± 12.9
Body mass index (kg/m^2)	26.7 ± 3.9
Kellgren-Lawrence classification	II: 8 knees, III: 35 knees, IV: 17 knees
Preoperative knee extension angle (°)	-9.1 ± 8.6
Preoperative knee flexion angle (°)	120.7 ± 18.8
Postoperative knee extension angle (°)	-4.8 ± 4.7
Postoperative knee flexion angle (°)	115.6 ± 15.5

Values are presented as numbers, or mean and standard deviation.

Table 2

Comparison of the tibial rotational position at each angle and the extent of tibial internal rotation among each flexion angle of the knee between pre-TKA and post-TKA.

	Pre-TKA	Post-TKA	*p* value
The tibial rotational position at maximum extension (°)	-3.2 (8.4)	1.1 (7.0)	<0.001*
The tibial rotational position at 30° flexion (°)	0.89 (8.0)	2.3 (7.6)	0.065
The tibial rotational position at 60° flexion (°)	2.8 (9.0)	2.3 (6.8)	0.514
The tibial rotational position at 90° flexion (°)	3.9 (8.8)	3.3 (6.5)	0.443
The tibial rotational position at maximum flexion (°)	5.4 (8.8)	6.2 (7.4)	0.292
The extent of tibial internal rotation from maximum extension to 30° flexion of the knee (°)	4.0 (4.9)	1.2 (3.2)	0.001*
The extent of tibial internal rotation from 30° to 60° flexion of the knee (°)	1.8 (4.4)	0.0 (3.2)	0.014*
The extent of tibial internal rotation from 60° to 90° flexion of the knee (°)	0.73 (3.8)	1.1 (3.3)	0.660
The extent of tibial internal rotation from 90° to maximum flexion of the knee (°)	2.0 (3.8)	2.9 (3.4)	0.080
The extent of tibial internal rotation from maximum extension to 90° flexion of the knee (°)	7.2 (7.4)	2.1 (6.1)	<0.001*
The extent of tibial internal rotation from maximum extension to flexion of the knee (°)	8.9 (8.6)	5.2 (8.0)	0.001*

Values are presented as mean (standard deviation).

The tibial rotational position was shown that internal rotation of the tibia relative to the femur was indicated as positive value.

The extent of tibial rotation was shown that internal rotation of the tibia between each knee flexion angle was defined as positive value.

*: significant difference between the groups

Table 3

Comparison of the tibial rotational position and the extent of tibial rotation at post-TKA between patients with a postoperative knee flexion angle of ≦120° and patients with a postoperative knee flexion angle of >120°.

	Postoperative knee flexion angle		*p* value
	≦120° (n=23)	>120° (n=37)	
Age (years)	76.7 ± 8.3	72.7 ± 7.3	0.082
Gender (male / female)	4 (4 knees) / 18 (20 knees)	11 (12 knees) / 21 (24 knees)	0.128
Preoperative knee extension angle (°)	-10.9 ± 7.9	-5.0 ± 4.8	0.004*
Preoperative knee flexion angle (°)	108.0 ± 17.9	132.4 ± 10.3	0.001*
Knee extension angle at 1 year (°)	-6.3 ± 5.1	-3.4 ± 3.7	0.032*
Knee flexion angle at 1 year (°)	102.6 ± 11.2	127.6 ± 6.4	<0.001*
Intraoperative maximum extension angle (°)	-10.2 ± 6.4	-12.4 ± 6.9	0.975
Intraoperative maximum flexion angle (°)	128.8 ± 10.9	137.3 ± 10.4	0.661
The tibial rotational position at maximum extension (°)	3.9 ± 6.8	-1.2 ± 6.5	0.011*
The tibial rotational position at 30° of flexion (°)	4.1 ± 7.9	0.84 ± 7.1	0.151
The tibial rotational position at 60° of flexion (°)	2.9 ± 6.7	1.6 ± 6.8	0.532
The tibial rotational position at 90° of flexion (°)	3.3 ± 6.5	3.0 ± 6.8	0.875
The tibial rotational position at maximum flexion (°)	5.7 ± 6.4	6.3 ± 8.3	0.802
The extent of tibial internal rotation from maximum extension to 30° of flexion (°)	0.18 ± 3.5	1.6 ± 2.9	0.058
The extent of tibial internal rotation from 30° to 60° of flexion (°)	-1.2 ± 2.5	0.72 ± 3.4	0.062
The extent of tibial internal rotation from 60° to 90° of flexion (°)	0.34 ± 3.3	1.4 ± 3.6	0.310

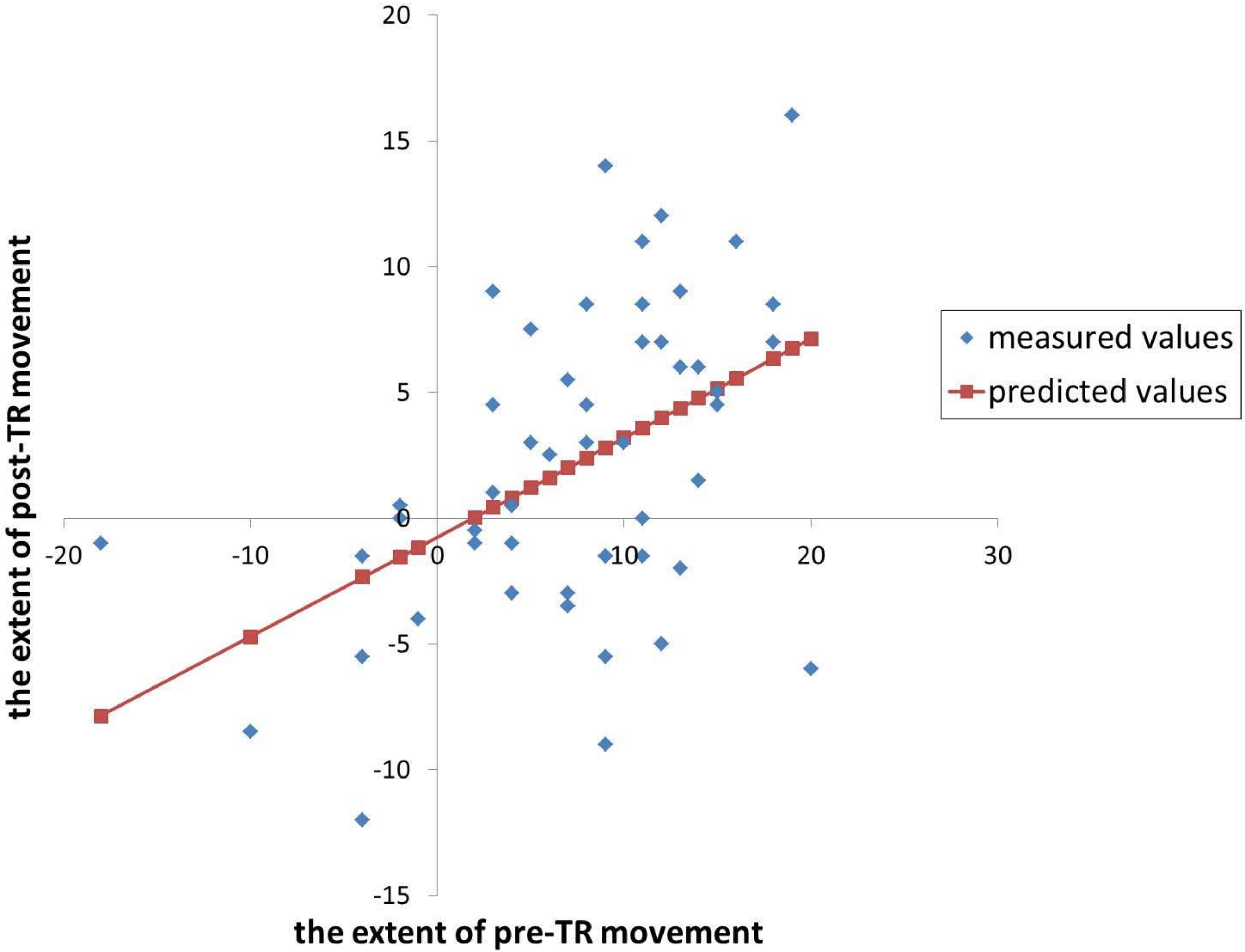
The extent of tibial internal rotation from 90° to maximum flexion (°)	2.5 ± 2.3	3.3 ± 4.7	0.520
The extent of tibial internal rotation from maximum extension to 90° of flexion (°)	-1.2 ± 5.0	3.8 ± 6.5	0.007*
The extent of tibial internal rotation from maximum extension to flexion (°)	1.2 ± 6.6	7.0 ± 8.6	0.017*

Values are presented as numbers, or mean and standard deviation.

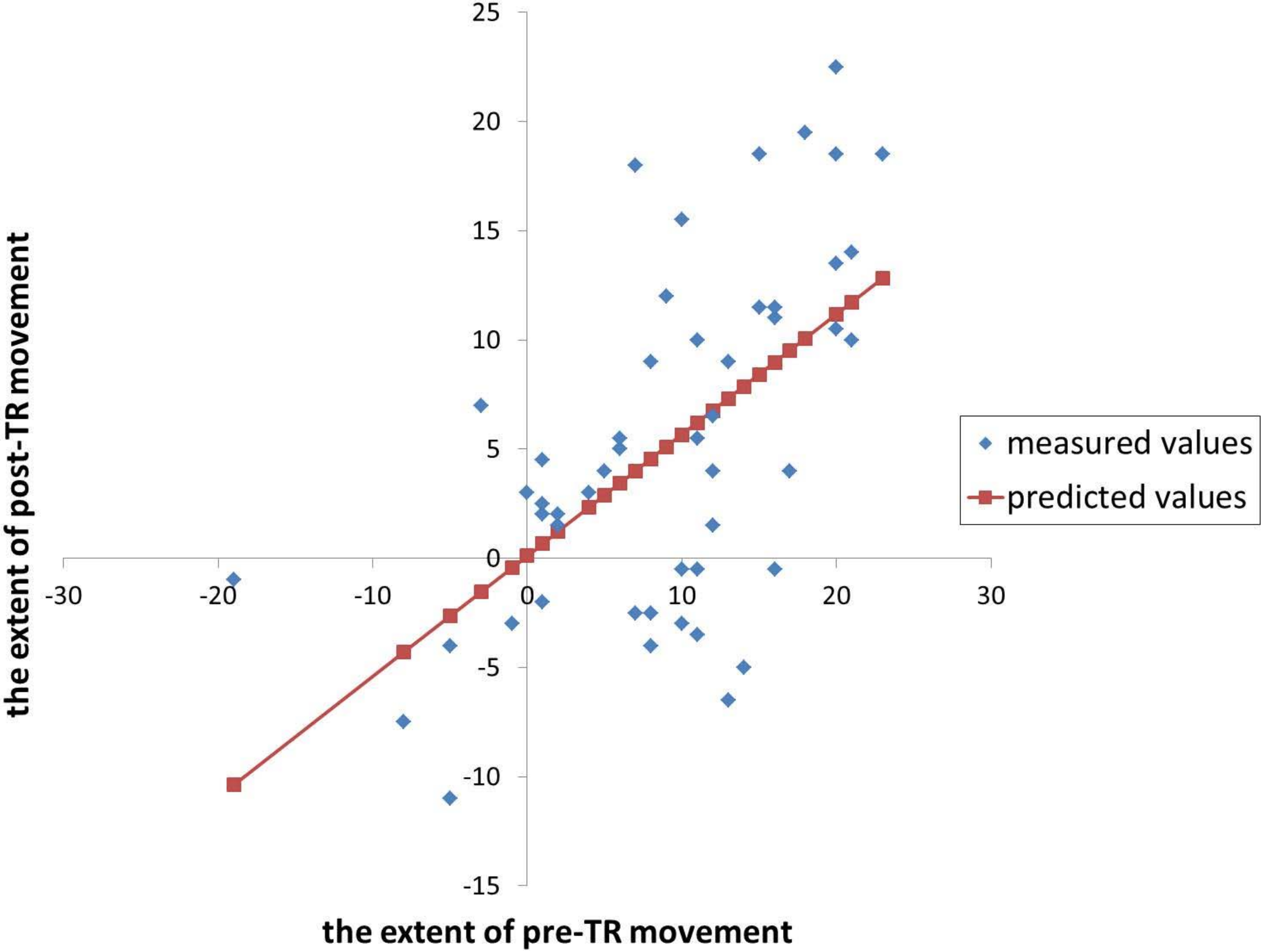
The tibial rotational position was shown that internal rotation of the tibia relative to the femur was indicated as positive value.

The extent of tibial rotation was shown that internal rotation of the tibia between each knee flexion angle was defined as positive value.

*: significant difference between the groups



20
15
10
5
0
-5
-10
-15
-20
-10
0
10
20
30
the extent of post-TR movement
the extent of pre-TR movement
measured values
predicted values



the extent of post-TR movement
the extent of pre-TR movement
measured values
predicted values
25
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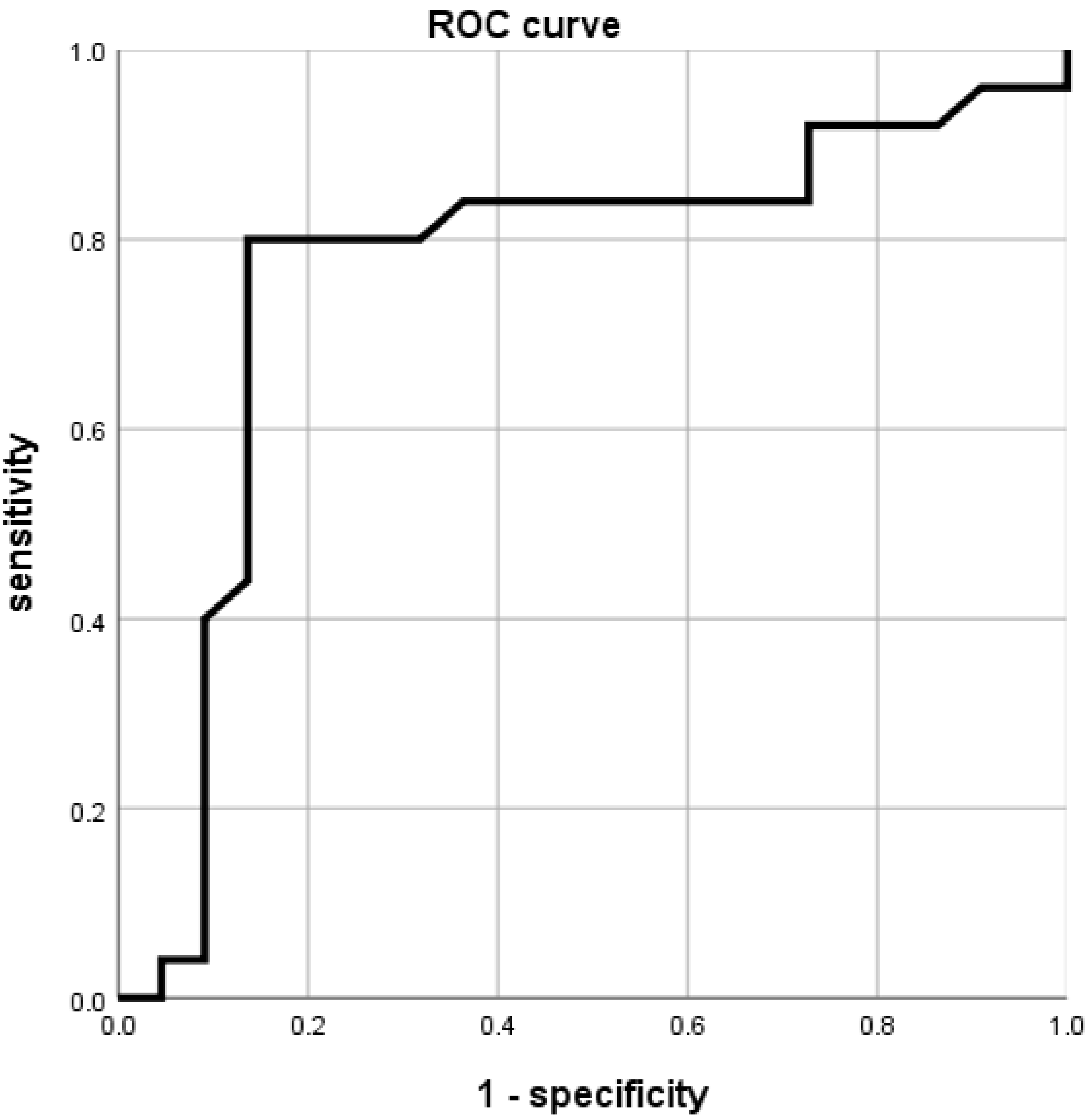
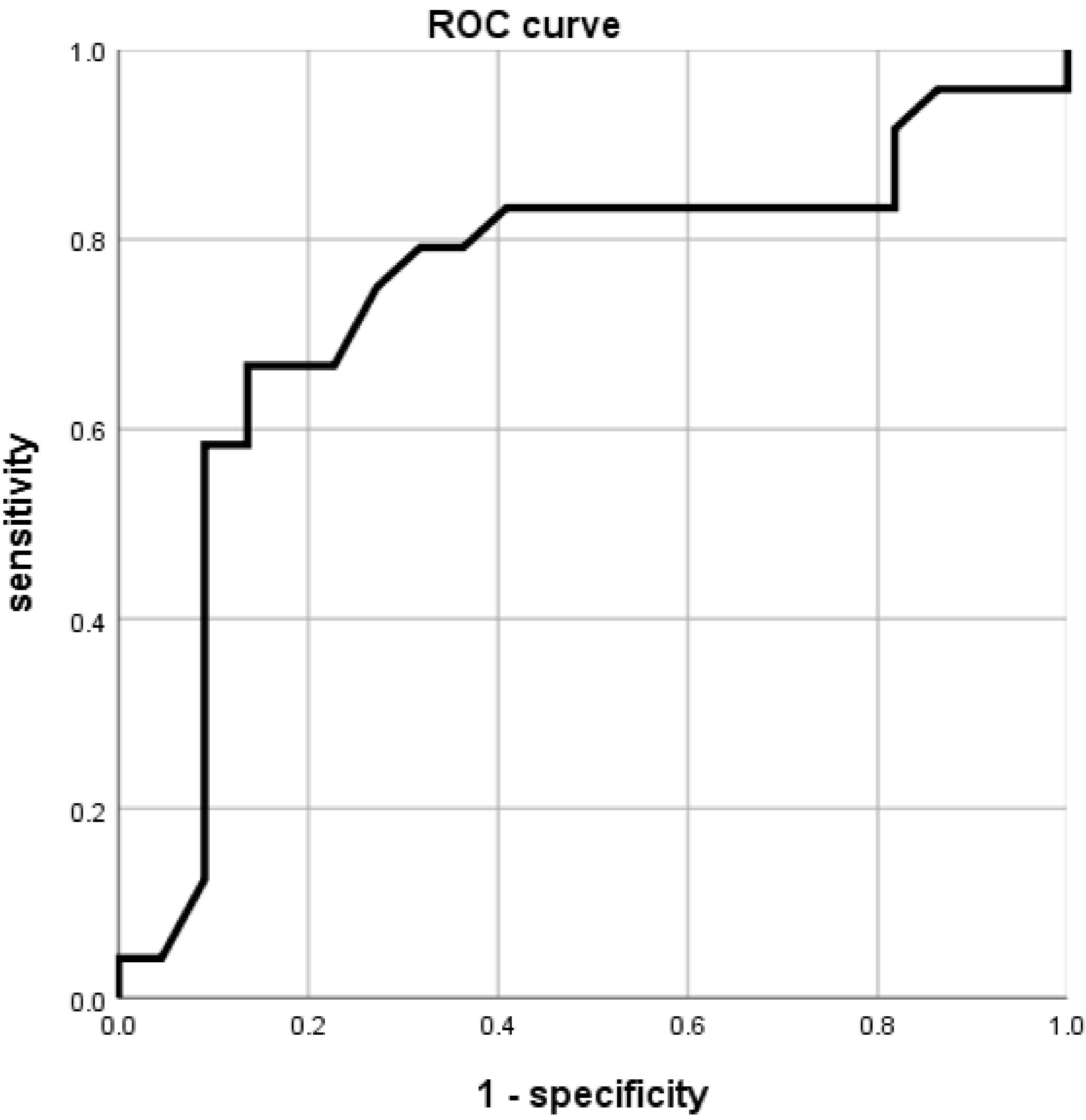
15
10
5
0
-5
-10
-15
-30
-20
-10
0
10
20
30



ROC curve
sensitivity
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1 - specificity


ROC curve
sensitivity
1 - specificity
0.0
0.2
0.4
0.6
0.8
1.0