



## Alternative method for direct measurement of tibial slope

### Alternativna metoda za direktno merenje tibijalnog nagiba

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#### Abstract

**Background/Aim.** The tibial slope is one of the most frequently cited anatomical causes of anterior cruciate ligament trauma. The aim of this study was to determine the possibility of direct measuring of the tibial slope of the knee without prior soft tissue dissection in cadavers. **Methods.** Measurement was performed on the two groups of samples: osteological and cadaveric. The osteological group consisted of 102 matured tibiae and measurement was performed: indirectly by sagittal photographing of the tibia, and directly by a set of parallel bars. The cadaveric group consisted of 50 cadaveric knees and measurement was performed directly by a set of parallel bars. The difference and correlation between indirect and the direct measurements were observed, which included also measuring of the difference and correlation of the tibial slope on the medial and lateral condyles. **Results.** A statistically significant difference between the direct and indirect method of measuring ( $p < 0.01$ ) of  $1^\circ$  was found for the tibial slope on the medial condyle, which is of no practical importance. Direct measurement of the osteological and cadaveric groups of samples did not show a statistically significant difference regarding the values of the tibial slope on the lateral condyle ( $p > 0.05$ ). However, the slope on the medial condyle, as well as indirect measurement showed a statistically significant difference ( $p < 0.01$ ). **Conclusion.** By the use of a set of parallel bars it is possible to measure the tibial slope directly without removal of the soft tissue. The results of indirect, photographic measurement did not statistically differ from the results of direct measurement of the tibial slope.

#### Key words:

tibia; anthropometry; photography; anterior cruciate ligament.

#### Apstrakt

**Uvod/Cilj.** Tibijalni nagib predstavlja jedan od najčešće navođenih anatomskih parametara koji mogu uticati na rupturu prednje ukrštene veze zgloba kolena. Cilj ove studije bio je određivanje mogućnosti merenja tibijalnog nagiba direktno na tibijama i nepreparisanim kadaverskim kolenima. **Metode.** Merenja su vršena na dve grupe uzoraka: osteološkoj i kadaverskoj. Osteološka grupa se sastojala od 102 golenjače, a merenje je vršeno indirektno, uz pomoć fotografija golenjača u sagitalnoj ravni i direktno, uz pomoć sistema poluga paralelnih pravaca. Kadaverska grupa se sastojala od 50 kadaveričnih kolena a merenje je vršeno direktno uz pomoć sistema poluga paralelnih pravaca. Testirane su razlike i povezanost između indirektnog i direktnog merenja, kao i razlike i povezanost tibijalnog nagiba na unutrašnjem i spoljašnjem kondilu golenjače. **Rezultati:** Utvrđena je statistički značajna razlika od  $1^\circ$  između indirektnog i direktnog načina merenja tibijalnog nagiba na unutrašnjem kondilu ( $p < 0.01$ ) koja nema praktičan klinički značaj. Direktno merenje tibijalnog nagiba na spoljašnjem kondilu golenjače nije pokazalo statistički značajnu razliku između osteološke i kadaverske grupe (0,05). Međutim, za nagib na unutrašnjem kondilu, kao i u slučaju indirektnog merenja utvrđena je statistički značajna razlika ( $p < 0.01$ ). **Zaključak.** Uz pomoć sistema poluga paralelnih pravaca izvodljivo je validno merenje tibijalnog nagiba direktno, bez preparisanja mekih tkiva. Rezultati indirektnog merenja tibijalnog nagiba uz pomoć fotografija ne razlikuju se značajno od rezultata dobijenih direktnim merenjem.

#### Ključne reči:

tibija; antropometrija; fotografija; ligament, prednji ukršteni.

## Introduction

The tibial slope is one of the anatomical structures most frequently implicated in the injuries of the anterior cruciate ligament (ACL). Even though its role has been extensively studied, results still remain elusive. While some studies support its role in ACL injury, others do not show a correlation between these two parameters<sup>1-6</sup>.

The greater the tibial slope, the greater the anterior tibial translation when weight is shifted onto the knee, which leads first to increased stretching and then the rupture of the ACL. Giffin et al.<sup>7</sup> have reported that a small increase in the tibial slope does not influence anterior tibial translation and that it may represent a protective factor in ACL-deficient knees. DeJour and Bonnin<sup>3</sup> have demonstrated in their study that an increase of every 10° in the tibial slope is associated with a 6 mm increase in anterior tibial translation. In their case control study, Stijak et al.<sup>6</sup> divided the tibial slope into the tibial slope on the medial and the tibial slope on the lateral condyle, and demonstrated that an increased slope on the lateral condyle as well as a positive difference between the slope on the lateral and on the medial condyle have an influence on ACL injury. Conversely, Meister et al.<sup>5</sup> did not find a statistical significance in the mean tibial slope between a group with ACL injury (50 knees) and a group with patellofemoral pain syndrome (50 knees).

The tibial slope is defined as the angle between the line perpendicular to the tibial axis and the posterior inclination of the tibial plateau. The direction of weight transmission from the femur to the tibia and on to the foot, i.e. from the tibial condyle onto the trochlea tali, overlaps with the tibial shaft anatomical axis (TSAA), which represents the ideal axis, which is, however, due to its position, difficult to measure. In their studies Brazier et al.<sup>8</sup> and Çullu et al.<sup>9</sup> examined correlations between different anatomical axes of the leg with TSAA and found that the tibial proximal anatomical axis (TPAA) had the biggest correlation with TSAA. One study<sup>10</sup> investigated the divergence of 5 anatomical axes of the leg from the mechanical axis, in relation to the tibial slope. In a study of 90 investigated female knees they have

demonstrated that the TPAA has the smallest divergence of the mechanical axis (0.2°).

Taking into consideration many magnetic resonance (MR) studies it can be said that the TPAA is one of the most commonly used axes which can be determined in an isolated tibia, on an X-ray image and a large MR imaging (MRI) but very difficult in intact cadaveric material.

The aim of the study was to research the possibility of direct measurement of the tibial slope of the knee without prior dissection of the soft tissue in cadavers.

## Methods

The data used in the study was obtained by measurement of the two groups of samples. The first group consisted of 102 matured tibias from the osteological collection belonging to the Department for Anatomy "Niko Miljanić", Faculty of Medicine, University of Belgrade. There were 47 right and 55 left tibias without gonarthrotic changes, of unknown sex and age. The second group consisted of 50 cadavers from the Institute of Forensic Medicine in Belgrade (32 male and 18 female cadavers, 30 right and 20 left ones) with an intact ACL, without diagnosed gonarthrosis from examinees aged 15–53 (mean 34; SD 11). The tibial slope was measured on the medial and lateral condyles of the tibia. On isolated tibias, measurement was performed by goniometer: directly – with a set of parallel bars – “parallel bars device”, and indirectly – on sagittal photographs of the tibia. In order to achieve objectivity, measurements were performed by independent researchers. The values of the angles were expressed with the precision of 1°.

We have designed the parallel bars device for direct measurement of: TPAA, the position of the anterior cruciate ligament in relation to the intercondylar notch and with TPAA. It consists of the “pointer of the tibial axis” and of the “pointer of direction” (Figure 1).

The pointer of the tibial axis consists of two parallel bars ( $a_1$  i  $a_2$ ) placed at the distal end of the bar “c” at a 100 mm distance from each other. On these two bars, four parallel pointed bars, running through the bars have been placed (two on each bar:  $b_1$ ,  $b_2$  and  $b_3$ ,  $b_4$ ). These pointed bars are per-

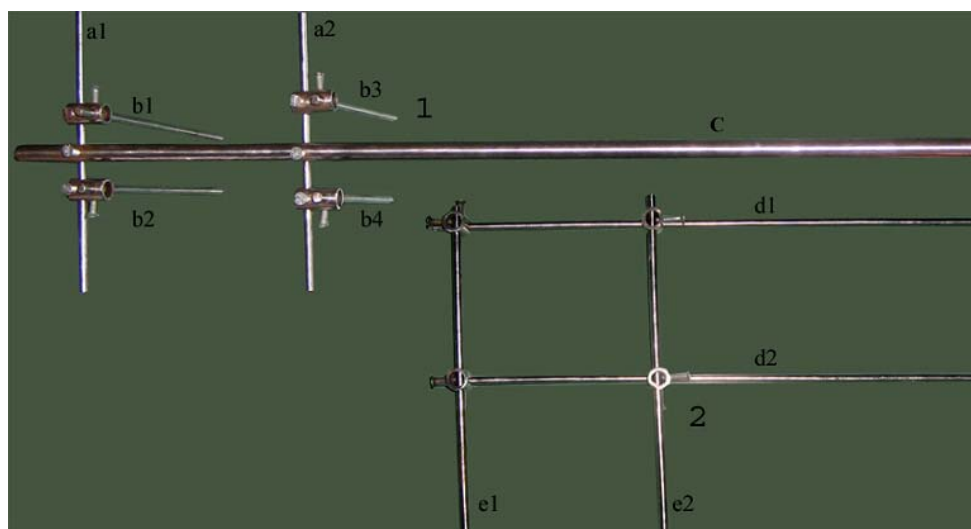
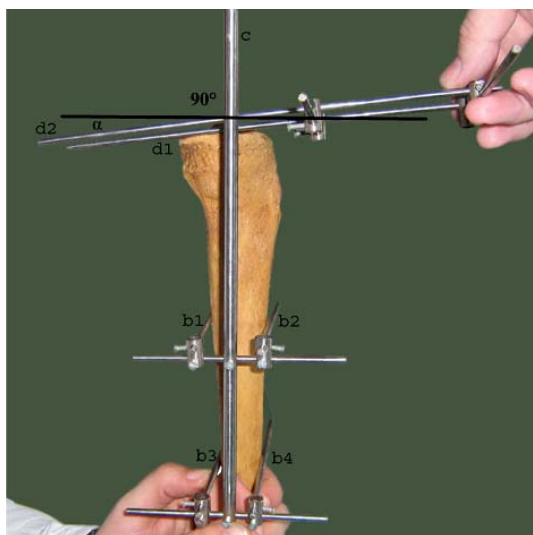


Fig. 1 – Parallel bars device. The pointer of tibial axis (1) and the pointer of direction (2).

pendicular to to direction “a” and can be moved along the bars “a”. The bar “c” is vertical to the axis “a” along which it can be moved and placed at an equal distance from the pointed bars “b”. The pointer of direction consists of two parallel bars ( $d_1, d_2$ ) which can be moved along the bars “e” ( $e_1, e_2$ ). The distance between the “e” bars can be changed accordingly.

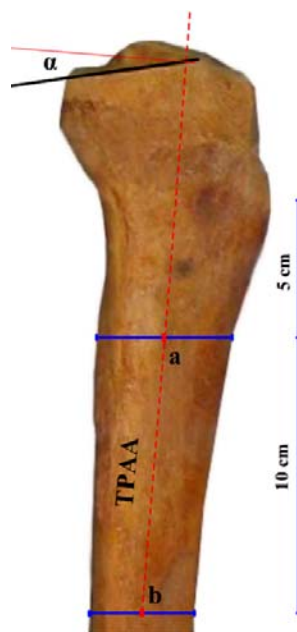
For the measurement of the tibial slope on the lateral and medial condyles, on isolated tibias, four pointed bars “b” of the pointer of the tibial axis are placed on the medial side of the tibia perpendicular to the saggital plateau, to be in contact with the anterior and posterior cortices of the tibias at a 50 mm and a 150 mm distance, distal to the tibial tuberosity (Figure 2). By moving the bar “c” along the bars “a”, i.e. by placing them at an equal distance from the pointed bars “b”, we obtain the direction of the TPAA. By placing the bar “d<sub>1</sub>” pointer of direction on the medial or lateral tibial plateau, the “d<sub>2</sub>” bar makes with the “c” bar (TPAA) the angle of the tibial slope on the lateral, i. e. medial condyle.



**Fig. 2 – Direct measurements of the tibial slope on the medial and lateral condyles of tibia. The angle “ $\alpha$ ” represents the angle of tibial slope on the medial (lateral) condyle.**

For indirect measurement, photographs were taken by a digital camera (with a resolution of 10.0 mega pixels) on the medial and lateral tibial sides (for the medial and the lateral tibial condyles). The digital camera and the upper end of the tibia were positioned in the same plain. The format of the printed photographs was 70 × 140 mm, while the proportion was 1 : 2. Afterwards, with the use of two median points located 50 and 150 mm away from the tibial tuberosity, the proximal tibial anatomical axis was determined (Figure 3). The values of the angles were expressed in relation to the line perpendicular to the TPAA.

Tibial measurement slope on cadaveric knees was performed with the aid of the parallel bars device. The knee joint was accessed from the anterior side (access according to Langebeck). Incision on the skin was performed between the patella and the interior longitudinal retinaculum, from the quadriceps muscle to the insertion of the „pes anserinus“.



**Fig. 3 – Indirect determination of the tibial slope ( $\alpha$ ). Using two median points (“a” and “b”) which were at 5 and consequently 15 cm from the tibial tuberosity, the TPAA was determined, as well the angle of slope of the medial (lateral) condyle of tibia “ $\alpha$ ”.**

By cutting the knee joint capsule, and moving the patella outward and by means of a 90° flexion, insight into the anterior portion of the knee joint was obtained. The four pointed bars “b” of the pointer of the tibial axis were placed on the medial side of the leg at a right angle to the saggital plane by piercing through this plane, so as to touch the anterior and posterior cortices of the tibia at a 50 mm, i.e. 150 mm distance, distally from the tibial tuberosity (Figure 4).



**Fig. 4 – Tibial slope determination directly on the knee of cadaver by a pointer of tibial axis and pointer of direction.**

By moving the bar “c” along bars “a”, i.e. by placing them at an equal distance from the pointed axes “b”, we obtained the direction of the TPAA. The “d<sub>1</sub>” bar of the pointer of direction was placed below the femoral condyles on the medial or lateral tibial plateau, while the “d<sub>2</sub>” bar made with the “c” bar the angle of the posterior tibial slope on the lateral i. e. medial condyle.

We compared the difference and correlation between the two ways of measurement of isolated tibias. In addition, we tested the difference in values of the tibial slope in two groups of samples obtained by means of direct measurement. Also, the difference and correlation of the tibial slope at the lateral and medial condyles, separately for both methods of measurement were compared. The Student's *t*-test for paired pairs and an independent *t*-test at the level  $p < 0.05$ , as well as the Pearson's correlation coefficient were used.

## Results

Although there is a statistically significant difference ( $p < 0.01$ ) between the two different methods of measurement of the tibial slope at the medial condyle, we have estimated that, from the practical point of view, the difference of less than  $1^\circ$  ( $0.9^\circ$ ), which represents the level of accuracy, has no significance (Table 1). There is no statistically significant

The value of the tibial slope obtained by the direct measurement method on cadaveric knees ranged from  $2^\circ$  to  $15^\circ$  (on the lateral condyle), i.e. from  $-1^\circ$  to  $16^\circ$  (on the medial condyle). By direct measurement of the two groups of samples, osteological and cadaveric, no statistically significant difference was obtained with regards to the value of the tibial slope on the lateral condyle ( $p > 0.05$ , Table 2). However, the slope on the medial condyle, as was the case with indirect measurement, showed a statistically significant difference ( $p < 0.01$ ). Basically, what we have here are the values of the slope on the medial condyle obtained through direct measurement on isolated tibias diverging from all the other measurements of the tibial slope.

## Discussion

Direct measurement of the tibial slope on the medial and lateral condyles on cadavers usually depends upon the previous preparation of the leg, i.e. dissection of the soft tissue structures in order to determine the TPAA. Due to these difficulties some authors<sup>11</sup> have chosen the margin of the anterior tibial cortex as a referent axis which exhibits a smaller degree of correlation with the TSAA than the TPAA. The use of markers of the TPAA enables the determining of the TPAA without prior dissection of soft-tissue structures

**Table 1**  
Difference between direct and indirect measurement of the tibial slope at medial and lateral condyles isolated tibias ( $^\circ$ )

Condyle	Direct measurement ( $\bar{x} \pm SD$ )	Indirect measurement ( $\bar{x} \pm SD$ )	<i>p</i> ( <i>t</i> -test)
Medial	$10.7 \pm 4.5$	$9.8 \pm 4.0$	$< 0.01$
Lateral	$7.7 \pm 4.8$	$7.6 \pm 3.9$	n.s.
<i>p</i> ( <i>t</i> -test)	$< 0.01$	$< 0.01$	-----

$\bar{x}$  – mean; SD – standard deviation; n.s. – non significant.

**Table 2**  
Differences between the values of the tibial slope for both groups of samples obtained by direct measurements ( $^\circ$ )

Condyle	Groups of samples		<i>p</i> ( <i>t</i> -test)
	osteological ( $\bar{x} \pm SD$ )	cadaveric ( $\bar{x} \pm SD$ )	
Medial	$10.7 \pm 4.5$	$7.0 \pm 3.7$	$< 0.01$
Lateral	$7.7 \pm 4.8$	$6.9 \pm 3.0$	n.s.
<i>p</i> ( <i>t</i> -test)	$< 0.01$	n.s.	-----

$\bar{x}$  – mean; SD – standard deviation; n.s. – non significant.

difference ( $p > 0.05$ ) between the values of direct and indirect methods of measurement. Both methods of measurements indicate higher values of the tibial slope at the medial than those at lateral condyle ( $p < 0.01$ ),  $3^\circ$  for direct and  $2.2^\circ$  for indirect measurement. The smallest tibial slope measured by direct measurement at the lateral condyle was  $-5^\circ$ , while the largest tibial slope at the medial condyle was  $21^\circ$ . The correlation coefficient between the two different methods of measurement was  $r = 0.84$  for the lateral and  $r = 0.87$  for the medial condyle. In both cases a statistically significant correlation was found ( $p < 0.01$ ). Also, a statistically significant direct connection ( $p < 0.01$ ) of the tibial slope was found at the medial and lateral condyles, both in direct ( $r = 0.43$ ), and in indirect ( $r = 0.46$ ) measurement.

with an anteromedial approach to the knee joint (Figure 4). Sharp, pointed bars (b1-b4) pass through soft-tissue structures, touching the anterior and posterior tibial cortices, while the bar “c” represents the TPAA. By positioning one bar (d<sub>1</sub>) of pointer of direction on the tibial condyle through the anteromedial portal of the knee, the other bar (d<sub>2</sub>) makes a measurable angle with the bar “c” (TPAA).

The results obtained by direct measurement of isolated tibias on the lateral tibial condyle are almost identical to the results obtained by indirect measurement. Somewhat higher values are obtained by direct measurement on the medial tibial condyle as compared to indirect measurement, however, this difference, although statistically significant, is below the level of accuracy, which is  $1^\circ$ . Based on this, it can

be said that the results obtained by direct and indirect measurement are “practically” the same. This is also confirmed by the existence of a high correlation between the data obtained by two different methods of measurement on both lateral and medial condyle.

Through direct measurement of the tibial slope of the lateral condyle of cadaveric knees we obtained the values which do not differ from tibial slope values on the lateral condyle of isolated tibias ( $6.9^\circ : 7.7^\circ$ ). These values are not different from the tibial slope on the medial condyle of the cadaveric group ( $7.0^\circ$ ). However, there is a difference between the values for the tibial slope obtained by direct measurement performed on the medial condyle of isolated tibias and the medial condyle of cadaveric knees ( $10.7^\circ : 7.0^\circ$ ). Looking at the values of the tibial slope published in other studies<sup>6, 11-14</sup> both sets of values obtained in our study can be accepted as valid. In fact, one of the main reasons for obtaining different values is the measurement of the tibial slope in two different groups – the osteological and the cadaveric. The similar values obtained by measurement of isolated tibias in two different ways, also speak to that effect.

However, if we ignore the fact that the tibias in question belong to two different groups, we can look for the reason for the differences in the measurement method itself. Namely, on isolated tibias, the pointer of direction was placed on tibial condyles in such a way as to follow the slope but also the antero-posterior direction of the condyle. In the case of the lateral condyle, which is round, the direction of the pointer of direction constructed an approximately right angle ( $90^\circ$ ) with the pointer of the tibial axis, while in the case of the medial condyle, which is directed from the front towards the back and the inside, this angle had a different value (depending on the direction of the condyle) but was always lesser than  $90^\circ$ . By placing the pointer of direction on cadaveric tibial condyles, we were able to do justice to the lateral condyle and place the pointer of direction at a  $90^\circ$  angle to the pointer of the tibial axis, but due to undissected structures of the knee we could not be completely certain that the direction of the pointer of direction was matching the anteroposterior axis of the medial condyle of the tibia. However, if we were to analyze the measuring technique in this way, we could then also criticize all studies performed on X-ray, MR and computed tomography (CT) images, with the exception of studies with a controlled position of leg rotation.

Chiu et al.<sup>11</sup> used the line of the anterior tibial cortex to determine the tibial slope on previously photographed tibias and obtained the values of  $14.8^\circ$  for the medial and  $11.8^\circ$  for the lateral tibial condyle. This study, as well as our study on isolated tibias, speaks in favor of a greater tibial slope on the medial than on the lateral plateau. On the other hand, the causes of substantially greater values of both the medial and the lateral plateau are multiple. One of them is the use of the anterior line of the tibial cortex as a starting axis in measurement by the cited authors. The other reason could be the difference between the Chinese and the European population. Both studies are the same in that they used (the cited study

and our own), from the clinical point of view, tibias from the population without data on possible ACL rupture. As the incidence of ACL injuries in the total population is relatively low, it can be assumed that in both cases tibias did not have ACL rupture. This data is substantiated by a greater tibial slope on the medial than on the lateral condyle. The difference between the tibial slope on the lateral and on the medial condyle has been established by Stijak et al.<sup>6</sup> in their case-control study on 66 examinees. The tibial slope was determined on MRI and TPAA with the use of X ray images of the leg. The patients with ACL rupture had a greater angle on the lateral ( $7.5^\circ$ ) than on the medial ( $5.3^\circ$ ) condyle, while the patients without a rupture had a ratio of the tibial slope on the medial and the lateral condyle similar to the one in our study; the angle on the medial condyle ( $6.6^\circ$ ) was greater than on the lateral condyle ( $4.4^\circ$ ). Somewhat smaller values obtained in the cited study could be attributed to the difference in the methodology.

In their study performed on MRI of patients without ACL rupture, Matsuda et al.<sup>14</sup> have shown a greater tibial slope on the medial than on the lateral condyle both in “normal” (lateral  $6.0^\circ$ ; medial  $9.9^\circ$ ) and in varus knees (lateral  $7.2^\circ$ ; medial  $10.7^\circ$ ). These values, although obtained by a different methodology are the closest to our results. Also, a recent radiographic study performed on 100 healthy patients has determined a greater tibial slope on the medial than on the lateral condyle ( $9.2^\circ : 4.8^\circ$ )<sup>13</sup>.

In their study on 50 osteoarthritic knees, Kuwano et al.<sup>12</sup> obtained values of  $9^\circ$  for medial and  $8.1^\circ$  on lateral condyle. Taking into account osteoarthritic changes and different methodology (3D CT scanner), these results are in accordance with the results obtained in both of our groups. Two different indirect methods for determining the tibial slope on MRI and radiographic images were performed by Hudek et al.<sup>15</sup> and demonstrated a significant correlation between these two measurements. The values of the tibial slope on the medial condyle showed in their study, were  $4.8^\circ$  on MRI and  $8.2^\circ$  on radiographic images. Taking into account that the authors used the images of patients with and without ACL rupture, it can be said that the results obtained in our study speak in favor of the values showed on their radiographic images.

## Conclusion

Based on the data obtained in this study it can be concluded that two methods of determining the tibial slope, direct and indirect, do not significantly differ and they exhibit correlation. With the use of the parallel bars device it is possible to determine the tibial slope directly on isolated tibias without significant differences as compared to the indirect measurement. Also, with the help of this apparatus it is possible to determine the tibial slope on cadaveric knees, and future studies should perfect measurement techniques and confirm the validity of data obtained by using a parallel bars device.

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