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TITLE:

Soft tissue landmarks for tibial baseplate rotational alignment in total knee arthroplasty. A cadaveric study

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ABSTRACT

Introduction:

The tip of the tibial tubercle (TTT) is used to assess tibial baseplate rotation in total knee arthroplasty (TKA) however it can be difficult to palpate and visualise intra-operatively. Several

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more easily accessible soft-tissue structures have been proposed as intra-operative assessments, including the patellar tendon's medial border (MBPT) and the junction of the medial third of the patellar tendon (mt-PT). No studies have described the relationship between the TTT and these proposed landmarks. The aims of the study were to 1) determine the relationship of the soft tissue landmarks to the TTT, and 2) identify any sex differences in these measures.

Materials and Methods:

Measurements of the position of these soft tissue landmarks relative to the TTT were made on 56 cadaveric knees (28 female) by two observers at the level of the standard tibial cut (10 mm distal to the lateral tibial plateau). The results obtained were compared by sex and side.

Results:

On average, 50.7% (SD 6.79, range 33.1 - 63.1%) of the patellar tendon footprint was medial to the TTT. There were no significant differences between the sexes or left and right lower limbs. However, there was large variability in the position of all the soft tissue landmarks relative to the TTT.

Conclusions:

The results indicate that on average, the patellar tendon footprint is evenly spread around the TTT. However, there is a large variability in the anatomical relationship between the soft tissue landmarks and the TTT. Caution is advised if relying on these structures intra-operatively.

KEYWORDS

Patellar tendon; tibial tubercle; cadaver; total knee arthroplasty; total knee replacement; rotation; tibial rotation

INTRODUCTION

Malrotation of the femoral or tibial components in total knee arthroplasty (TKA) can result in knee pain (Berger, 1998; Barrack et al., 2001; Nicoll & Rowley, 2010; Bell, 2014; Planckaert et al., 2018), stiffness (Bédard et al., 2011) and decreased function (Kawahara, 2014a), and are a cause of revision of TKAs – with malrotation/malalignment reportedly leading to 2.9% - 20.7% (Dalury et al., 2013; Thiele et al., 2015) of TKA revisions. Internal rotation of the tibial component, relative to the native tibial plateau, is associated with anterior knee pain. Barrack et al. (2001) demonstrated that patients who developed anterior knee pain post-TKA had an average of 6.2° internal rotation of the tibial component compared to 0.4° of external rotation in the control group. Nicoll and Rowley (2010) also showed that patients with anterior knee pain had an average of 4.3° of internal rotation of the tibial component compared to 2.2° of external rotation in those that were pain free, and a systematic review by Panni et al. (2018) demonstrated that >10° of tibial component internal rotation is a significant risk factor for pain following TKA.

In patients who develop knee pain post-TKA, part of the investigation includes a radiological assessment of the rotational alignment of the tibial component. The tip of the tibial tubercle (TTT) is used as a landmark to assess tibial baseplate rotational alignment on post-operative CT scans, as described by Berger et al. (1998). Decisions on revision surgery are influenced by these rotational measurements. In addition to its use as a radiological reference for post-operative rotational alignment, the tibial tubercle is also a bony landmark used to assess tibial baseplate rotation intra-operatively (Popescu et al., 2020) in both primary and revision surgery. However, the morphology of the tibial tubercle can be difficult to assess intra-operatively, due to overlying soft tissue structures that should be kept intact. As a result, a number of different methods have been proposed to try to replicate the native proximal tibial rotation during TKA, including the selfpositioning method (Berhouet et al., 2011), where tibial rotation is determined by the rotational alignment of the femoral component, use of other bony landmarks (e.g. the anterior tibial surface curvature (Baldini et al., 2013)), various radiologically defined reference axes (Akagi et al., 2004; Akagi et al., 2005; Cobb et al., 2008), or the use of overlying soft tissue landmarks, such as the medial border of the patellar tendon (MBPT) (Akagi et al., 2004; Akagi et al., 2005; Kawahara, et al., 2014b) and the junction between the medial third and lateral two-thirds of the patellar tendon (mt-PT) (Saffarini et al., 2019). Although some of the radiologically-defined reference axes have been shown to be reliable, they still require the use of bony landmarks intra-operatively, which may be difficult to determine. The variety of methods proposed illustrates the lack of a widely accepted method for determining tibial baseplate rotational alignment intra-operatively. An easily visualised soft tissue landmark for tibial baseplate rotation would be an ideal surrogate for the TTT in TKA. Despite the use of the TTT for radiological assessment of tibial component rotation post-operatively, no studies have demonstrated that intra-operative soft-tissue landmarks have a reliable anatomic relationship to the TTT.

The purpose of this study was to examine the relationship of certain easily identifiable soft tissue landmarks to the TTT – the patellar tendon footprint, and three other soft tissue landmarks that have previously been proposed for intra-operative tibial baseplate rotational alignment: the MBPT in its anatomical position; the MBPT in its subluxed position when the patella is displaced to the lateral edge of the lateral femoral condyle (sMBPT); and the mt-PT. The aims of the study were to 1) measure the patellar tendon footprint to determine its relationship to the TTT and also to allow the position of certain landmarks (e.g. the mt-PT) to be derived, 2) determine the relationship of the MBPT, sMBPT, and mt-PT to the TTT, and 3) identify any sex differences in these measurements.

MATERIALS AND METHODS

Materials

Fifty-six knees from 28 donors – 14 male and 14 female, mean age: 83.93 years (range: 60 – 103 years), mean height: 1.64 m (range: 1.35 – 1.80 m), were examined. The bodies were embalmed using preservation fluid – Cambridge Formulation (Vickers, Pudsey, UK). Measurements of the patellar tendon borders in their anatomical position were made on 55 knees (27 male and 28 female) and measurements of the sMBPT were only possible on 54 knees (26 male and 28 female). One male cadaver had a right TKA in situ, so this knee was excluded from both measurements, and another had the right knee embalmed in deep flexion so the patella could not be subluxed. The donors had bequeathed their bodies to the Anatomy Facility at the University of Glasgow for educational and research purposes, and permission for photographic imaging had been given by the donors from whom images were taken.

Cadaveric dissection and measurements

The skin, soft tissue, retinaculum and paratenon overlying the patellar tendon were carefully dissected off to define the edges of the patellar tendon. An osteotome was used to mark the bony surface of the proximal tibia (by lightly tapping the osteotome against the bone with a mallet) at the medial and lateral extents of the patellar tendon in its anatomical position (Fig. 1).

A medial arthrotomy was performed and the patella was subluxed to the lateral edge of the lateral femoral condyle to mimic its intra-operative position during TKA (Fig. 2).

The subluxed MBPT (with the patella displaced) was marked on the tibial surface, and the patellar tendon was dissected off its insertion on the tibial tubercle. The knee was subsequently disarticulated and the proximal tibia skeletalized.

The TTT was identified visually by resting the foot of the cadaver on a flat surface and looking from the tibial plateau, distally along the tibial crest to identify the most prominent point of the tibial tubercle (Fig. 3). This point was marked with an indelible marker. This method of identification of the TTT was used as it replicates the axial cuts used during CT assessment of tibial rotation.

Several markings were made on the proximal tibia during the dissection (Fig. 4).

The following measurements were taken:

- The distance between medial and lateral bony markings of the patellar tendon footprint, at the level of the TTT, parallel to the marking of the tibial cut
- The distance between the TTT and the medial bony markings of the patellar tendon footprint at the level of the TTT, parallel to the marking of the tibial cut
- The distance between the markings of the MBPT in its anatomical and subluxed positions, at the level of the standard tibial cut (10 mm distal to the lateral tibial plateau) to mimic the intra-operative position of the patellar tendon where the tibial cut is made

All measurements were taken independently by two different observers. Each observer made three repeat measurements of each distance on separate occasions, using a calliper that measured to a tenth of a millimetre, and the mean was calculated.

Two distances were then calculated from the cadaveric measurements, as they could not be readily measured on the cadavers:

- The distance between the TTT and the sMBPT (at the level of the tibial cut) was derived for each cadaveric limb by subtracting the mean lateral displacement of the MBPT (mean measured distance between MBPT and sMBPT) from the mean distance between the TTT and the MBPT

- The distance between the mt-PT and TTT was derived for each cadaveric limb by subtracting a third of the mean PT width from the mean distance between the TTT and the MBPT

The results for the patellar tendon spread were analyzed looking at the proportion of the tendon footprint medial to the tibial tubercle, since most TKAs are performed through a medial parapatellar approach, which exposes the medial aspect of the patellar tendon.

Statistical analysis

The Statistical Package for the Social Sciences (SPSS) Version 26.0 for Windows (IBM Corp., Armonk, New York) was used to perform paired and unpaired T-tests to compare the results by sex and side; and to calculate intra-class correlation coefficients for assessments of intra- and inter-observer reliability. P values of <0.05 were considered significant for the T-tests. Correlation coefficients >0.80 were considered to be excellent reliability.

RESULTS

Reliability calculations

Table 1 shows the intra-class correlation co-efficient (ICC) for the measurements made by each observer, and the ICC when the measurements were compared between observers. The ICC figures indicate excellent intra-observer (O.E. (first author): 0.97, M.M. (second author): 0.98) and inter-observer reliability (ICC of 0.93).

Width of the patellar tendon footprint

The mean width of the patellar tendon footprint at the level of the TTT was 26.8 mm ± 2.7 mm. There was no significant difference between the sexes in an unpaired t-test ($p = 0.56$) (Table 2). There was also no significant difference in the footprint width between left and right limbs on a paired t-test ($p = 0.61$).

Spread of patellar tendon footprint in relation to the tip of the tibial tubercle

The mean distance between the TTT and MBPT in its anatomical position was 13.5 mm ± 2.0 mm. There was no significant difference in this distance between male and female cadavers in an unpaired t-test ($p = 0.429$) (Table 2). The results of the mediolateral spread of the patellar tendon footprint were standardized, so that they could be expressed as a proportion of the total width of the tendon footprint (which was standardized to 100), to facilitate their interpretation. The mean standardized proportion of the tendon footprint medial to the TTT was 50.7% ± 6.8% (Table 3 and figure 5). There was no significant difference in the proportion of the footprint medial to the TTT in male and female cadavers ($p = 0.60$). There was no significant difference in the mean standardised proportion of the tendon footprint medial to the tip of the tibial tubercle between left and right limbs on a paired t test (p = 0.69).

Subluxation of medial border of the patellar tendon with patellar displacement

The mean lateral subluxation of the MBPT with patellar displacement was 8.6 mm ± 2.4 mm (Table 2). There was no significant difference between male and female cadavers in an unpaired t-test (p = 0.70). Expressed as a proportion of the tendon footprint, the mean standardized lateral subluxation of the MBPT was 32.3% ± 8.6% (Table 3). There was no significant difference between male and female cadavers in an unpaired T-test (p = 0.92). There was also no significant difference in the MBPT lateral subluxation between left and right limbs on a paired T-test (p = 0.64)

Distance between TTT and sMBPT

The mean distance between the TTT and sMBPT derived from the cadaveric measurements (Fig. 6) was 4.9 mm ± 2.8 mm (Table 2). There was no significant difference between male and female cadavers in an unpaired t-test (p = 0.80), and there was no significant difference between right and left lower limbs (p = 0.41) in a paired t-test.

Distance between TTT and mt-PT

The mean distance between the TTT and mt-PT derived from the cadaveric measurements (Fig. 7) was 4.6 mm ± 1.8 mm (Table 2). There was no significant difference between male and female cadavers in an unpaired t-test ($p = 0.55$), and there was no significant difference between right and left lower limbs ($p = 0.79$) in a paired t-test.

DISCUSSION

Our results demonstrate that the patellar tendon footprint is, on average, evenly spread on either side of the TTT. This may lead one to conclude that that the midpoint of the patellar tendon can be a useful surrogate marker for the TTT at the level of the tibial cut (10 mm distal from the native tibial articulating surface), however, the wide variation in the mediolateral spread of the tendon footprint in relation to the TTT cautions against the use of the MBPT in its anatomical position, as an intra-operative landmark.

The sMBPT or mt-PT are more lateral soft tissue landmarks than the MBPT, so they should lead to either minor internal rotation, or external rotation of the tibial baseplate if used as landmarks for tibial baseplate rotation planning. External rotation of the tibial baseplate has not been found to be associated with pain (Nicoll & Rowley, 2010), and causes similar stress on the tibial insert to normal positioning. Osano et al. (2014) showed that 15^{o} external rotation of the tibial component results in similar stress patterns on the tibial insert to normal positioning in deep knee flexion, whereas 15^{o} of internal rotation increased stress by a magnitude of 1.6X compared to normal, which might lead to increased wear. External rotation of the tibial component has also been associated with decreased retro patellar pressure (Steinbrück et al., 2016), increased TKA survival (Kim et al., 2014), and better knee function (Valkering et al., 2015). Since the sMBPT and mt-PT are more likely to lead to external rotation of the tibial baseplate, they are preferable landmarks for tibial baseplate rotational alignment than the MBPT in its anatomical position.

However, there was still variability in the position of the sMBPT and mt-PT in relation to the TTT. Therefore, there is still a risk that the operating surgeon, if using these landmarks, may inadvertently place the tibial baseplate in internal rotation in an individual who has a more medial spread of their patellar tendon around the tibial tubercle. Appreciation of these anatomical landmarks and their variable relationship to the TTT is particularly important when trying to correct tibial baseplate rotational errors during revision TKA surgery.

There were no significant sex differences in the mediolateral spread of the tendon footprint or in the lateral subluxation of the patellar tendon in this study, suggesting that the difference in the Q-angle in males and females does not seem to affect the spread of the tendon footprint around the TTT, or predispose females to a larger lateral excursion of their tendon border intra-operatively. To our knowledge, this is the first study that indicates that demonstrates this.

This study has several limitations. The cadavers were all derived from a Northern European population. Considering the variation detected in this sample, a larger, more diverse sample may identify even greater variation, and may also show significant differences (e.g. between the sexes) that this sample could not identify.

The embalmed cadaveric tissue used in this study was stiffer, and less pliable than in-vivo tissue, so we were unable to flex the cadaveric knees to simulate the intra-operative position of the knee during TKA, or evert the patella as is done by a large cohort of surgeons. The use of fresh frozen cadavers may have improved the accuracy of the results, however, we were unable to source an adequate number of such cadavers for use in this study. We were able to sublux the patella to mimic its position during TKA using the embalmed cadavers, and the results still indicate that using the sMBPT as a landmark may decrease the risk of internal rotation of the tibial baseplate. This is an important message.

The TTT was assessed visually on the cadavers, which may have introduced bias. A more objective method (e.g. using shape modelling software) may have improved our methodology, but the current method corresponds to the methods used intra-operatively and on post-operative CT scans, where the TTT is identified visually by the surgeon.

This is the first study to demonstrate that on average, the patellar tendon footprint is evenly spread around the TTT and that there are no sex differences in this spread. This study adds to anatomical knowledge of the morphology of the patellar tendon footprint, and assessment of rotational alignment in TKA, as it has demonstrated the variability of these soft tissue landmarks, which makes them potentially unreliable for determining tibial baseplate rotational alignment.

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LEGENDS

Figure 1. Marking medial and lateral borders of the patellar tendon on the proximal tibia by lightly tapping the osteotome against the bone with a mallet. PT: patellar tendon

Figure 2. Post medial arthrotomy and patellar displacement. QT: quadriceps tendon, P: patella, PT: patellar tendon, T: trochlea of femur

Figure 3. Identification of the tip of the tibial tubercle. LTP: lateral tibial plateau, MTP: medial tibial plateau, TT: tibial tubercle

Figure 4. Markings on the proximal tibia following dissection.

TC: standard tibial cut, MBPT: medial border of the patellar tendon, sMBPT: subluxed medial border of the patellar tendon, LBPT: lateral border of the patellar tendon, TTT: tip of tibial tubercle

Figure 5. Representation of mean and end-range mediolateral patellar tendon footprint. a. 33.1% of tendon medial to tip; b. 50.7% of tendon medial to tip (mean); c. 63.1% of tendon medial to tip

TABLES

	TTT to MBPT measurement	TTT to Lateral border of the patellar tendon measurement	Measurement of patellar tendon subluxation	Mean
OE	0.96	0.98	0.96	0.97
MM	0.98	0.98	0.98	0.98
OE vs MM	0.93	0.96	0.91	0.93

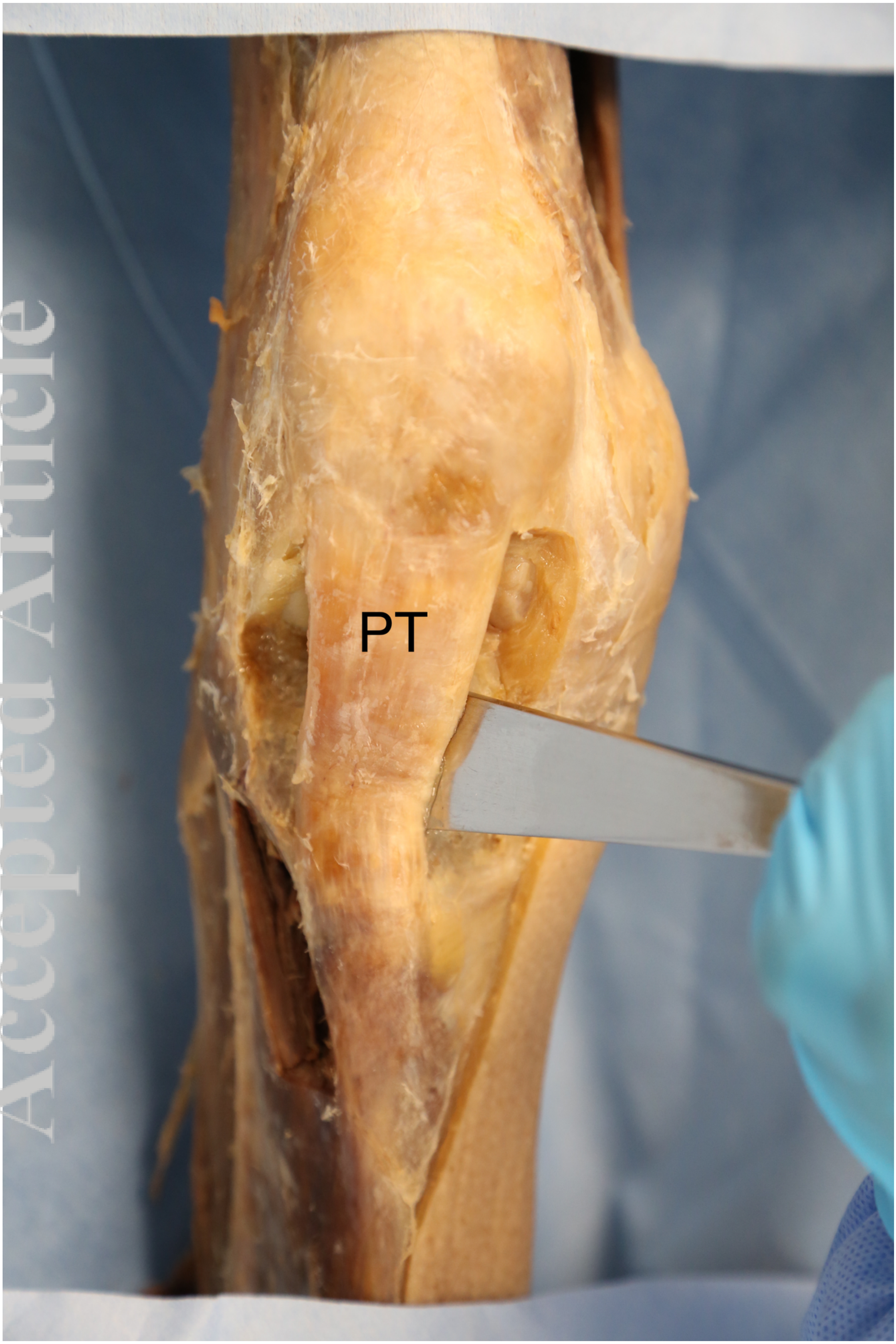
Table 1. ICC for observer measurements

		Mean (mm)	Standard deviation (mm)
Width of patellar tendon footprint	All	26.8	2.7
	Female	27.0	2.9
	Male	26.5	2.4
Distance between TTT and MBPT	All	13.5	2.0
	Female	13.7	2.0
	Male	13.3	2.0
Lateral subluxation of MBPT with patellar displacement	All	8.6	2.4
	Female	8.8	2.6
	Male	8.5	2.3
Distance between the TTT and sMBPT	All	4.9	2.8
	Female	5.0	2.7
	Male	4.8	2.9
Distance between the TTT and mt-PT	All	4.6	1.8
	Female	4.8	1.8
	Male	4.5	1.9

Table 2: Summary of measurements

		Mean (%)	Standard deviation (%)
Standardized proportion of patellar tendon medial to TTT	All	50.7	6.8
	Female	51.1	6.8
	Male	50.2	6.8
Standardized lateral subluxation of MBPT	All	32.3	8.58
	Female	32.3	7.97
	Male	32.3	9.35

Table 3: Summary of standardized measurements



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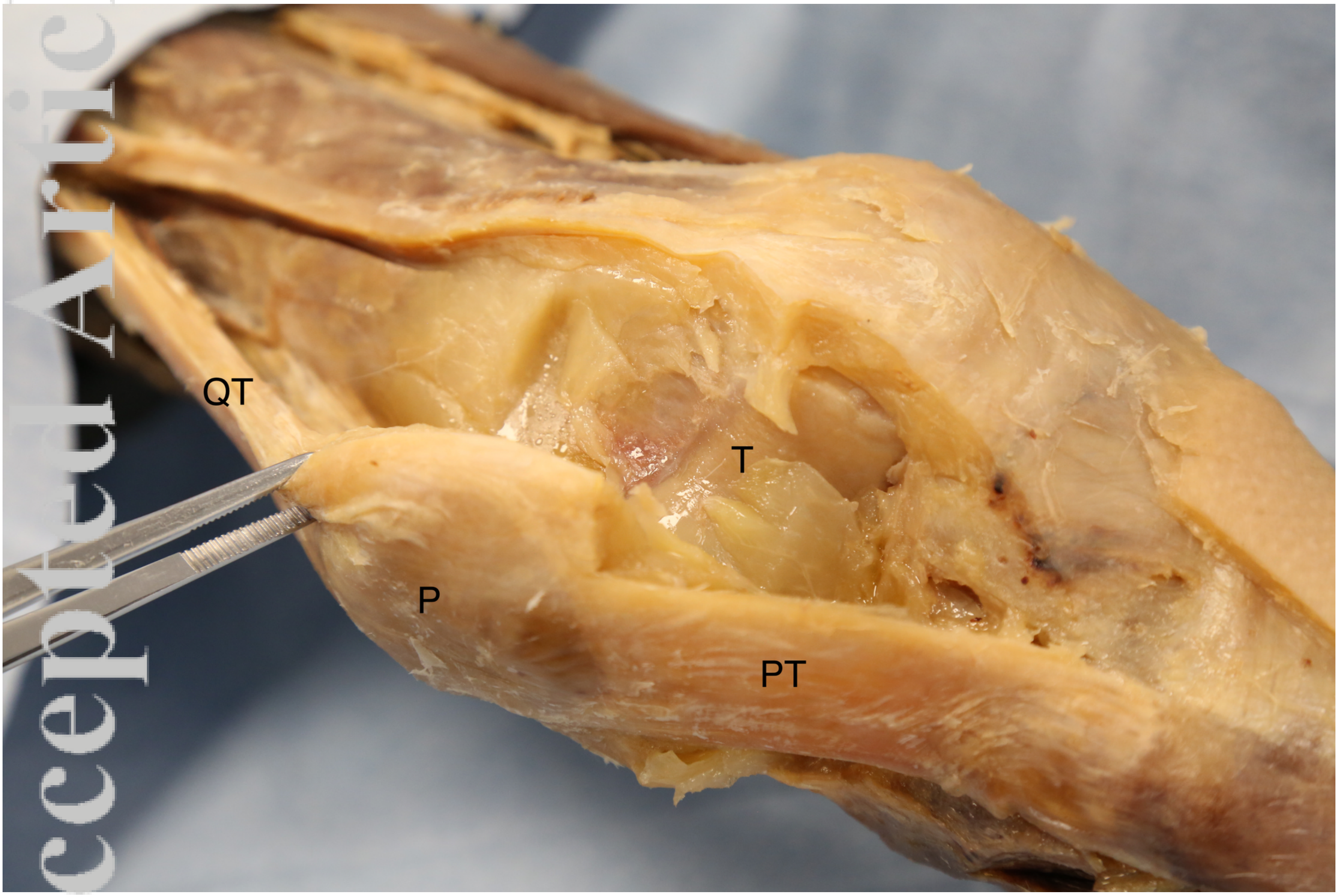

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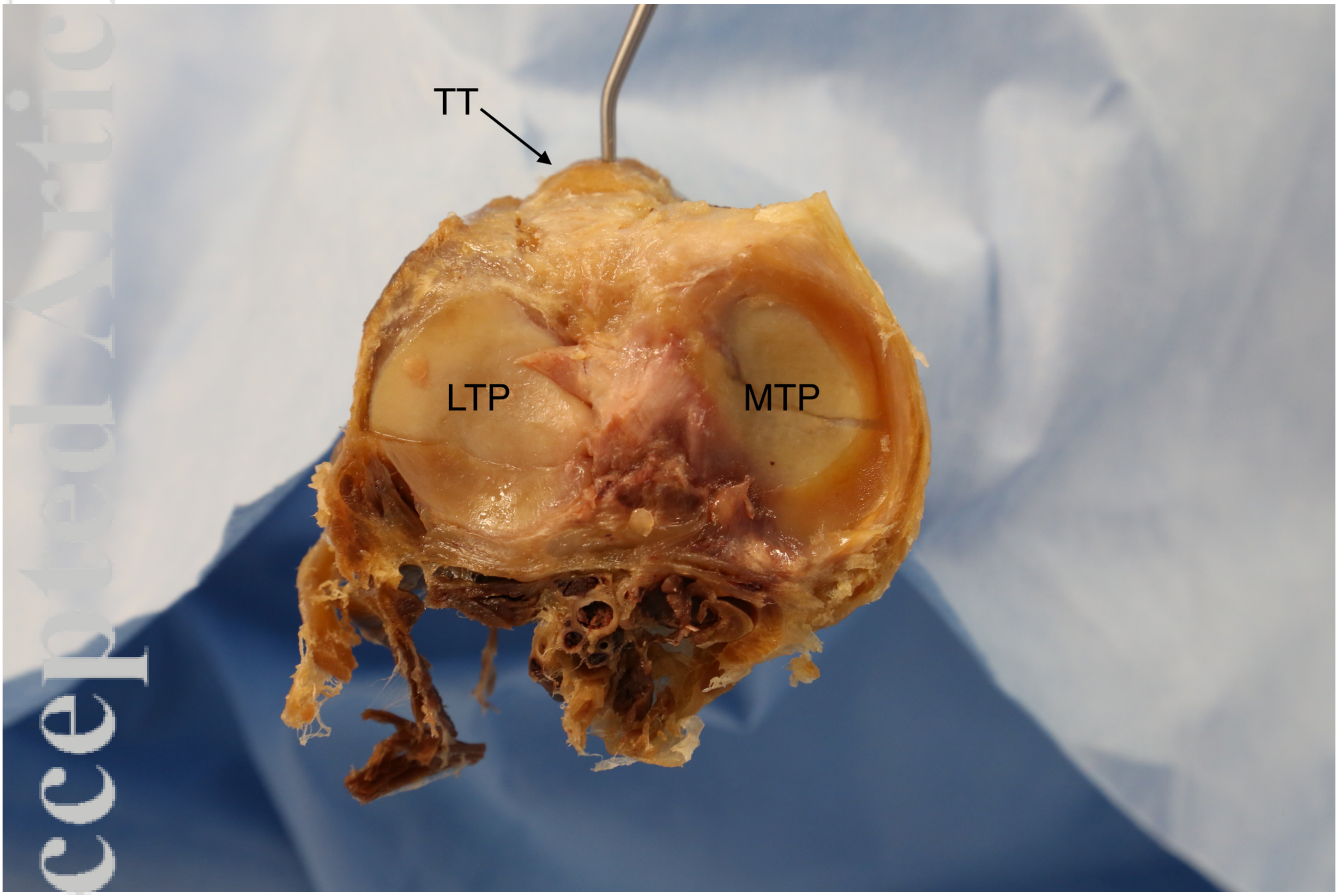

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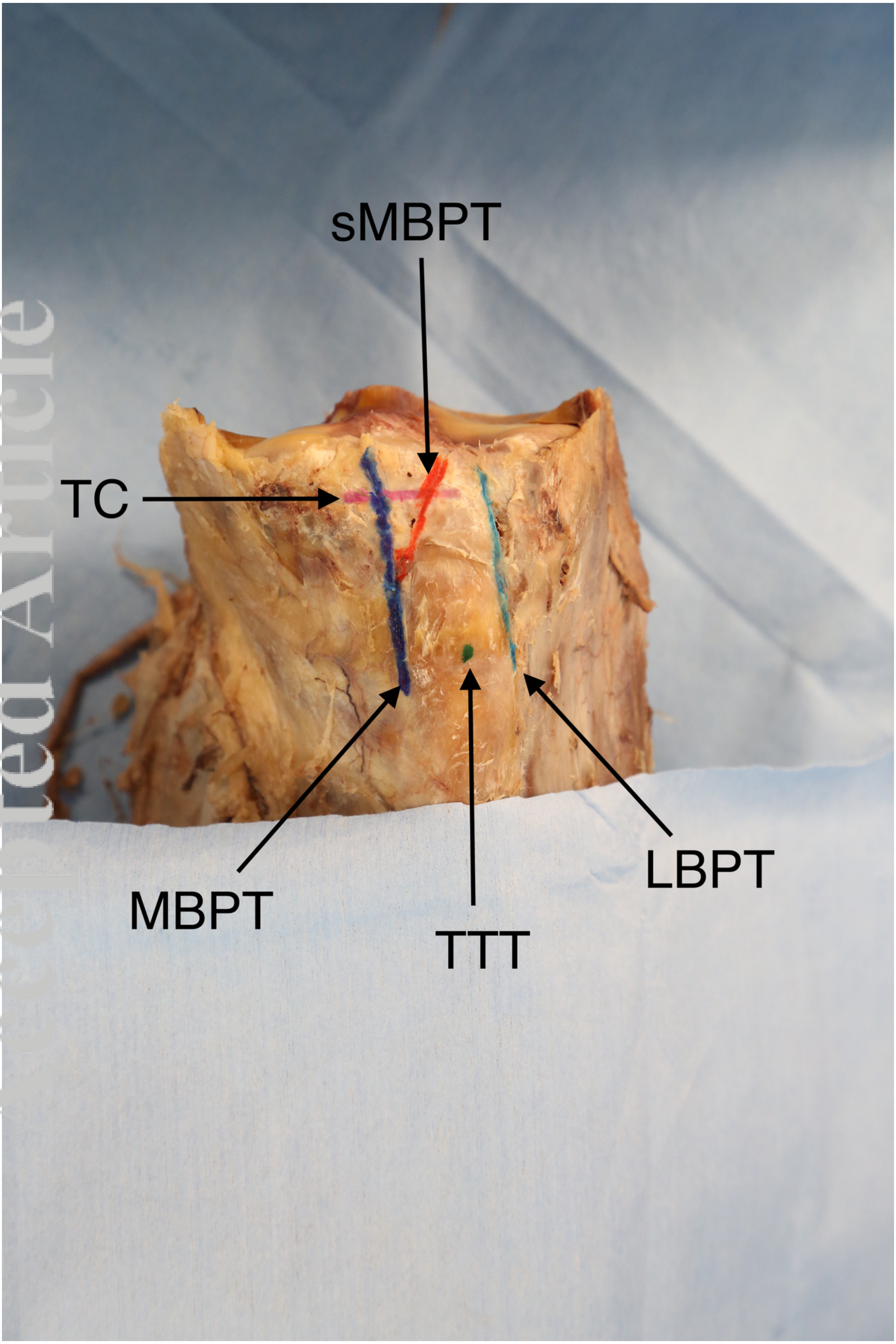

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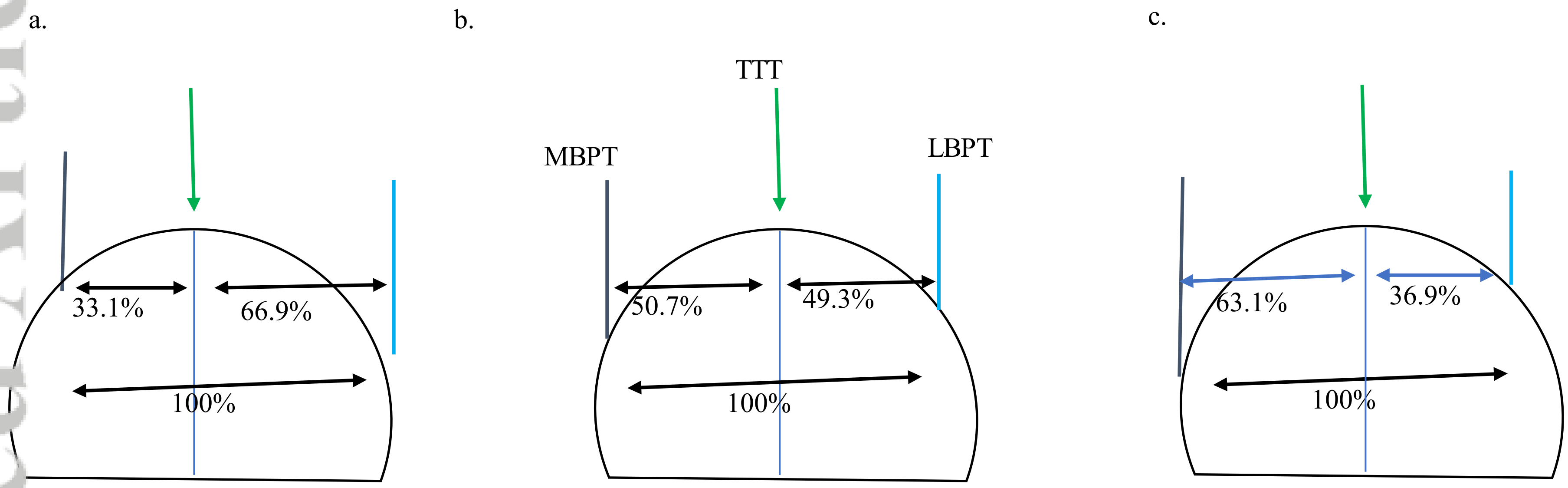

Figure 5. Representation of mean and end-range mediolateral patellar tendon footprint. a. 33.1% of tendon medial to tip b. 50.7% of tendon medial to tip (mean) c. 63.1% of tendon medial to tip.