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TRAUMA SURGERY

Peroneal nerve location at the fibular head: an anatomic study using 3D imaging

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Abstract

Introduction Injuries to the peroneal nerve are a common complication in operative treatment of proximal tibial or fibular fractures. To minimize the risk of iatrogenic injury to the nerve, detailed knowledge of the anatomy of the peroneal nerve is essential. Aim of this study was to present a detailed description of the position and branching of the peroneal nerve based on 3D-images to assist preparation for surgical approaches to the fibular head and the tibial plateau.

Methods The common peroneal nerve, the deep and the superficial peroneal nerve were marked with a radiopaque thread in 18 formalin-embalmed specimens. Three-dimensional X-ray scans were then acquired from the knee and the proximal lower leg in full extension of the knee. In 3D-reconstructions of these scans, distances of the common peroneal nerve and its branches to clearly defined osseous landmarks were measured digitally. Furthermore, the height of the branching of the common peroneal nerve was measured in relation to the landmarks.

Results The mean distance of the common peroneal nerve at the level of the tibial plateau to its posterior osseous limitation was 7.92 ± 2.42 mm, and 1.31 ± 2.63 mm to the lateral osseous limitation of the tibia. In a transversal plane, distance of the common peroneal nerve branching was 27.56 ± 3.98 mm relative to the level of the most proximal osseous extension of fibula and 11.77 ± 6.1 mm relative to the proximal extension of the tibial tuberosity. The deep peroneal nerve crossed the midline of the fibular shaft at a distance of 22.14 mm ± 4.35 distally to the most proximal extension of the fibula, the superficial peroneal nerve at a distance of 33.56 mm ± 6.68.

Conclusion As the course of the peroneal nerve is highly variable in between individuals, surgical dissection for operative treatment of proximal posterolateral tibial or fibular fractures has to be done carefully. We defined an area were the peroneal nerve and its branches are unlikely to be found. However, specific safe zones should not be utilized due to the individual anatomic variation.

Keywords Peroneal nerve · Fibular head · Nerve injury · Tibia fracture · 3D imaging · Anatomy

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Introduction

The sciatic nerve branches at the proximal thigh and then divides into the tibial nerve and the common peroneal nerve. The common peroneal nerve follows the back of the biceps femoris and branches up into the deep and superficial peroneal nerve roughly at the level of the fibular head. The deep peroneal nerve innervates the anterior extensor muscles for dorsal extension of the foot. The area between the first and second toe is innervated sensorial by the deep peroneal nerve. The superficial nerve innervates the peroneus longus and brevis muscles to enable eversion of the foot. Sensorial, the superficial nerve characteristically innervates the anterolateral aspect of the distal leg and the skin of the dorsal foot.

Due to the proximity of the common peroneal nerve and its branches to the lateral aspect of the proximal lower leg, injuries of the peroneal nerve are a possible complication of dislocations of the knee, fractures of the tibial plateau or surgical interventions at this region [1–3].

Operative approaches to the proximal tibia are necessary for several procedures such as (corrective) osteotomies and lengthening procedures using circular frame fixation [4, 5]. Additionally, in case of fractures of the posterolateral aspect of the tibia, posterolateral plating can be necessary [6]. Operative treatment of the proximal fibula can be necessary in exceedingly rare cases of a proximal talofibular joint dislocation accompanying a Maisonneuve fracture [7, 8]. All these procedures bear the risk of nerve injury, since the peroneal nerve and its branches are in close proximity [9].

Injuries to the superficial peroneal nerve may result in a loss of sensibility of the anterolateral foot and an inability to evert the foot. Injuries to the deep peroneal nerve may result in a foot drop. As a result, these injuries can be devastating for the patient, since inability to use these muscles leads to a strongly impaired gait.

Previous anatomic studies of the peroneal nerve focused on the relationship of the peroneal nerve to Gerdy's tubercle or rely on sole dissection of the peroneal nerve and macroscopic measurements with analogue rulers [5, 10–15]. Furthermore, Moskovich et al. used plain radiographs analyzing distances of the peroneal nerve marked with radiopaque threads to osseous landmarks [16].

In the present study, we evaluated the anatomic relation of the common peroneal nerve and the branching into the superficial and the deep peroneal nerve to clearly defined osseous landmarks. With our results, we aimed to improve the spatial idea of the course of the peroneal nerve in preoperative planning. We hypothesized that the anatomic course of the peroneal nerve is highly variable and previously described safe zones should, therefore, be used with great care to not jeopardize the peroneal nerve.

Materials and methods

Eighteen formalin embalmed specimens (9 male, 9 female) were used for this study. The median age of the donors was 79.5 years (range 49–98). From the 18 specimens, we analyzed nine right lower limbs and nine left lower limbs, each from a different donor. The study was approved by the local ethics committee (registration number 13–191).

To radiographically illustrate the anatomic course of the peroneal nerve at the proximal lower leg, the native course of the nerve was marked with radiopaque wires. To prepare for this, the nerve was carefully dissected: after skin incision, the subcutaneous tissue was dissected. Then, the fascia at the back of the biceps tendon was incised and the common peroneal nerve was carefully identified following the back of the biceps femoris tendon. The course of the common peroneal nerve was then followed with minimal dissection of the tissue and without altering its native position in the connecting tissue. The nerve was carefully followed along its branching and continuing into the deep and superficial peroneal nerve. The common peroneal nerve and its superficial and deep branches were then marked with a 0.3 mm radiopaque thread by tagging it on the nerve every 2 cm, using 4.0 monofilament thread. Great care was taken not to change the original localization of the respective anatomic structures. Following these preparatory steps, the skin was again closed using running stitches.

Three-dimensional scans of the knee and the proximal lower leg were then acquired using an Arcadis Orbic 3D imaging intensifier (Siemens Healthcare Diagnostics GmbH, Eschborn, Germany) in full extension of the knee (Fig. 1). For data processing and measurement, the DICOM images were exported into the Impax EE software (Agfa HealthCare, Bonn, Germany). Using the Impax-software, 3D-reconstruction of the scans were built: (1) with the *x*-axis oriented along the shaft of the fibula, (2)

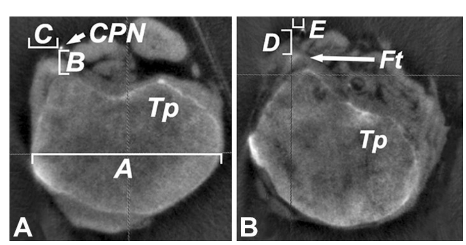

Fig. 1 Example for an axial reconstruction of the acquired 3D-images. **a** The common peroneal nerve (CPN) is marked with radiopaque wire. The width (A) of the tibial plateau (Tp) and distances of the common peroneal nerve (CPN) from the most lateral extension of the Tp (C) and the most dorsal extension of the Tp (B) were measured. **b** At the level of the fibular tip (Ft), dorsal distance (D) and mediolateral distance (E) to the Ft was measured

the *y*-axis oriented along the widest mediolateral distance of the tibial plateau (Fig. 2), the *z*-axis oriented at the level of the tibial plateau (Fig. 3). Constructing sagittal, axial and coronar planes, the following parameters could be measured with Impax-software: (A) the width of the tibial plateau, the distance of the common peroneal nerve to the (B) posterior and the (C) lateral osseous limitations of the tibia at the level of the tibial plateau (Fig. 2a), the (D) posterior and (E) lateral distances of the common peroneal nerve to the most proximal osseous extension of the fibula (Fig. 2b), the axial distances of the branching of the peroneal nerve into its deep and superficial branches to the (F) most proximal extension of the fibula and the (G) level of the proximal extension of the tibial tuberosity (Fig. 3a), the axial distances of the crossing of the (H) deep and (I) the superficial peroneal nerve at the fibular shaft from the most proximal extension of the fibula (Fig. 3b).

For each of the parameters, the median, mean, minimum and maximum, standard deviation and the 95% confidence interval were calculated. Besides the distances in mm, the mediolateral distance from the peroneal nerve to the fibular head and the tibia was calculated relative to the width of the tibial plateau in ten cases.

After validation of normal distribution of our data using the Kolmogorov–Smirnov test, we calculated the Pearson's correlation coefficient to analyze linear correlation between two variables.

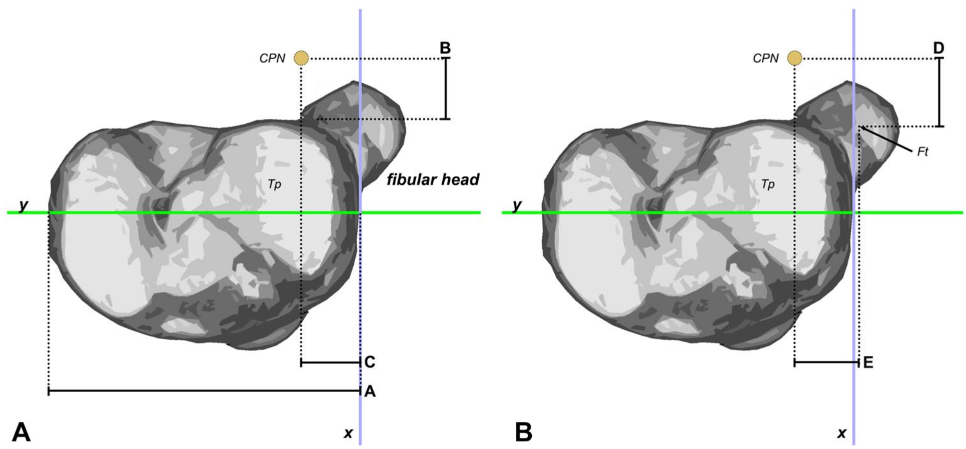

Fig. 2 Schematic illustration of constructed planes in axial reconstruction using the 3D-images. **a** The *x*-axis (*x*) was oriented along the shaft of the fibula, the *y*-axis (*y*) along the widest distance at the tibial plateau. The width (A) of the tibial plateau (Tp) and distances of the common peroneal nerve (CPN) from the most lateral extension of the Tp (C) and the most dorsal extension of the Tp (B) were measured. **b** At the level of the fibular tip (Ft), dorsal distance (D) and mediolateral distance (E) to the Ft was measured

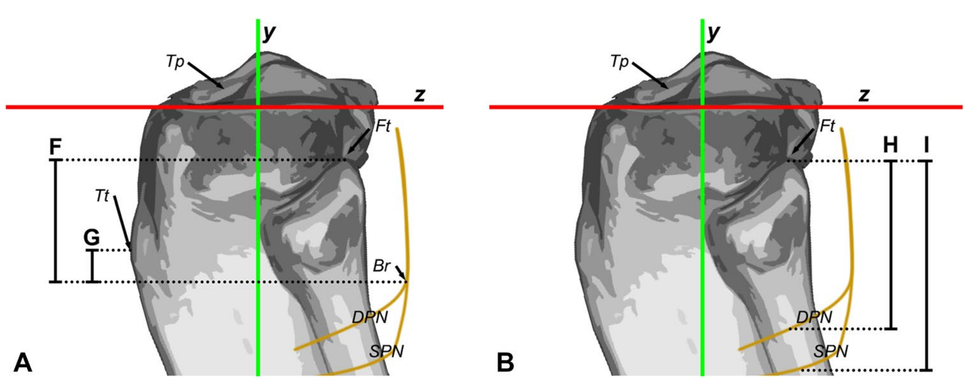

Fig. 3 Schematic illustration of constructed planes in sagittal reconstruction using the 3D-images. The *z*-axis (*z*) was oriented along the level of the tibial plateau (Tp). **a** Distances of the branching (Br) of the common peroneal nerve into its deep (DPN) and superficial (SPN) branches was measured in relation to the fibular tip (Ft, distance F) and the proximal extension of the tibial tuberosity (Tt, distance F). **b** Axial distance of the crossing of the deep peroneal nerve (DPN, distance H) and the superficial peroneal nerve (SPN, distance I) at midshaft of the fibula was measured in relation to the fibular tip (Ft)

Results

Distances of the peroneal nerve to the respective anatomical structures are depicted in Table 1. At the level of the tibial plateau, the mean distance of the common peroneal nerve to the posterior osseous limitation at the level of the tibial plateau was 7.92 mm (± 2.42, range − 2.4 to 21.7, Fig. 4A distance B) (Fig. 3). The distance relative to the lateral osseous limitation at the level of the tibial plateau was 1.31 mm (± 2.63, range − 9.9 to 14.2, Fig. 4A distance C).

At the level of the tip of the fibula, the mean distance in posterior orientation to the common peroneal nerve was 8.23 mm (± 1.77, range 2.1–15.0, Fig. 4B distance D), in mediolateral orientation the distance was − 2.77 mm (± 1.76, range − 10.7 to 3.4, Fig. 4B distance E).

The branching of the common peroneal nerve relative to the proximal extension of the fibula was found at a mean axial distance of 27.56 mm (± 3.98, range 6.2–41.7, Fig. 4C distance F) and at a mean axial distance of 11.77 mm (± 6.1, range − 19.7–40.4, Fig. 4C distance G) to the most proximal extension of the tibial tuberosity.

The mean distance of the crossing of the deep peroneal nerve at the middle of the fibular shaft was 38.04 mm (± 3.52, range 27.8–57.1, Fig. 4D distance H) relative to the fibular tip. The mean distance of the crossing of the superficial peroneal nerve at the middle of the fibular shaft was 48.74 mm (± 5.55, range 32.4–71.4, Fig. 4D distance I) relative to the fibular tip.

The height of the branching of the peroneal nerve relative to the tibial tuberosity and the fibular tip respectively was highly significant different ($p < 0.0001$).

In 10 patients, we correlated the width of the tibial plateau to the distances to the peroneal nerve, the branching of the peroneal nerve and the distances of the superficial and deep peroneal nerve at the fibular shaft to the fibular tip and the tibial tuberosity. Correlation revealed no significant correlation between the tibial width and the distances to the peroneal nerve, the branching height or the distances to the superficial and deep peroneal nerve ($r < \pm 0.3$; $p > 0.05$). Therefore, the tibial width was not measured in the remaining cases.

Discussion

We present a detailed anatomic analysis of the native course of the peroneal nerve and its relation to the proximal tibia and fibula using 3D-imaging.

According to the presented data, the distances of the branches of the peroneal nerve at the fibular shaft relative to the tip of the fibula were highly individual and substantially higher than in the studies from Stitgen et al. and Rubel et al. with a mean of 38.04 mm for the deep peroneal nerve and 48.74 mm for the superficial nerve in our specimens [10, 12]. The shortest distance between the fibular shaft and the peroneal nerve was 27.8 mm.

Existing anatomic studies mainly used dissection of specimens and measured distances to the peroneal nerve using calipers [10–14]. Rubel et al. dissected the proximal peroneal nerve of 31 unembalmed specimens and measured the distance of the nerves' trajectory to Gerdy's tubercle using a precision caliper. They found Gerdy's tubercle to be in the center of a circular trajectory in all specimens. Rubel et al. concluded by proposing individual safe zones defined by transposing the distance between Gerdy's tubercle and the posterior border of the fibula to the anterior aspect of the leg [12]. Stitgen et al. dissected 20 knees from ten specimens and measured the distance of the peroneal nerve to a line drawn between the tip of the fibula and the tibial tuberosity [10]. They defined the proximal 2 cm measured from the

Table 1 Measured distances of the peroneal nerve in 3D-imaging

	Mean	Minimum	Maximum	SD	95% confidence interval
Distance common peroneal nerve to					
Back of tibial plateau (anterioposterior)	7.2	− 2.4	21.7	5.2	2.4
Side of tibial plateau (mediolateral)	1.3	− 9.9	14.2	5.7	2.6
Tip of the fibular head (mediolateral)	− 2.8	− 10.7	3.4	3.8	1.8
Tip of the fibular head (anterioposterior)	8.2	2.1	15.0	3.8	1.8
Distance of the branching to					
The fibular tip (axial)	27.6	6.2	41.7	8.6	4.0
The tibial tuberosity (axial)	11.8	− 19.7	40.4	13.2	6.1
Distance at midshaft fibula to the tip of the fibula					
To the superficial peroneal nerve	48.7	32.4	71.4	11.3	5.6
To the deep peroneal nerve	38.0	27.8	57.1	7.4	3.5

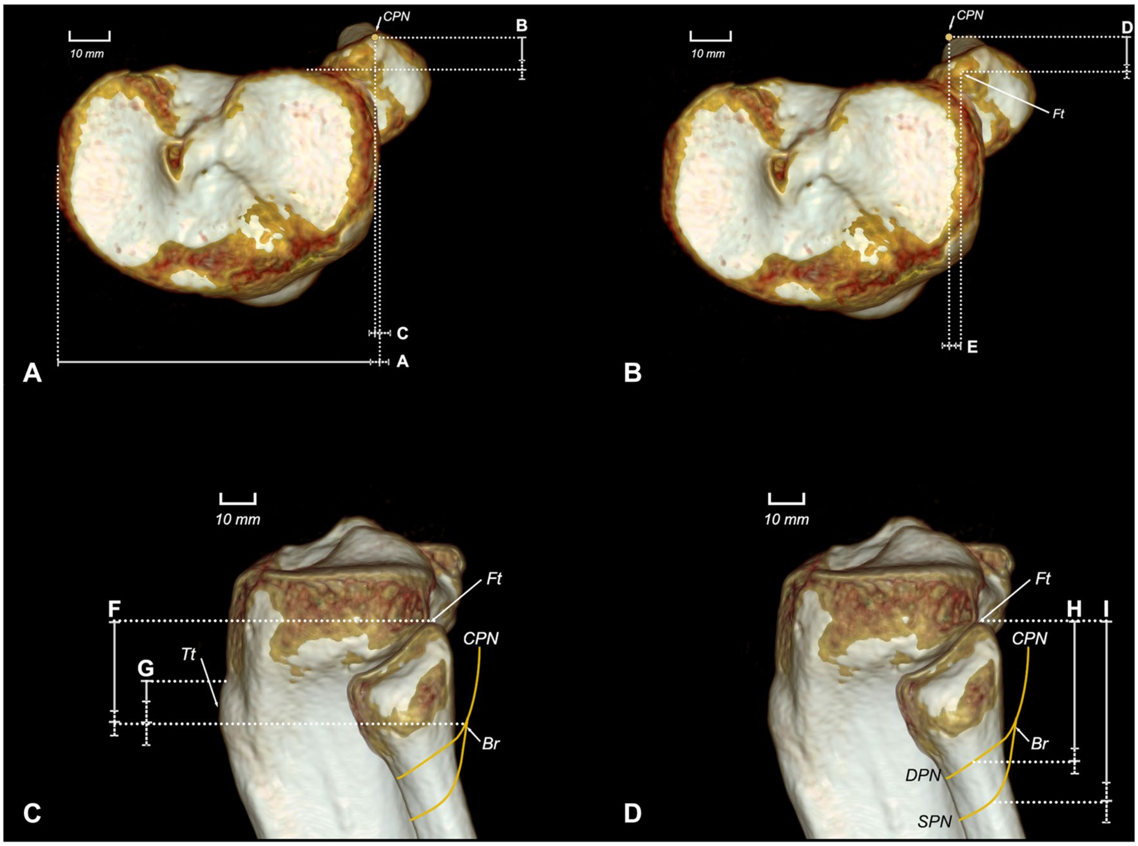

Fig. 4 Measured distances of the peroneal nerve and its branches. Scaled measured distances. The 95%-confidence interval of each measurement is depicted by a dashed line. **a** The tibial plateau (A), posterior distance (B) and distance to the lateral border (C) were measured. **b** At the level of the fibular tip (Ft), posterior distance (D) of the common peroneal nerve (CPN) and mediolateral distance (E) were measured. **c** In reconstructed sagittal images, axial distances of the branching (Br) of the common peroneal nerve (CPN) in relation to proximal extension of the tibial tuberosity (Tt, distance G) and the fibular tip (Ft) were measured. **d** Axial distance of the crossing deep (DPN, distance H) and superficial nerve (SPN, distance I) at midshaft fibula in relation to the fibular tip were measured

tip of the fibula as a safe zone, which is in accordance to the safe area proposed by Rubel et al. [10, 12]. Takeda et al. measured distances from the proximal end of the fibula to the deep peroneal nerve (26 ± 0.32 mm) and the intermuscular septum (15 ± 0.19 mm) to define a safe zone for biopsies in the proximal tibia [11]. Moskovich et al. described the anatomical relations of the peroneal nerve using radiopaque threads on conventional radiographs [16]. They concluded to pass pins in the proximal tibia strictly through the middle of the tibia in the coronal plane to avoid damage to the peroneal nerve [16].

Use of image intensifiers to acquire anatomical data, as in the presented study, generally offers the advantage of gaining reliable landmarks that can also be found using X-ray imaging intraoperatively. The data presented by applying this method confirm the reported safe-zones for surgery around the proximal fibula [10]. We present a more detailed method to describe the course of the peroneal nerve and its branches at the proximal fibula additionally measured with a more reliable and precise technique than used by previous studies. Furthermore, we found the standard deviation of the measured distances to be high, indicating a highly individual course of the peroneal nerve and its branches in each specimen. Although orientation on osseous landmarks can be helpful to find and dissect the peroneal nerve, our data suggests that to prevent injuries to the peroneal nerve, previously identified safe-zones should not be relied upon. This applies, in particular, in treatment of complex (posterolateral) tibial fractures, rarely necessary osteosyntheses of proximal fibular fractures or corrective osteotomies using percutaneous pinning for a circular frame fixator.

Furthermore, consideration should be given to the fact that due to trauma or anatomic deformity in this region, even higher deviations than in the normal anatomy described in the presented study of distances between the peroneal nerve and its surrounding structures may appear. Therefore, any reliance on proposed safe areas always bears the risk of intraoperative damages to nerves that are closer to the fibular tip or which vary from the normal anatomy especially when an underlying pathology is addressed. When operating on this area, an open approach with direct visual contact to the bone might, therefore, be favored instead of percutaneous techniques. Additionally, for corrective osteotomies alternative techniques at the (medial) proximal tibia or the distal femur do not require an approach close to the peroneal nerve, and therefore, do not bear the risk of an injury due to the reliance of a safe zone [17–19]. Accordingly, injuries to the peroneal nerve are usually not found in proximal tibial osteotomies [20].

In our study, distance of the nerve was measured in full extension of the knee. Consequently, data from our study is only valid in this anatomic position. Although anatomic distances between anatomic structures can change in relation to the degree of flexion, open procedures at the knee are usually performed in full extension and hence our results may well be used for most surgical procedures. However, Cuéllar et al. could found the distance of the peroneal nerve to the medial and lateral popliteal hiatus to be the smallest in full extension of the knee [21]. This might also be true for the branching of the common peroneal nerve, although to our knowledge no study supports this. Hence, when operating in flexion of the knee, the peroneal nerve could be at even greater risk than in full extension. Furthermore, predefined safe zones are generally described in full extension of the knee, and reliance on such safe zones in other positions of the knee bears even higher risks of false estimations.

Use of formalin-fixated specimens in our study also poses a possible limitation due to shrinkage of the tissue, and therefore, potentially altered anatomic measurements.

Conclusion

When treating proximal tibia fractures, the posterolateral part on the proximal fibula should be avoided. Pins or screws should only be inserted through the anterior or lateral proximal 27 mm of the fibula. Generally, careful dissection of the tissue is preferred to avoid damage to the peroneal nerve and predefined safe zones should not be relied upon as we found high individual anatomic variation.

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