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ORIGINAL PAPER

Anatomy of the ilium for bone marrow aspiration: map of sectors and implication for safe trocar placement

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Abstract

Purpose The bony anatomy of the human ilium has been well described from a qualitative perspective; however, there are little quantitative data to help the surgeon to perform bone marrow aspiration from the iliac crest in the thickest part of the ilium. The minimum thickness of the spongiousus bone in an iliac wing (transverse thickness between the two tables) is an important factor in ensuring the safe placement of a trocar between the two tables of the iliac wing. For example, with an 8-gauge (3.26 mm) trocar, one can consider that if the transverse thickness of the spongiousus bone of the iliac wing is <3 mm, it will be difficult to insert the trocar safely between the two tables.

Methods For this study, we measured spongiousus bone thickness on 48 iliac wings to map the ilium in six sectors, which were defined by drawing lines from equidistant points spaced along the rim of the iliac crest to the centre of the hip. These sectors can be transposed in the same manner to any patient. To evaluate the risks to reach vascular or neurologic structures, 410 trocars were introduced in the different sectors of 20 iliac bones of ten cadavers.

Results A map was constructed indicating the thickness of the spongiousus bone in each sector. The thickness data was used to create a map that identifies the sites where bone marrow can be obtained with a trocar of 3-mm diameter according to the thickness of the spongiousus bone. Sectors 2, 3 and 6 appear to be more favourable for accommodating a 3-mm diameter trocar. Sectors 1, 4 and 5 comprise the areas with the thinnest parts of the iliac crest, with some areas being thinner than the trocar diameter. The sector system reliably predicted safe and unsafe areas for trocar placement. In cadavers, dissection demonstrated nine vascular or neurologic lesions created when trocars were introduced into sectors 1, 5 and 6.

Conclusion Using the sector system, trocars can be directed away from neural and vascular structures and towards zones that are likely to contain larger bone marrow stock.

Keywords Ilium map for bone marrow aspiration · Ilium sectors · Mesenchymal stem cells · Iliac crest · Ilium thickness

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Introduction

The potential therapeutic benefits [5, 6] of using autologous adult mesenchymal stem-cell-containing preparations have received increasing attention in a wide variety of biomedical fields. Bone marrow aspiration is performed with a trocar introduced between the two tables of the ilium (percutaneous technique) (Fig. 1). However, the technical aspects in bone marrow aspiration are not well described, and the anatomy of the ilium is not well defined in the context of a reference from an iliac entry point. In a previous study [4], we divided the ilium into sectors to define the frequency of risk of a trocar being inserted outside the iliac crest during bone marrow aspiration for each sector. We then described anatomical structures at risk during trocar placement by determining the relative contiguity of intrapelvic neural and vascular structures to trocars placed in specific locations of the iliac bone. The risk appeared to be directly related to the anatomy of the ilium. In particular, the minimum thickness of spongiousus bone in an iliac wing (transverse thickness between the two tables) is an important factor in ensuring safe placement of a trocar between the two tables. For example, with an 8-guage trocar (3.26 mm), one can consider that if the transverse thickness of the spongiousus bone of the iliac wing is <3 mm, it will be difficult to safely insert the trocar (Fig. 2).

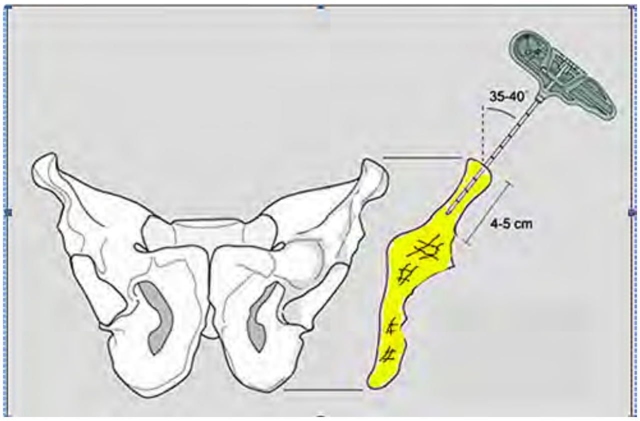

Fig. 1 Trocar introduced between the two tables of the ilium

The anatomy of the ilium is well described in anatomic and surgical textbooks. Judet [7] was probably the first to document the anatomic features of the ilium for hip surgery. Radiologists [3, 10] performed descriptive anatomic study of human ilium correlating the anatomic landmarks to computed tomography (CT) findings, but no quantitative analysis was done. The first quantitative description of the human ilium, to our knowledge, was by Antoniades and Pellegrini [1]. They determined the thickness of the human ilium and related it to acetabulum cup coverage in high hip centre reconstructions. They sectioned 16 cadaveric hips from the anterior superior iliac spine to the anatomic teardrop in 5-mm increments and then measured the thickness of the ilium for each cross section. They described the human ilium in a clinically relevant context, referencing the anatomically constant acetabular teardrop for hip revision. However, the horizontal cuts did not show the iliac crest above the ilium, which would be relevant for bone marrow aspiration from the iliac crest.

The purposes of this study, therefore, were to: (1) determine the thickness of the spongiousus bone of the human ilium from the iliac crest on vertical sections relevant for bone marrow aspiration, (2) evaluate areas where thickness allows placement of an 8-gauge trocar (3.26 mm) and therefore allows safe introduction of the tocar between the two tables in each sector, and (3) evaluate the risks of reaching vascular or neurologic structures during bone marrow aspiration. These measurements were performed on cadavers, with the hypothesis that during insertion of the trocar in some thin areas (Fig. 1), there is a higher risk of inadvertent breach in these zones, resulting in increased risk of injury to specific intrapelvic and extrapelvic vascular or neurologic structures.

Material and methods

Two series of data were independently obtained: (1) measurements of iliac wings where sectors where defined; (2) cadavers on which multiple trocars were indroduced to evaluate the risk of a trocar being directed outside the iliac wing and thus reaching vascular or neurologic structures.

Thickness of spongiousus bone in different sectors

We examined pelvic CT scans of 24 mature, living adults [12 men, 12 women; median age 50 (range 20–80) years] for vascular exploration. From 2D images (1-mm cuts), 3D reconstructions were made using software available with this CT scanner (General Electric, LightSpeed). As previously described [4], the iliac wing was divided into six sectors by drawing lines (Fig. 3) from equidistant points spaced along the rim of the iliac crest to the centre of the hip. The mean length of the

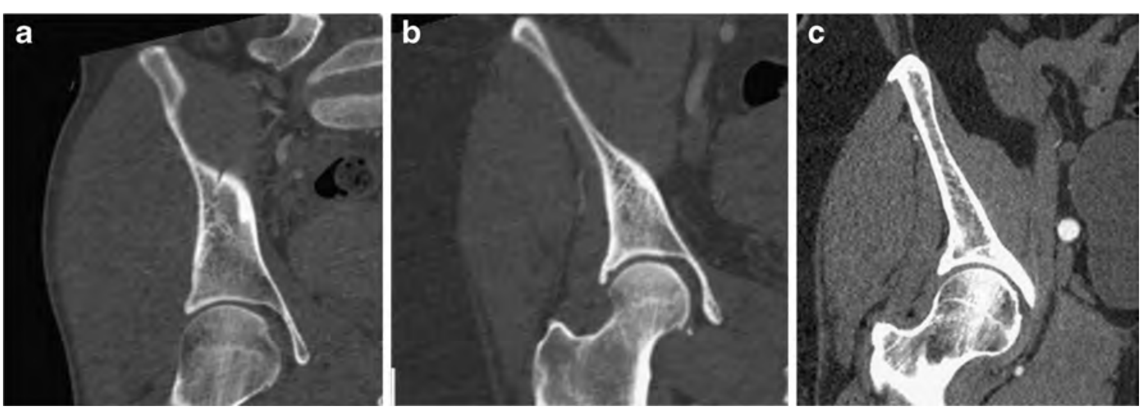

Fig. 2 Spongious internal thickness between the two tables of the iliac wing is an important factors in ensuring safe placement of the trocar between the tables. **a** Drastic change in the shape of the iliac crest creates the risk of breaching the table during bone marrow aspiration. **b** When the iliac wing is too thin, the trocar cannot progress deeply without inadvertent breach of the internal or external table. **c** When the ilium is thick everywhere, as in this example, the trocar can progress straight from the iliac crest to a depth of 9 cm

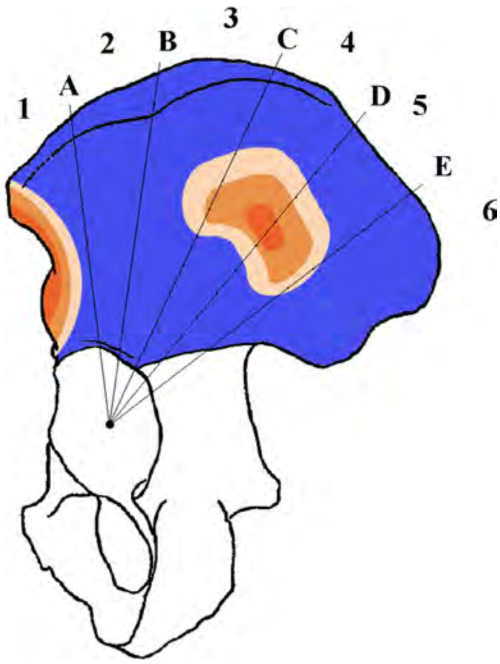

Fig. 3 Map of the ilium. The *blue zone* is the part of the ilium where the thickness of the spongiousus bone is always >3 mm. The *yellow area* corresponds to the zone where in 50 % of cases the thickness is <3 mm but >2 mm. The *orange area* corresponds to the zone where in 25 % of cases the thickness is <2 mm but >1 mm. The *red area* corresponds to the zone where in 20 % of cases the thickness is <1 mm. The *yellow*, *orange* and *red* zones are in sectors 1, 4 and 5. *Line A* is the border between sectors 1 and 2 and *line B* the border between sectors 2 and 3, and so forth

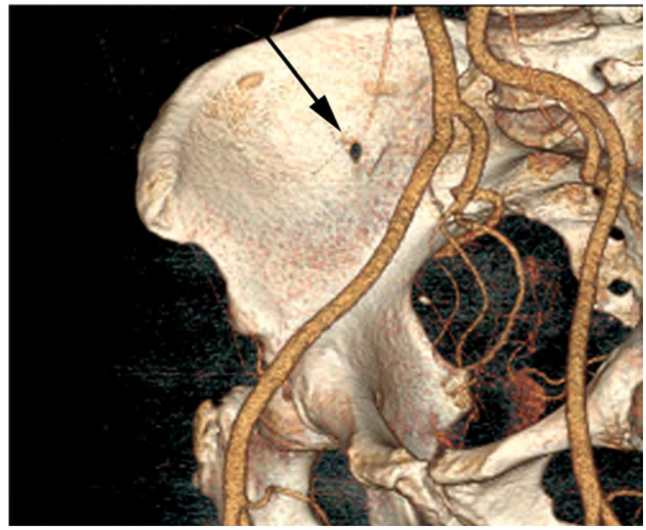

Fig. 4 Hole in the iliac crest in sector 4

iliac crest was 24 cm, and each half of the iliac wing was divided into three sectors by drawing lines from points 4-cm apart on the iliac crest to the centre of the hip. These lines were approximately perpendicular to the curve of the iliac crest. The six sectors were defined by these lines (Fig. 3). The corresponding sectors can be found and marked using the same technique.

The minimum thickness of spongiousus bone in an iliac wing (transverse thickness between the two tables) is an important factor in ensuring the safe placement of a trocar between the two tables of the iliac wing. For example, with an 8-gauge trocar (3.26 mm), one can consider that if the transverse thickness of the spongiousus bone of the iliac wing is <3 mm, it will be difficult to insert the trocar safely between the two tables (Fig. 2a, b). In some cases, a hole may be present (Fig. 4). From the 2D transverse images with 0.6-mm cuts, 3D reconstructions were made. Radial cuts were obtained perpendicular to the iliac crest and directed to the centre of the hip (24 per ilium; four for each sector; average 5° of arc between two consecutive cuts). On each image (*radial cut*), spongiousus bone thickness (Fig. 5) was measured at different depths (each cm) from the superficial iliac crest to a depth of 9 cm. We constructed one map (Fig. 3) that identifies the sites where an 8-gauge trocar can readily penetrate between the tables.

Anatomic structure impingement risk assessment

To evaluate the risk of reaching vascular or neurologic structures during bone marrow aspiration, the pelvis of ten mature adult cadavers, including muscles, nerves, abdominal contents and vasculature, were obtained. Trocars 10-cm long were inserted at different entry points (every cm on both iliac crests from anterior to posterior with different installations: cadaver supine, prone or lateral according to the entry point). A total of 410 trocars were introduced in 20 iliac bones. The trocar remained in situ insertion was completed to the presumptive correct site for aspiration or when the needle lost contact with bone, after which anatomical dissections were performed. Evisceration was performed through a midline abdominal incision, with care taken not to disturb the parietal peritoneum covering the iliac vessels and inner pelvic wall. Trocars that penetrated the bone and entered the pelvis or were at the outer surface of the pelvis were then analysed in relation to nerves and vessels. These trocars were traced back to the iliac crest to record sector and radial location of insertion points.

Statistical analysis

Statistical analysis was performed using Logiciel Excel for Windows. Descriptive statistics were obtained on all variables collected during the study. Continuous

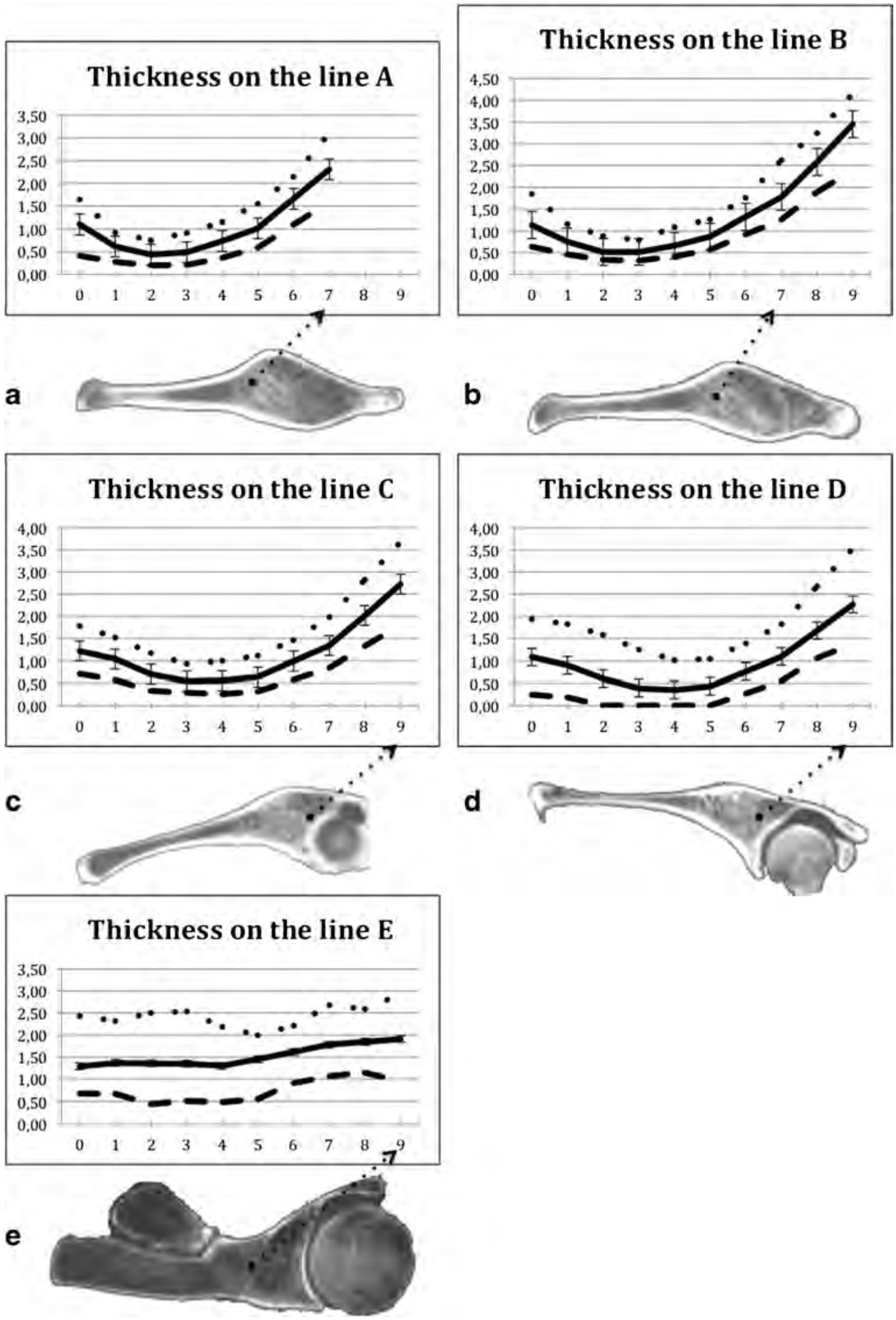

Fig. 5 Cross sections of the ilium oriented from the iliac crest to the acetabulum. *Line A* is the border between sectors 1 and 2, *line B* the border between sectors 2 and 3, and so on. These lines correspond to the five radial cuts separating the different sectors in Fig. 6. Average spongiousus bone thickness (cm) versus the distance from the iliac crest (cm) is shown with standard deviations (SD) and minimum and maximum values. These cross sections demonstrate that the ilium decreases in thickness 3 cm from the iliac crest and that decrease is most pronounced on *line C* (between sectors 3 and 4) and *line D* (between sectors 4 and 5), as demonstrated on the map in Fig. 6

variables were angle, distance from trocar to vital structures, distance from pelvic bone to structure and bone thickness in each zone. Categorical values were iliac crest side, age, sex, height, body mass index (BMI) and sector. A p value <0.05 was considered significant. According to the number of CT cuts (each 0.6 mm) and the matrix (512 × 512), the theoretical accuracy was 0.5 mm for linear measurements and 1° for angular measurements. Interobserver reliability was assessed by calculating the intraclass correlation coefficient (ICC) for repeated measures. Interobserver reliability for distance and angles demonstrated intraclass correlation coefficients of 0.90 and 0.87, respectively, representing good reliability.

Results

The sector system reliably facilitated the identification of safe and unsafe areas for trocar placement.

Variations of iliac thickness in each sector

Thickness was used to create a map (Fig. 3) that identifies sites where bone marrow can be obtained with a trocar of 3-mm diameter according to the thickness of spongiousus bone in the iliac crest: sectors 2, 3 and 6 appear to be most favourable; sectors 1, 4 and 5 indicate the thinnest parts, with some areas thinner than the trocar diameter. Some iliac wings had a hole in sectors 4 or 5 (Fig. 4) without any cortex and, of course, without bone marrow. The average bone thickness for each sector is illustrated in Fig. 4. Sector 6 has statistically significant ($p<0.001$) differences in average bone thickness when compared with sectors 2 and 3. When compared with the average bone mass of sectors 2 and 3, it is evident that the posterior iliac crest (sector 6) had greater spongiousus bone thickness close to the entry point, but sectors 2 and 3 appeared also to be appropriate for bone marrow aspiration, as the thickness of the spongiousus bone was >3 mm and the trocar can penetrate to a depth of 9 cm (Fig. 5). There was no correlation between thickness of the iliac crest in each sector and sex, age, side (left or right), height and BMI ($p>0.05$ for all). Analysis of variance (ANOVA) and post hoc testing demonstrated statistically significantly difference in thickness between all sectors ($p<0.001$).

Vascular and neurologic lesions

Among the 410 trocar entry points assessed in the study, 114 breaches of the medial or lateral table were observed. During insertion, there was a higher frequency of breaking through the inside table (82 breaches, 72 %) due to the shape of the iliac crest. Breaches occurred more frequently in sectors 1, 4 and 5 (Fig. 6a, b). Subsequent dissection demonstrated nine lesions of vascular or neurologic structures, which occurred in sectors 1, 5 or 6. Trocars placed in anterior sector 1 caused lesions to the external iliac artery (five cases) and the lateral femoral cutaneous nerve (two cases). One trocar placed in posterior sector 5 caused a lesion to the inferior gluteal vessel. Furthermore, one lesion of the sacroiliac joint was observed in sector 6.

Discussion

Morbidity from standard bone graft harvest in the pelvic region is well described [3, 8, 9, 11, 12]. Complications of graft harvest include inadvertent bicortical disruption of the pelvis, injury to neural, soft tissue or vasculature, infection, fracture, pelvic visceral injury and postoperative pain issues. An alternative to using bone graft in many applications is bone marrow grafting using marrow harvested from the patient's iliac crest. Understanding how anatomical positioning of the trocar differs between sectors can inform surgeons of the most appropriate areas in which to perform bone marrow aspiration.

Clearly, as shown in Fig. 3, sectors 4 and 5 are the thinnest parts of the iliac wing, and when the patient is in a lateral position, the surgeon will have greater difficulty keeping the trocar between the two tables of the iliac crest. Furthermore, the volume of bone marrow is very low in sectors 4 and 5, the thinness sectors, which limits insertion depth to no more than 3 cm. Deeper insertion in these sectors results in the trocar reaching the thinnest portions of the iliac crest. Placing trocars in the most anterior sector, sector 1, should be avoided whenever possible, because the decreased bone thickness exacerbates the risk for involving the lateral femoral cutaneous nerve and the external iliac artery (which is relatively immobile in this zone and is close to the anterior column). Because of the more medial position of the vein with respect to the artery, as well as the paucity of intervening tissue along

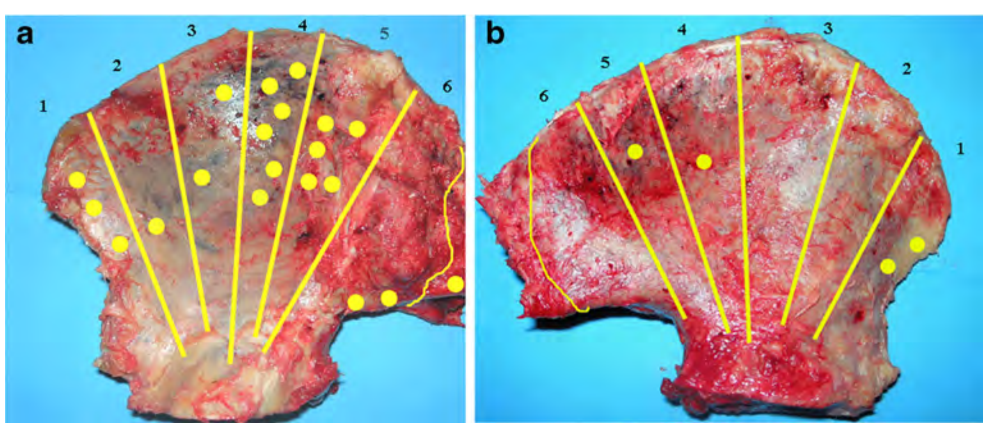

Fig. 6 Representation of observed iliac breaches. **a** Internal view of the ilium after dissection; each *yellow point* represents four breaches. **b** External view of the ilium after dissection; each *yellow point* represents four breaches

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the pelvic brim, the external iliac artery [2] is at greater risk of injury than is the vein, as no venous lesions were observed in any cadaver. Trocar insertion in sectors 2 and 3 is frequently performed with the patient in a supine position. If placed correctly, a large volume of bone marrow is accessible there, as the trocar can be introduced to a depth of 10 cm. In contrast to the shallow bone in the anterior sectors, the bone width in posterior sectors 5 through 6 allows trocars to be placed easily within the tables of the posterior iliac crest. However, in the most posterior sector, sector 6, the trocar may reach the sciatic nerve and the superior gluteal vessels if introduced to a depth >6 cm or at an incorrect angle.

In conclusion, when bone marrow aspiration is performed, a working knowledge of available iliac bone stock is important in establishing trocar placement in the iliac crest. Here we describe the human ilium in a clinically relevant context with reference to bone marrow aspiration from the iliac crest. Consideration of the patient's anatomy and positioning will influence the selection of sector insertion points so that trocars can be directed toward zones that are likely to contain the best available bone marrow stock. A predictable and rapid decrease in thickness of the ilium occurred at 3 or 4 cm under the iliac crest in sectors 4 and 5. The width of the ilium decreased to approximately 50 % of its maximum thickness. The resulting spongiousus bone iliac thickness decrease to less than the diameter of the trocar, which may explain why the trocar may lose contact with bone even in expert hands.

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