Morphological Classification of Trochlear Dysplasia Based On Three-Dimensional Models

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Research article

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Abstract

Background:

Trochlear dysplasia (TD) is a common risk factor for the development of patellofemoral instability (PI). Dejour's classification shows low agreement between conventional radiography and axial magnetic resonance imaging. The present study aimed to evaluate and categorize the true lateral view of three-dimensional (3D) femoral models in patients with TD.

Methods:

Computed tomography (CT) scans of 96 hip-knee-ankle joints (49 PI patients: 34 female, 15 male; mean age 19.1±6.7 years, range 12–41 years) during 2017–2019 were collected and analyzed. A senior orthopedic surgeon classified the true lateral views of femoral 3D models and raw CT images. The crossing-point site and lateral condyle/facet morphology (lateral condyle bump or supratrochlear spur) were the main criteria.

Results:

TD cases were classified into four types and their frequencies recorded: type 1 (7.3%) = crossing-point site in the proximal trochlear area and no lateral condyle bump or supratrochlear spur; type 2 (19.8%) = crossing-point site in the proximal trochlear area and presence of a lateral condyle bump or supratrochlear spur; type 3 (13.5%) = crossing-point site in the distal trochlear area and no lateral condyle bump or supratrochlear spur; type 4 (59.4%) = crossing-point site in the distal trochlear area and presence of lateral condyle bump or supratrochlear spur.

Conclusion:

The presentation of TD varies greatly among PI patients and can be categorized into four types. This new classification, based on true lateral views of 3D femoral models, may provide relatively reliable guidance when using trochleoplasty to treat TD.

Level of Evidence: II, development of diagnostic or monitoring criteria in consecutive patients.

Introduction

Trochlear dysplasia (TD) has been cited as a major predisposing factor for patellofemoral instability (PI), and its classification is used to select the appropriate surgical approach to treat it [1–7].In 1998, Dejour et al. suggested a classification for TD that is now mature and in widespread clinical application [8]. In all versions of the Dejour classification, however, true lateral conventional radiographs (TLCRs) of the knee are essential to the imaging [9–13].

Dejour et al. classified TD into four types based on TLCRs and CT images, as follows [9, 13].

- Type A: crossing sign (TLCR) + shallow trochlea (CT)
- Type B: crossing sign (TLCR) + supratrochlear spur (TLCR) + flat trochlea (CT)
- Type C: crossing sign (TLCR) + double contour (TLCR) + asymmetry of trochlear facets (TLCR)
- Type D: crossing sign (TLCR) + double contour (TLCR) + supratrochlear spur (TLCR) + asymmetry of trochlear facets (TLCR) + cliff pattern (CT)

Type A is defined as low-grade TD and types B, C, and D as high-grade TD [5]. It is noteworthy that, for types A and B, there is no mention of the symmetry or asymmetry of the sides of the trochlear facets. Hence, in 1994, Dejour defined type I as having two condylar outlines, with the outline of the trochlear floor (symmetrical) and the proximal area [10]. In 1998, Remy described TD as follows: TLCR type I (upper area of the two condyles–trochlea crossing = symmetrical); type II (upper area of the lateral condyle–trochlea crossing and lower area of the medial condyle–trochlea crossing = asymmetrical); type III (lower area of the two condyles–trochlea crossing, with no mention of its symmetry) [12]. Remy also mentioned two intermediate trochlear types: type A1 (trochlear groove line ends near the anterior border of the condyles, no crossing) and type B2 (only the medial condyle–trochlea crossing, with no lateral condyle–trochlea crossing). The definitions of types A1 and B2 did not include the relations of the two trochlear facets (symmetry vs. asymmetry) [12]. In addition, these TD classifications do not provide an alternative surgical suggestion for each type. The lack of consensus may be related to the definitions being based on rotated conventional radiographs. Sander et al. reported that minimal rotation aberrations of 5° would cause false-positive or false-negative radiographs [11].

Standard, strictly TLCRs were defined as having perfect superimposition of the condyles posteriorly [10, 14], although strictly TLCRs are difficult to obtain. External rotation causes the crossing point to be in the lower position of the femoral condyle, and internal rotation can change the trochlear shape [11]. The double contour—a marked characteristic of Dejour's classification of types C and D—does not represent the features of the trochlear facets and has been found in patients who were exposed to multiple doses of unnecessary radiation.

Little research has focused on selecting a surgical method according to the type of TD. This study aimed to evaluate the true lateral view of three-dimensional (3D) femoral models in patients with TD using engineering software based on CT data. We hypothesize that classification based on 3D models may provide clinical surgeons and radiologists with the option of diagnosing trochlear dysplasia. Our results may thus provide relatively reliable guidance for trochleoplasty to treat TD.

Methods

All patients provided written informed consent, and the study was approved by the ethics committee of our hospital. Hip-knee-ankle CT (SOMATOM Sensation 16; Siemens Medical Solutions, Erlangen, Germany) was used for retrospective analysis of 96 knees in 49 PI patients (ages 12–41 years; 34 female, 15 male) who underwent imaging at one institution during 2017–2019. Among the 49 patients, the PI was bilateral in 47 and unilateral in 2. All patients had PI (objective PI, potential PI, or painful patellar syndrome) [9], and all were diagnosed by one senior orthopedic surgeon. None had a history of knee surgery or patellofemoral arthritis. Table 1 shows data on the presence of femoral anteversion (FA) and external tibial torsion (ETT) [15]; the sulcus angle (SA) and patellar tilt angle (PTA); and the mediolateral width of the epicondyles (ML width), lateral anterior condyle height (LAC height), trochlear groove anterior height (TGA height), and medial anterior condyle height (MAC height) [16].

Table 1 Patient Demographics (n = 96 Sides, 49 Patients)

Age, y, mean±SD	19.1±6.7
Gender, male:female, n	15:34
Femoral anteversion, °, mean±SD	24.10±10.37
External tibial torsion, °, mean±SD	31.72±8.75
Sulcus angle, °, mean±SD	154.51±5.76
Patellar tilt angle, °, mean±SD	26.87±8.32
Medial-lateral width of epicondyle, mm, mean±SD	75.04±5.28
Lateral anterior condyle height, mm, mean±SD	38.42±2.07
Trochlear groove anterior height, mm, mean±SD	33.31±2.82
Medial anterior condyle height, mm, mean±SD	34.24±2.81

The scanning procedure was performed to acquire 1-mm CT slices for the hip-knee-ankle joints (resolution 512 × 512 pixels) [17]. All measurements were obtained using RadiAnt-DICOM software 5.0.1 (Medixant Ltd., Poznan, Poland).

Shital et al. measured the condylar height, trochlear height, and trochlear bump of 175 knees with trochlear dysplasia in nine age groups [18]. They found that all linear trochlear measurements increased with age, whereas the overall shape of TD did not. After age 11 years, there were no significant changes in the sulcus angle [18]. The FA was measured according to the axis of the femoral neck and the posterior bicondylar line. External tibial torsion is the angle formed by the posterior axis of orientation of the tibial epiphysis and the bi-malleolar axis, as described by Galland [15]. The mediolateral width is the maximum width of the surgical trans-epicondylar axis (sTEA) [16, 19]. LAC height was defined as the distance between the sTEA and the most anterior point of the lateral condyle. MAC height was defined as the distance between the sTEA and the most anterior point of the medial condyle. TGA height was defined as the distance between the sTEA and the lowest point of the trochlear groove (Fig. 1). To minimize measurement errors, all measurements were made by two physicians (Observer 1, Observer 2). After an interval of 10 days, Observer 1 again measured the same parameters of the 96 sets of the three joints. Inter-observer and intra-observer reliability was determined by evaluating the intra-class correlation coefficient values of the investigated parameters (Table 2) [1, 2, 20].

Table 2 The intra-observer and inter-observer correlation coefficients of measurements with 95% confidence intervals

Measurement	Intra-observer ICC	95%CI for ICC		Inter-observer ICC	95%CI for ICC	
		Lower	Upper		Lower	Upper
FA	0.993	0.990	0.995	0.961	0.942	0.974
ETT	0.972	0.958	0.981	0.945	0.919	0.963
SA	0.977	0.963	0.989	0.964	0.941	0.981
PTA	0.966	0.944	0.970	0.954	0.938	0.971
ML width	0.969	0.954	0.979	0.965	0.948	0.976
LAC height	0.916	0.877	0.943	0.915	0.874	0.942
TGA height	0.977	0.966	0.985	0.952	0.929	0.968
MAC height	0.983	0.974	0.989	0.952	0.929	0.967

CI: confidence interval; FA: Femoral anteversion; ETT: External tibial torsion;

SA: Sulcus angle; PTA: Patellar tilt angle;

ML width: Medial-lateral width of epicondyle;

LAC height: Lateral anterior condyle height;

TGA height: Trochlear groove anterior height;

MAC height: Medial anterior condyle height.

3D knee models

To analyze the morphology of the true lateral view of the femurs, CT scans were introduced into a 3D image processing software system (Mimics 19.0; Materialise, Haasrode, Belgium) to create smooth 3D surface models of the knee bones. These 3D surface models were subsequently loaded into engineering software (Rhino 6; Robert McNeel & Associates, Seattle, WA, USA). All samples with perfect superimposition of the posterior condyles were obtained and then analyzed. This evaluation was repeated three times by a senior surgeon.

Statistical analysis

The measurements were analyzed using SPSS 21.0 software (IBM Corp., Armonk, NY, USA). All measurements are expressed as means ± standard deviations. The inter-observer and intra-observer reliability was determined by evaluating the intra-class correlation coefficient values of the investigated parameters.

Results

The general information of the 49 patients is shown in Table 1. The mean age at CT was 19.1 ± 6.7 (range 12–41) years. The measurements included the rotational deformity of the femur (FA 24.10° ± 10.37°, range 0.90°–49.80°) and the tibia (ETT 31.72° ± 8.75°, range 6.60°–49.50°); anterior femoral malformation data (SA 154.51° ± 5.76°, range 146.4°–175.5°; LAC height 38.42 ± 2.07 mm, range 34.10–44.80 mm; TGA height 33.31 ± 2.82 mm, range 27.00–40.20 mm; and MAC height 34.24 ± 2.81 mm, range 28.30–40.50 mm). In addition, the mean patellar tilt angle was 26.87° ± 8.32° (range 7.6°–58.4°), and the mean mediolateral width of the epicodyles was 75.04 ± 5.28 mm (range 66.30–88.90 mm).

Altogether, 96 samples of the distal femur were evaluated in a descriptive manner using images (translucent true lateral view) produced by engineering software. The proximal and distal areas of the trochlea were distinguished in Fig. 2 (line B). Figure 3 depicts the specific characteristics and proportion of each type of trochlear dysplasia. The position of the crossing point (where the trochlear groove line crosses the medial condyle/lateral condyle) and the lateral condyle/facet morphology (lateral condyle bump or supratrochlear spur) were the main classification criteria.

- Type 1 (7.3%): crossing point is in the proximal area of the trochlea + no lateral condyle bump or supratrochlear spur
- Type 2 (19.8%): crossing point is in the proximal area of the trochlea + the presence of a lateral condyle bump or supratrochlear spur
- Type 3 (13.5%): crossing point is in the distal area of the trochlea + no lateral condyle bump or supratrochlear spur
- Type 4 (59.4%): crossing point is in the distal area of the trochlea + the presence of a lateral condyle bump or supratrochlear spur

The incidence of a double contour sign for all cases was 62.5%, although 56.7% (34/60) of the double contour signs disappear after rotation of 5°–10°.

Discussion

The most important finding of this study is that the classification described—which includes new, more accurate criteria for assessing TD—may provide relatively reliable guidance for trochleoplasty performed to treat TD. We obtained the most accurate true lateral-view photographs using engineering software. Even minimal rotation aberrations of 5° during conventional radiography causes false-positive or false-negative results [11]. This novel classification may reduce the false-positive and false-negative rates, especially when it is difficult to obtain TLCRs.

Previous studies have found that various selected levels for magnetic resonance imaging (MRI) reflect different TD types [5, 21]. The Dejour classification of TD shows low agreement between conventional radiography and axial MRI [5, 14]. Sabine et al. showed that intra-observer and inter-observer agreement is only fair with Dejour’s four-type classification (24–78%) [14]. Gian et al. showed that plain axial conventional radiography does not represent the true bony trochlear morphology and may result in inappropriate clinical management [21]. Philippe et al. believed that axial MRI analysis of the entire distal femur can obtain more accurate clinical classification [5]. Because of the influence of selected levels of CT/MRI [5, 22], our study mainly focused on the true lateral view of the TD. Our research aimed to reevaluate the true lateral view of femoral models in patients with TD using 3D software. The false-positive and false-negative rates can be minimized by using the most accurate true lateral view imaging.

Trochleoplasty is designed to change the morphology of the trochlea to stabilize an unstable patella [9, 23, 24]. Patellofemoral congruence may be promoted by lateral-facet elevating trochleoplasty or by sulcus-deepening trochleoplasty [9]. Albee’s lateral-facet elevating trochleoplasty has been nearly abandoned because of the great pressure it applies on the lateral patellofemoral area and the subsequent patellofemoral osteoarthritis [25]. Sulcus-deepening trochleoplasty [26], first described by Masse in 1978, has been the basis for several techniques and modified techniques [23, 24, 27–30]. The sulcus-deepening trochleoplasty is designed to eliminate the prominence of the femoral trochlea and re-shape a groove of suitable depth [9, 23].

Among the four types of TD in our 96 cases, type 1 was found in 7.3%, type 2 in 19.8%, type 3 in 13.5%, and type 4 in 59.4%. Type 1 TD deserves little consideration of trochleoplasty. Other surgical procedures (e.g., medial patellofemoral ligament reconstruction, tibial tuberosity medialization osteotomy) should be considered for the management of patellofemoral instability. Type 2 TD is characterized by a bump of the lateral condyle or a supratrochlear spur that often causes great pressure on the lateral patellofemoral joint. Arthroscopic lateral patelloplasty [31] or arthroscopic deepening trochleoplasty [27] may be considered if the patient has lateral patellar compression syndrome. These techniques can reduce pressure on the articular surface of the lateral patellofemoral area, thereby relieving symptoms. We suggest that both type 3 and type 4 require sulcus-deepening trochleoplasty. The crossing point located in the distal area of the trochlea means that the trochlea is fairly shallow over a long distance. Longo et al. compared the clinical outcomes of these patients treated with three trochleoplasty procedures [24]. Dejour’s “V-shaped” sulcus deepening trochleoplasty, Bereiter’s “U-shaped” deepening trochleoplasty, and Goutallier’s “recession trochleoplasty” are associated with significantly improved stability and function and a low rate of osteoarthritis and pain. However, the sulcus-deepening trochleoplasty is never performed alone as other procedures must be combined with it to correct patellofemoral instability [23].

The “crossing sign” of Dejour’s classification is a distinguishing feature of TD [13]. Dejour et al. noted that the crossing sign is different in three types of TD [10].

- Type I: The crossing of the two condylar outlines with the trochlear groove line is symmetrical and proximal.

- Type II: The two condyles are asymmetrical, and the trochlear groove line crosses first the medial condyle, at a variable level, and then the lateral condyle.
- Type III: The crossing of the two condylar outlines with the trochlear groove line is symmetrical and situated distally.

It should be noted that we did not observe that the trochlear groove line crossed with the medial condyle first and then crossed the lateral condyle. We only found two types of crossing sign. The most common was that the trochlear groove line crossed the medial condyle but did not cross the lateral condyle (68.9%). Another form was defined as the trochlear groove line crossing the two condylar outlines at the same point (31.1%). We believe that the site of the crossing point is more important than the form of the crossing point.

Dejour et al. described a cortical beak (later called the supratrochlear spur), which is the superolateral trochlear facet (type III) [10]. Later, in 2006, Dejour et al. described type D, which had a convex lateral facet [13]. We think that the two qualitative criteria are controlled by the same mechanism but in different trochlear positions (Fig. 4). There is no consensus on whether the lateral condyle bump should be removed surgically. In our opinion, trochleoplasty (perhaps in concert with other procedures) is required if the enlarged lateral facet or the supratrochlear spur affects patellar tracking or increases pressure on the patellofemoral joint. When the patella is taken through its whole range of motion, there must be no patellar impingement during the process [9].

According to Dejour's classification, the double contour is a marked characteristic of types C and D [9, 13]. The reason we do not use the double contour as a reference for classification is that the double contour does not represent features of the trochlear facets. As far as we know, the double contour is not caused by projection of the medial facet of the trochlea. It is caused by the extended anterior cortex of the bilateral trochlea—there is no cartilage. Although the incidence of the double-contour sign in all cases was 62.5%, rotation of 5°–10° caused the double contour sign to disappear in 56.7% (34/60) of cases. Therefore, the rotation that occurs while obtaining lateral conventional radiographs may lead to misclassification.

Limitations

This study has several limitations. First, although four types of TD were found in this study, there may be other types. A larger sample may be needed. Although this classification may not be perfect, it may indicate that the appearance of TD is diverse. Second, the 1-mm CT slices may have resulted in the loss of some information. Perhaps 0.625-mm CT slices would have been a better choice. Third, these images generated by the engineering software may not be exactly the same as the true lateral view of conventional radiographs. Nevertheless, automated classification might be a good option in the future [7].

Conclusion

The presentation of TD varies greatly among PI patients and can be categorized into four types. This new classification, based on true lateral views of 3D femoral models, may provide relatively reliable guidance when using trochleoplasty to treat TD.

Abbreviations

TD: Trochlear dysplasia; PI: Patellofemoral instability; 3D: Three-dimensional; CT: Computed tomography; TLCR: True lateral conventional radiograph; FA: Femoral anteversion; ETT: External tibial torsion; SA: Sulcus angle; PTA: Patellar tilt angle; ML width: Mediolateral width of the epicondyles; LAC height: Lateral anterior condyle height; TGA height: Trochlear groove anterior height; MAC height: Medial anterior condyle height; sTEA: surgical Trans-epicondylar axis; MRI: Magnetic resonance imaging

Declarations

Authors' contributions

F (Wang) and JF (L) conceived the idea for the study; JF (L) designed the study. JF (L) and G (Ji) collected the relevant data. JF (L) prepared the figures and tables. YR (Wang) performed the statistical analyses. All the authors interpreted the data and contributed to the preparation of the manuscript. The authors have read and approved the manuscript.

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Availability of data and materials

The data and materials contributing to this article may be made available upon request by sending an e-mail to the corresponding author.

Ethics approval and consent to participate

This study was approved by the ethics committee of the Third Hospital of Hebei Medical University. Informed consent was obtained from all the participants.

Competing interests

The authors declare that they have no competing interests.

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References

1. Cao P, Niu Y, Liu C, Wang X, Duan G, Mu Q, Luo X, Wang F. Ratio of the tibial tuberosity-trochlear groove distance to the tibial maximal mediolateral axis: A more reliable and standardized way to measure the tibial tuberosity-trochlear groove distance. Knee. 2018;25(1):59–65. https://doi.org/10.1016/j.knee.2017.10.001.
2. Liu X, Ji G, Wang X, Kang H, Wang F. CT-based morphological analysis of the posterior femoral condyle in patients with trochlear dysplasia. Knee. 2017;24(2):231–6. https://doi.org/10.1016/j.knee.2016.12.008.
3. Nelitz M, Lippacher S, Reichel H, Dornacher D. Evaluation of trochlear dysplasia using MRI: correlation between the classification system of Dejour and objective parameters of trochlear dysplasia. Knee Surg Sports Traumatol Arthrosc. 2014;22(1):120–7. https://doi.org/10.1007/s00167-012-2321-y.
4. Paiva M, Blønd L, Hölmich P, Steensen RN, Diederichs G, Feller JA, Barfod KW. Quality assessment of radiological measurements of trochlear dysplasia; a literature review. Knee Surg Sports Traumatol Arthrosc. 2018;26(3):746–55. https://doi.org/10.1007/s00167-017-4520-z.
5. Tscholl PM, Wanivenhaus F, Fucentese SF. Conventional Radiographs and Magnetic Resonance Imaging for the Analysis of Trochlear Dysplasia: The Influence of Selected Levels on Magnetic Resonance Imaging. Am J Sports Med. 2017;45(5):1059–65. https://doi.org/10.1177/0363546516685054.
6. Van Haver A, De Roo K, De Beule M, Labey L, De Baets P, Dejour D, Claessens T, Verdonk P. The effect of trochlear dysplasia on patellofemoral biomechanics: a cadaveric study with simulated trochlear deformities. Am J Sports Med. 2015;43(6):1354–61. https://doi.org/10.1177/0363546515572143.
7. Van Haver A, Mahieu P, Claessens T, Li H, Pattyn C, Verdonk P, Audenaert EA. A statistical shape model of trochlear dysplasia of the knee. Knee. 2014;21(2):518–23. https://doi.org/10.1016/j.knee.2013.11.016.
8. Dejour D, Reynaud P, Lecoultre B. Douleurs et instabilite´ rotulienne: essai de classification. Med Hyg. 1998;56:1466–71.
9. Dejour D, Le Coultre B. Osteotomies in patello-femoral instabilities. Sports Med Arthrosc Rev. 2007;15(1):39–46. https://doi.org/10.1097/JSA.0b013e31803035ae.
10. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc. 1994;2(1):19–26. https://doi.org/10.1007/BF01552649. PMID: 7584171.

11. Koëter S, Bongers EM, de Rooij J, van Kampen A. Minimal rotation aberrations cause radiographic misdiagnosis of trochlear dysplasia. Knee Surg Sports Traumatol Arthrosc. 2006;14(8):713–7. https://doi.org/10.1007/s00167-005-0031-4.
12. Remy F, Besson A, Migaud H, Cotten A, Gougeon F, Duquennoy A. Reproducibility of the radiographic analysis of dysplasia of the femoral trochlea. Intra- and interobserver analysis of 68 knees. Rev Chir Orthop Reparatrice Appar Mot. 1998;84(8):728–33.
13. Tecklenburg K, Dejour D, Hoser C, Fink C. Bony and cartilaginous anatomy of the patellofemoral joint. Knee Surg Sports Traumatol Arthrosc. 2006;14(3):235–40. https://doi.org/10.1007/s00167-005-0683-0.
14. Lippacher S, Dejour D, Elsharkawi M, Dornacher D, Ring C, Dreyhaupt J, Reichel H, Nelitz M. Observer agreement on the Dejour trochlear dysplasia classification: a comparison of true lateral radiographs and axial magnetic resonance images. Am J Sports Med. 2012;40(4):837–43. https://doi.org/10.1177/0363546511433028.
15. Galland O, Walch G, Dejour H, Carret JP. An anatomical and radiological study of the femoropatellar articulation. Surg Radiol Anat. 1990;12(2):119–25. https://doi.org/10.1007/BF01623337.
16. Roger J, Lustig S, Cerciello S, Bruno CF, Neyret P, Servien E. Short lateral posterior condyle is associated with trochlea dysplasia and patellar dislocation. Knee Surg Sports Traumatol Arthrosc. 2019;27(3):731–9. https://doi.org/10.1007/s00167-018-5023-2.
17. Chen S, Du Z, Yan M, Yue B, Wang Y. Morphological classification of the femoral trochlear groove based on a quantitative measurement of computed tomographic models. Knee Surg Sports Traumatol Arthrosc. 2017;25(10):3163–70. https://doi.org/10.1007/s00167-016-4236-5.
18. Parikh SN, Rajdev N, Sun Q. The Growth of Trochlear Dysplasia During Adolescence. J Pediatr Orthop. 2018;38(6):e318–24. https://doi.org/10.1097/BPO.0000000000001168.
19. Kobayashi H, Akamatsu Y, Kumagai K, Kusayama Y, Ishigatsubo R, Muramatsu S, Saito T. The surgical epicondylar axis is a consistent reference of the distal femur in the coronal and axial planes. Knee Surg Sports Traumatol Arthrosc. 2014;22(12):2947–53. https://doi.org/10.1007/s00167-014-2867-y.
20. Shih YF, Bull AM, Amis AA. The cartilaginous and osseous geometry of the femoral trochlear groove. Knee Surg Sports Traumatol Arthrosc. 2004;12(4):300–6. https://doi.org/10.1007/s00167-003-0414-3.
21. Salzmann GM, Weber TS, Spang JT, Imhoff AB, Schöttle PB. Comparison of native axial radiographs with axial MR imaging for determination of the trochlear morphology in patients with trochlear dysplasia. Arch Orthop Trauma Surg. 2010;130(3):335–40. https://doi.org/10.1007/s00402-009-0912-y.
22. Pfirrmann CW, Zanetti M, Romero J, Hodler J. Femoral trochlear dysplasia: MR findings. Radiology. 2000;216(3):858–64. https://doi.org/10.1148/radiology.216.3.r00se38858.
23. Ren B, Zhang X, Zhang L, Zhang M, Liu Y, Tian B, Zhang B, Zheng J. Isolated trochleoplasty for recurrent patellar dislocation has lower outcome and higher residual instability compared with

combined MPFL and trochleoplasty: a systematic review. Arch Orthop Trauma Surg. 2019;139(11):1617–24. https://doi.org/10.1007/s00402-019-03244-1.

24. Longo UG, Vincenzo C, Mannering N, Ciuffreda M, Salvatore G, Berton A, Denaro V. Trochleoplasty techniques provide good clinical results in patients with trochlear dysplasia. Knee Surg Sports Traumatol Arthrosc. 2018;26(9):2640–58. https://doi.org/10.1007/s00167-017-4584-9.
25. Albee F. Bone graft wedge in the treatment of habitual dislocation of the patella. Med Record. 1915;88:257–9.
26. Masse Y. Trochleoplasty. Restoration of the intercondylar groove in subluxations and dislocations of the patella. Rev Chir Orthop Reparatrice Appar Mot. 1978;64(1):3–17.
27. Blønd L, Haugegaard M. Combined arthroscopic deepening trochleoplasty and reconstruction of the medial patellofemoral ligament for patients with recurrent patella dislocation and trochlear dysplasia. Knee Surg Sports Traumatol Arthrosc. 2014;22(10):2484–90. https://doi.org/10.1007/s00167-013-2422-2.
28. Camathias C, Studer K, Kiapour A, Rutz E, Vavken P. Trochleoplasty as a Solitary Treatment for Recurrent Patellar Dislocation Results in Good Clinical Outcome in Adolescents. Am J Sports Med. 2016;44(11):2855–63. https://doi.org/10.1177/0363546516652894.
29. Donell ST, Joseph G, Hing CB, Marshall TJ. Modified Dejour trochleoplasty for severe dysplasia: operative technique and early clinical results. Knee. 2006;13(4):266–73. https://doi.org/10.1016/j.knee.2006.01.004.
30. Fucentese SF, Zingg PO, Schmitt J, Pfirrmann CW, Meyer DC, Koch PP. Classification of trochlear dysplasia as predictor of clinical outcome after trochleoplasty. Knee Surg Sports Traumatol Arthrosc. 2011;19(10):1655–61. https://doi.org/10.1007/s00167-011-1410-7.
31. Wu T, Tang S, Wang F. Treatment for lateral patellar impingement syndrome with arthroscopic lateral patelloplasty: a bidirectional cohort study. J Orthop Surg Res. 2017;12(1):173. https://doi.org/10.1186/s13018-017-0676-y.

Figures

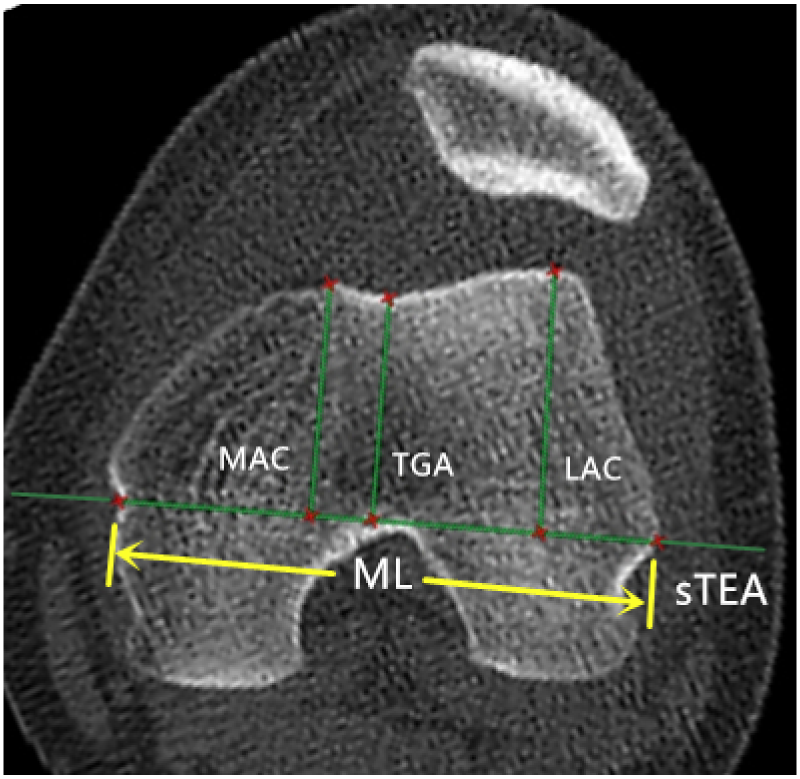

Figure 1

Representation of the ML width, LAC height, TGA height and MAC height measurements. The ML width (ML) is the maximum width of sTEA. LAC height (LAC) was defined as the distance between sTEA and most anterior point of lateral condyle. TGA height (TGA) was defined as the distance between sTEA and the lowest point of trochlear groove. MAC height (MAC) was defined as the distance between sTEA and most anterior point of medial condyle.

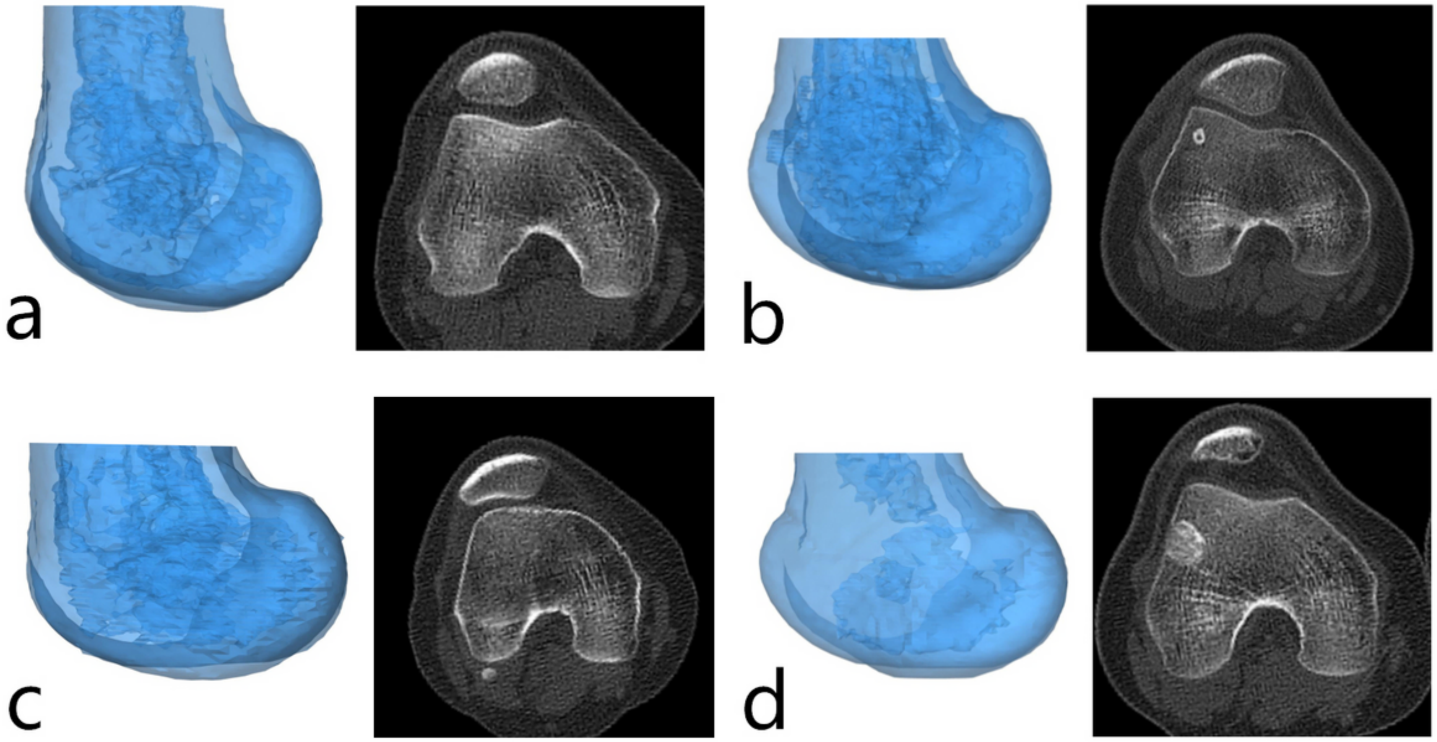

Figure 2

True lateral view representation. Line A is the axis of the femoral anatomy. Line B passes through the most proximal point of the posterior condyles and is perpendicular to line A. Point C (red dot) is the crossing point of the trochlear groove line and two condylar outlines. Line B is the boundary between the proximal and distal areas

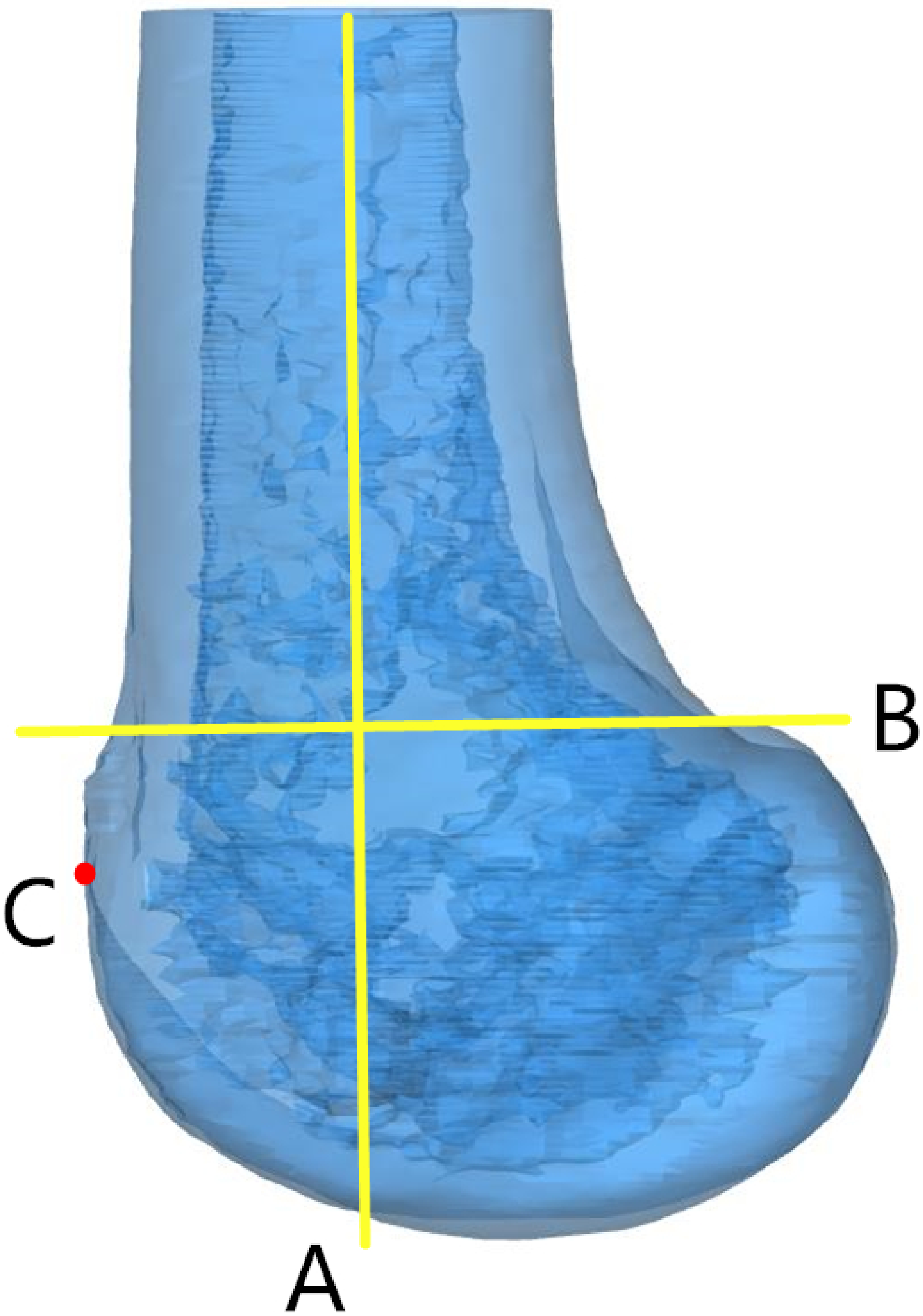

Figure 3

Four types of trochlear dysplasia, shown in three-dimensional models and computed tomographic images 3a: Type 1 (7.3%): crossing point is in the proximal area of the trochlea + no lateral condyle bump or supratrochlear spur 3b: Type 2 (19.8%): crossing point is in the proximal area of the trochlea + the presence of a lateral condyle bump or supratrochlear spur 3c: Type 3 (13.5%): crossing point is in the distal area of the trochlea + no lateral condyle bump or supratrochlear spur 3d: Type 4 (59.4%): crossing point is in the distal area of the trochlea + the presence of a lateral condyle bump or supratrochlear spur

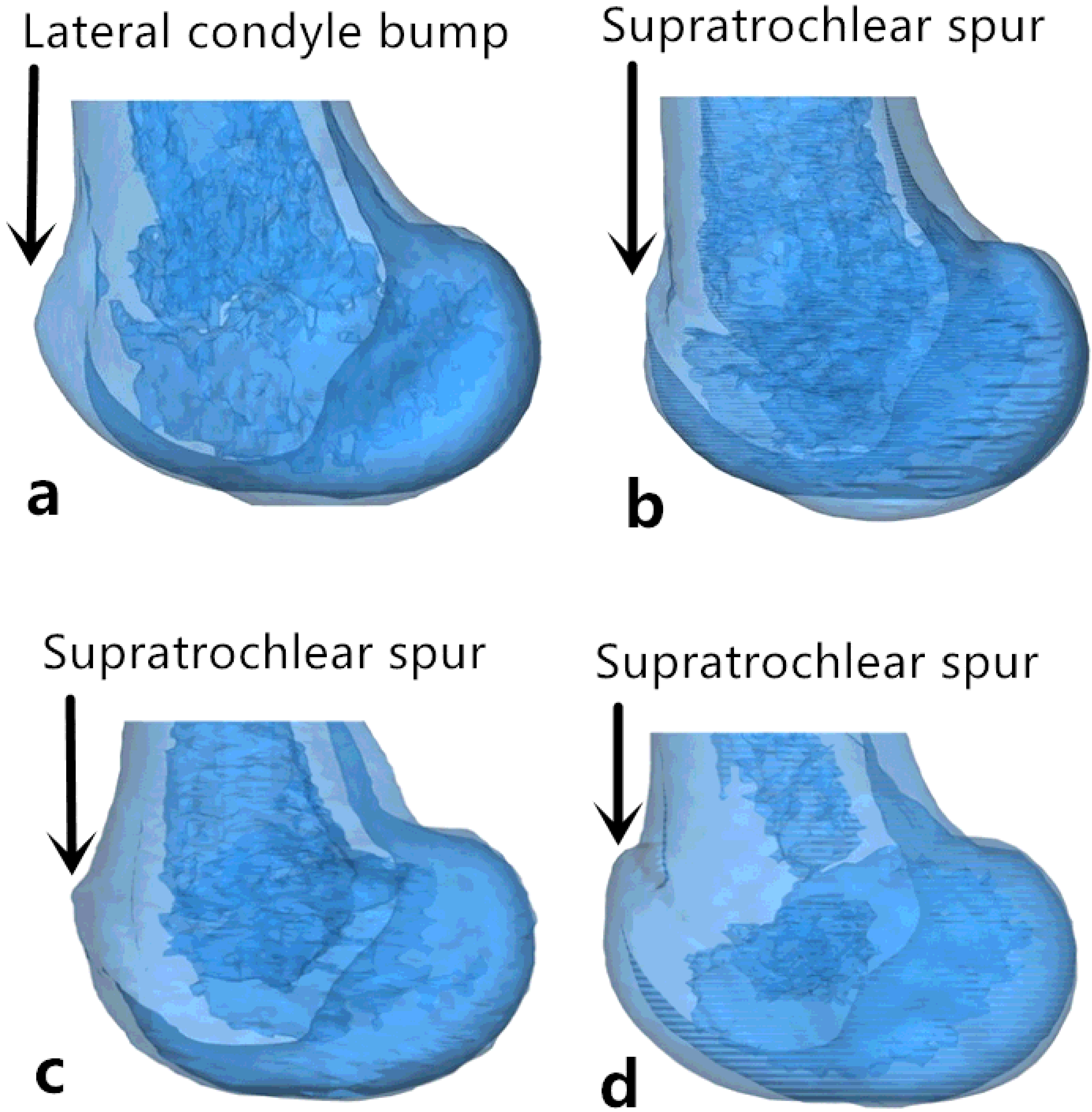

Figure 4

Four cases of type 4 trochlear dysplasia in true lateral three-dimensional models 4a: a prominence/bump of lateral condyle/facet (black arrow); 4b: a small supratrochlear spur (black arrow); 4c: a large supratrochlear spur (black arrow); 4d: a ‘cliff’ supratrochlear spur (black arrow).