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Diagnostic performance of modern computed tomography in cruciate ligament injury detection: A comprehensive study

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ABSTRACT

Background: This study aimed to evaluate the clinical utility of modern single and dual-energy computed tomography (CT) for assessing the integrity of the cruciate ligaments in patients that sustained acute trauma.
Methods: Patients who underwent single- or dual-energy CT followed by 3 Tesla magnetic resonance imaging (MRI) or knee joint arthroscopy between 01/2016 and 12/2022 were included in this retrospective, monocentric study. Three radiologists specialized in musculoskeletal imaging independently evaluated all CT images for the presence of injury to the cruciate ligaments. An MRI consensus reading of two experienced readers and arthroscopy provided the reference standard. Diagnostic accuracy parameters and area under the receiver operator characteristic curve (AUC) were the primary metrics for diagnostic performance.
Results: CT images of 204 patients (median age, 49 years; IQR 36 – 64; 113 males) were evaluated. Dual-energy CT yielded significantly higher diagnostic accuracy and AUC for the detection of injury to the anterior (94% [240/255] vs 75% [266/357] and 0.89 vs 0.66) and posterior cruciate ligaments (95% [243/255] vs 87% [311/357] and 0.90 vs 0.61) compared to single-energy CT (all parameters, $p < .005$). Diagnostic confidence and image quality were significantly higher in dual-energy CT compared to single-energy CT (all parameters, $p < .005$).
Conclusions: Modern dual-energy CT is readily available and can serve as a screening tool for detecting or excluding cruciate ligament injuries in patients with acute trauma. Accurate diagnosis of cruciate ligament injuries is crucial to prevent adverse outcomes, including delayed treatment, chronic instability, or long-term functional limitations.

1. Introduction

The cruciate ligaments are vital for stabilizing the knee joint by preventing excessive movements, such as translation, rotation, and lateral stress [1]. While injuries to the posterior cruciate ligament (PCL) are uncommon, injuries to the anterior cruciate ligament (ACL) are more prevalent, with reported incidences around 1% in the general population and even higher rates among athletes [2–4].

The management of cruciate ligament injuries involves both surgical and nonoperative approaches. Cruciate ligament injuries compromise the stability of the knee and increase the stress on other ligamentous structures, menisci, and cartilage. Consequently, surgical reconstruction is generally recommended for younger patients and athletes to preserve their ability to participate in high levels of physical activity. In this context, early reconstruction of the ACL has been shown to reduce subsequent damage to other structures of the knee and improve long-

Abbreviations: ACL, Anterior cruciate Ligament; AUC, Are under the curve; DECT, Dual-energy computed tomography; FOV, Field of view; SECT, Multidetector computed tomography; NPV, Negative predictive value; PCL, Posterior cruciate ligament; PPV, Positive predictive value; ROC, Receiver operator characteristic; SD, Standard deviation.

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term knee motion compared to delayed reconstruction [5–8]. Moreover, early ACL reconstruction decreases the duration before patients can resume physical activity, reducing the socioeconomic burden associated with the injury [9].

Magnetic resonance imaging (MRI) continues to be recognized as the reference standard for imaging the cruciate ligaments [10]. However, its availability is often limited during on-call hours, potentially delaying diagnosis, treatment, and recovery. CT scans, in contrast, are readily accessible for evaluating musculoskeletal trauma and are typically employed to depict complex knee injuries or when conventional radiographs are inconclusive. However, studies investigating the diagnostic accuracy of early CT devices demonstrated a limited capability to detect injuries to the cruciate ligaments [11].

In recent years, advancements in CT technology and the introduction of dual-energy CT have significantly improved spatial resolution and the ability to visualize soft tissues. This has expanded the diagnostic capabilities of CT to detect musculoskeletal pathologies that were previously only visible on MRI [12–16]. In line with these developments, some small pilot studies have suggested an improved diagnostic value of early dual-energy CT in assessing the integrity of the ACL. However, more extensive studies involving more patients are still lacking [17,18]. Therefore, this study aimed to evaluate the clinical utility of modern single and dual-energy CT in assessing the integrity of the cruciate ligaments in patients that have sustained acute trauma.

2. Materials and methods

The institutional review board approved this retrospective study and waived the requirement to obtain written informed consent.

2.1. Patient selection

For this study, 246 consecutive patients aged 18 years and older with acute knee injuries (within three days of trauma) who had undergone non-contrast CT between January 2016 and December 2022 were considered for study inclusion. These patients subsequently underwent MRI and/or arthroscopic inspection of the knee joint within 14 days. Exclusion criteria were inadequate imaging quality due to metallic implants and chronic inflammatory conditions of the knee joint.

2.2. CT protocol

CT images were acquired using either a conventional single-energy CT (SOMATOM Definition AS Sliding; Siemens Healthineers, Forchheim, Germany) or a third-generation dual-source CT system in dual-energy mode (SOMATOM Force; Siemens Healthineers, Forchheim, Germany). In dual-energy CT, the two x-ray tubes operated at different kilovoltage settings (tube A: 90 kVp, 180 mAs; tube B: Sn150 kVp [0.64 mm tin filter], 180 mAs). No contrast agent was administered during the examinations. Image series (axial, coronal, and sagittal: section thickness 1 mm, increment 0.75 mm) were reconstructed with dedicated dual-energy bone (Br69f) and soft-tissue kernels (Br40). The image series were automatically transferred to the picture archiving and communication system (PACS; GE Healthcare, Munich, Germany).

2.3. MRI protocol

MRI was conducted using a 3 Tesla system (PrismaFit, Siemens Healthineers, Forchheim, Germany). The examinations included non-contrast proton density-weighted sequences with fat suppression in the transversal, sagittal, and coronal planes (slice thickness: 3 mm), T2-weighted turbo spin-echo sequences with fat suppression in the coronal plane, and T1-weighted turbo spin-echo sequences without fat suppression in the coronal plane. The pulse sequence parameters (echo time, repetition time, flip angle), field of view (FOV), and acquisition matrix were adjusted for each examination to optimize image quality and diagnostic information.

2.4. Image analysis

An independent reference standard for the integrity of the ACL and PCL was provided by two board-certified radiologists (K.E. and T.V.) with 17 and 35 years of experience in musculoskeletal imaging who independently reviewed all MRI series. In disagreement (n = 4), a third board-certified radiologist (T.G.) with 11 years in musculoskeletal imaging was consulted to reach a consensus. The evaluation of the ligaments was performed separately, with a grading scale of 1 indicating absence of a rupture, 2 indicating total rupture, and 3 indicating avulsion fractures.

Three radiologists independently and consecutively reviewed all CT images. The panel of readers consisted of two board-certified radiologists (C.B. and I.Y.) and one radiologist in training (S.M.) with 4 to 8 years of experience in musculoskeletal imaging. All readers were blinded to clinical data, imaging results, and follow-up examinations. The protocol for assessing the cruciate ligaments included grayscale images in axial, coronal, and sagittal planes; the preset window settings could be freely modified. Readers reviewed both protocols for injury to the ACL and PCL (1 = rupture absent, 2 = total rupture, 3 = avulsion fracture). Furthermore, readers rated their overall diagnostic confidence in the assessment of cruciate ligament injury as well as the image quality (ranging from 1 = poor to 5 = excellent) for each imaging protocol and patient. After 8 weeks, cases were shuffled, and readouts were repeated in the subgroup of patients without total rupture of the cruciate ligaments to investigate for partial ruptures.

2.5. Arthroscopy

Arthroscopy procedures were performed by two board-certified orthopaedic surgeons (V.H. and K.Z.) with 8 and 17 years of experience, respectively, in this field. In cases where MRI and arthroscopy data were available, arthroscopy findings were considered the reference standard for comparison and validation.

2.6. Statistical analysis

Statistical analysis was performed with MedCalc (Windows Version 20.1, MedCalc) and R (Windows Version 4.2.2, The R Foundation). To test for normal distribution, the Kolmogorov–Smirnov test was used. Continuous variables are presented as median with interquartile range (IQR). Differences in baseline characteristics were assessed using Mann-Whitney-tests or Chi-Squared-tests. Imaging findings were analyzed individually for ligamentous injury and avulsion fractures, as mentioned above. Furthermore, analysis was performed after lesions were dichotomized (0 = injury absent, 1 = injury present) in an intention-to-treat approach. Findings were compiled in cross-tables, and diagnostic accuracy parameters (area under the curve [AUC], sensitivity, specificity, positive predictive value [PPV], and negative predictive value [NPV]) for the detection of injury to the cruciate ligaments were calculated. Receiver operator characteristic curve comparison was used to determine the differences in diagnostic performance between single-energy CT and dual-energy CT. Interreader agreement was evaluated using the intraclass correlation coefficient (ICC) in a 2-way mixed-effects model for absolute agreement. Logistic regression analysis was performed to evaluate the relationship between image quality and correct readings. Statistical significance was considered at $p < .05$.

3. Results

Of 246 patients considered for study inclusion, 33 patients were excluded due to inadequate imaging quality caused by metallic implant artifacts, and nine patients were excluded due to chronic inflammatory conditions of the knee. Therefore, a total of 204 patients who had undergone non-contrast CT of the knee joint followed by MRI (n = 192) or arthroscopic inspection (n = 40) were finally included in this study (113 male and 91 female, median age, 49 years, IQR 36–68 years; Fig. 1). The reference standard revealed an injury to the ACL in 28 patients (14%; complete tear = 18; avulsion fracture = 10) and to the PCL in 14 patients (7%; complete tear = 2; avulsion fracture = 12). No significant difference was observed between the demographics of patients with injury to the cruciate ligaments and patients without injury. Patient characteristics are summarized in Table 1. The mean interval between dual-energy CT and MRI or arthroscopic inspection was four days (range, 0 – 9 days).

3.1. Diagnostic accuracy of ACL injury

Dual-energy CT showed higher overall sensitivity (80% [41/51]) vs 55% [18/33]), specificity (98% [199/204] vs 77% [248/324]), PPV (95% [199/209] vs 94% [248/263]), NPV (89% [41/46] vs 19% [18/94]), accuracy (94% [240/255] vs 75% [266/357]) and AUC (0.89 vs 0.66) for the detection of injury to the ACL compared to single-energy CT (ΔAUC = 0.23, p =.003, Table 2). Inter-reader agreement was excellent for single-energy CT (ICC = 0.82) and dual-energy CT (ICC = 0.88). The difference in AUC between single-energy CT and dual-energy CT was significant for complete ACL tears (0.89 vs 0.57, ΔAUC = 0.32, p <.001), whereas no significant difference was observed for avulsion fractures (0.91 vs 0.92, ΔAUC = −0.01, p =.889). Example cases demonstrating complete ACL tears are illustrated in Figs. 2 and 3. A supplementary readout for detection of partial ACL tears yielded similar AUC values for dual-energy CT and single-energy CT (0.83 vs 0.67, ΔAUC = 0.16, p =.19) (Supplementary Table 1). Individual readings are

Table 1
Characterization of the patient population.

Patient characteristics - median (IQR) or n (%)	SECT (n = 119)	DECT (n = 85)	p-value
Age (years)	50 (37–69)	49 (35–60)	0.114
Sex (n)			0.278
Male	63 (53%)	50 (59%)	
Female	56 (47%)	35 (41%)	
ACL injury	n = 11 (9%)	n = 17 (20%)	<0.001
• Complete tear	n = 7 (6%)	n = 11 (13%)	
• Avulsion fracture	n = 4 (3%)	n = 6 (7%)	
PCL injury	n = 4 (3%)	n = 10 (12%)	<0.001
• Complete tear	n = 1 (1%)	n = 1 (1%)	
• Avulsion fracture	n = 3 (3%)	n = 9 (11%)	

No significant differences were observed between the demographics of patients with injury to the cruciate ligaments and patients without cruciate ligament injury. Patients that underwent DECT had significantly more often injuries to the ACL and PCL.
Abbreviations: IQR, interquartile range. SECT, single-energy computed tomography. DECT, dual-energy computed tomography. ACL, anterior cruciate ligament. PCL, posterior cruciate ligament. Age is given as median with interquartile range in parenthesis.

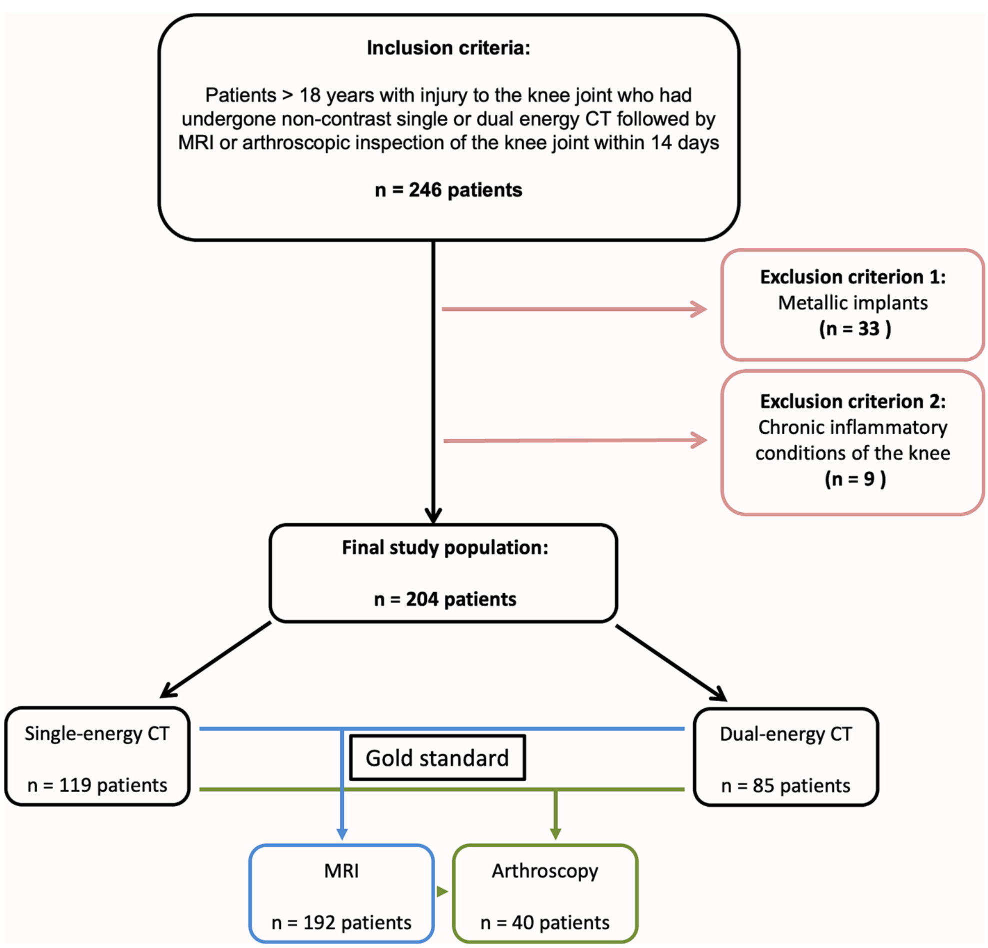

Fig. 1. Expanded STARD (Standards for Reporting of Diagnostic Accuracy Studies) flow chart of patient inclusion and downstream patient flow.

Table 2
Diagnostic accuracy of MDCT and DECT for the ACL and PCL.

ACL injury	AUC	Sensitivity	Specificity	PPV	NPV	Accuracy	p-value
Total							
SECT	0.66 (0.57–0.75)	55% (18/33)	77% (248/324)	94% (248/263)	19% (18/94)	75% (266/357)	0.003
DECT	0.89 (0.84–0.94)	80% (41/51)	98% (199/204)	95% (199/209)	89% (41/46)	94% (240/255)	0.003
Complete tear							
SECT	0.57 (0.47–0.67)	29% (6/21)	85% (284/336)	95% (284/299)	10% (6/58)	81% (290/357)	<0.001
DECT	0.89 (0.82–0.95)	79% (26/33)	100% (222/222)	97% (222/229)	100% (26/26)	97% (248/255)	<0.001
Avulsion fracture							
SECT	0.92 (0.84–0.98)	92% (11/12)	93% (321/345)	100% (321/322)	31% (11/35)	93% (332/357)	0.889
DECT	0.91 (0.82–0.99)	83% (15/18)	98% (232/237)	99% (232/235)	75% (15/20)	97% (247/255)	0.889
PCL injury	**AUC**	**Sensitivity**	**Specificity**	**PPV**	**NPV**	**Accuracy**	***p*-value**
Total							
SECT	0.61 (0.49–0.74)	33% (4/12)	89% (307/345)	97% (307/315)	10% (4/42)	87% (311/357)	0.003
DECT	0.9 (0.83–0.97)	83% (25/30)	97% (218/225)	98% (218/223)	78% (25/32)	95% (243/255)	0.003
Complete tear							
SECT	0.5 (0.49–0.5)	0% (0/3)	99% (351/354)	99% (351/354)	0% (0/3)	98% (351/357)	0.48
DECT	0.67 (0.5–1)	33% (1/3)	100% (252/252)	99% (252/254)	100% (1/1)	99% (253/255)	0.48
Avulsion fracture							
SECT	0.67 (0.5–0.84)	44% (4/9)	90% (313/348)	98% (313/318)	10% (4/39)	89% (317/357)	0.007
DECT	0.95 (0.89–0.99)	93% (25/27)	97% (221/228)	99% (221/223)	78% (25/32)	96% (246/255)	0.007

Diagnostic accuracy of SECT and DECT for detecting cruciate ligament injury with MRI or arthroscopic inspection as the reference standard.
Abbreviations: SECT, single-energy computed tomography. DECT, dual-energy computed tomography. ACL, anterior cruciate ligament. PCL, posterior cruciate ligament. PPV, positive predictive value. NPV, negative predictive value. AUC, area under the curve. Confidence intervals are given in parentheses.

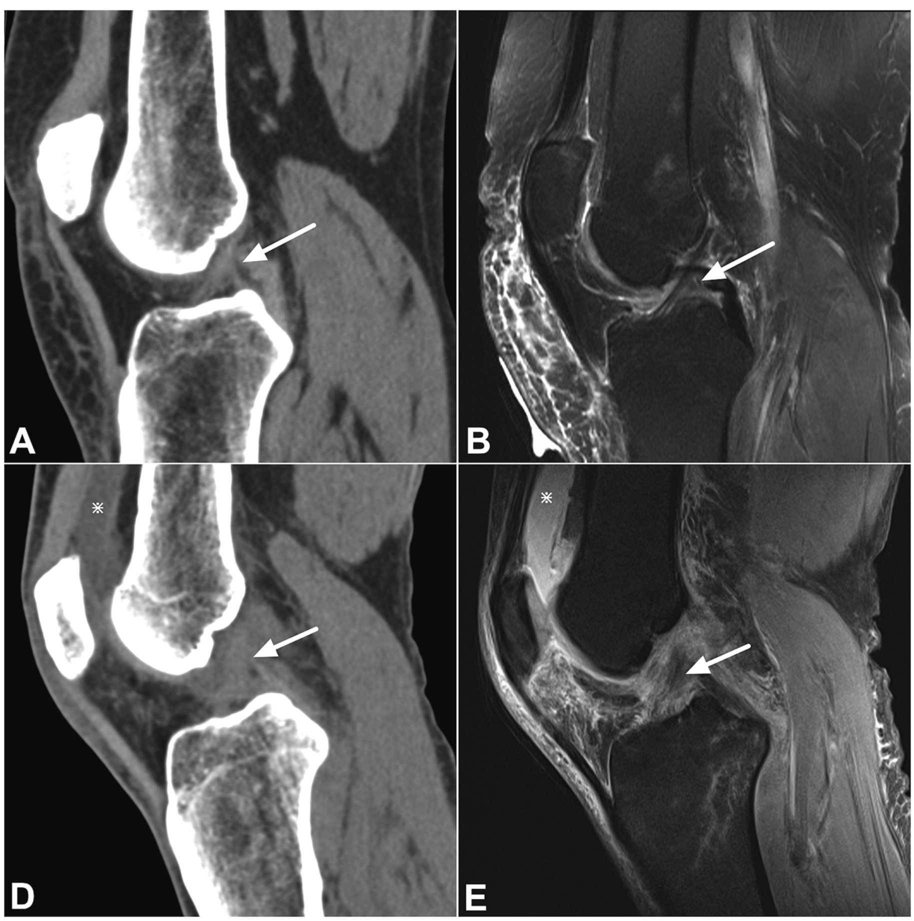

Fig. 2. Standard sagittal unenhanced single-energy CT (A, D) and unenhanced proton density-weighted MR images with fat saturation (B, E) of patients that sustained acute trauma to the knee. A and B show an intact anterior cruciate ligament of a patient with knee pain after a sudden stop in basketball practice (arrows). D shows a ligamentous defect of the anterior cruciate ligament (arrows) in a 28-year-old athlete that twisted his knee during a soccer match. Note the joint effusion suggesting damage to the internal structures of the knee (asterisks). This patient underwent early arthroscopic repair on the following day after magnetic resonance imaging confirmed the diagnosis of a complete ACL tear (E). *Abbreviations: ACL, anterior cruciate ligament.*

Fig. 3. Standard sagittal unenhanced dual-energy CT (A, D) and unenhanced proton density-weighted MR images with fat saturation (B, E) of patients that sustained acute trauma to the knee. A and B show an intact anterior cruciate ligament of a patient with pain after a bicycle accident (arrows). D shows abnormal orientation of the anterior cruciate ligament in a 23-year-old patient that sustained a skiing accident, suggesting a complete tear (arrow). A supplementary performed MRI confirmed the diagnosis. Note the joint effusion suggesting damage to the internal structures of the knee (asterisks) *Abbreviations: ACL, anterior cruciate ligament.*

Table 3
Individual readings of diagnostic accuracy for the ACL and PCL.

ACL injury	AUC	Sensitivity	Specificity	PPV	NPV	Accuracy	p-value
Reader 1							
SECT	0.61 (0.45–0.77)	45% (5/11)	77% (83/108)	93% (83/89)	17% (5/30)	74% (88/119)	<0.001
DECT	0.97 (0.91–1)	94% (16/17)	100% (68/68)	99% (68/69)	100% (16/16)	99% (84/85)	<0.001
Reader 2							
SECT	0.65 (0.5–0.8)	55% (6/11)	76% (82/108)	94% (82/87)	19% (6/32)	74% (88/119)	0.229
DECT	0.79 (0.67–0.9)	65% (11/17)	93% (63/68)	91% (63/69)	69% (11/16)	87% (74/85)	0.229
Reader 3							
SECT	0.7 (0.56–0.84)	64% (7/11)	77% (83/108)	95% (83/87)	22% (7/32)	76% (90/119)	0.043
DECT	0.91 (0.82–1)	82% (14/17)	100% (68/68)	96% (68/71)	100% (14/14)	96% (82/85)	0.043
PCL injury	**AUC**	**Sensitivity**	**Specificity**	**PPV**	**NPV**	**Accuracy**	***p*-value**
Reader 1							
SECT	0.57 (0.42–0.82)	25% (1/4)	89% (102/115)	97% (102/105)	7% (1/14)	87% (103/119)	0.055
DECT	0.89 (0.75–1)	80% (8/10)	99% (74/75)	97% (74/76)	89% (8/9)	96% (82/85)	0.055
Reader 2							
SECT	0.69 (0.44–0.95)	50% (2/4)	89% (102/115)	98% (102/104)	13% (2/15)	87% (104/119)	0.154
DECT	0.92 (0.82–0.99)	90% (9/10)	95% (71/75)	99% (71/72)	69% (9/13)	94% (80/85)	0.154
Reader 3							
SECT	0.57 (0.43–0.83)	25% (1/4)	90% (103/115)	97% (103/106)	8% (1/13)	87% (104/119)	0.055
DECT	0.89 (0.75–0.99)	80% (8/10)	97% (73/75)	97% (73/75)	80% (8/10)	95% (81/85)	0.055

Individual readings of SECT and DECT diagnostic accuracy for detecting cruciate ligament injury with MRI or arthroscopic inspection as the standard of reference. Abbreviations: SECT, single-energy computed tomography. DECT, dual-energy computed tomography. ACL, anterior cruciate ligament. PCL, posterior cruciate ligament. PPV, positive predictive value. NPV, negative predictive value. AUC, area under the curve. Confidence intervals are given in parentheses.

given in Table 3.

3.2. Diagnostic accuracy of PCL injury

Dual-energy CT showed higher overall sensitivity (83% [25/30)] vs 33% [4/12]), specificity (97% [218/225] vs 89% [307/345]), PPV (98% [218/223] vs 97% [307/315]), NPV (78% [25/32] vs 10% [4/42]), accuracy (95% [243/255] vs 87% [311/357]) and AUC (0.9 vs 0.61) for the detection of injury to the PCL compared to single-energy CT (ΔAUC = 0.29, p =.003, Table 2). Inter-reader agreement was excellent for single-energy CT (ICC = 0.89) and dual-energy CT (ICC = 0.89). The difference in AUC between single-energy CT and dual-energy CT was significant for avulsion fractures (0.95 vs 0.67, ΔAUC = 0.28, p =.007), but not for complete PCL tears (0.67 vs 0.5, ΔAUC = 0.17, p =.48). An example case demonstrating an avulsion fracture is illustrated in Fig. 4. No partial tears of the PCL were observed in our study population. Individual readings are given in Table 3.

3.3. Diagnostic confidence, image quality, and image noise

The diagnostic confidence was significantly higher for the detection of ACL injuries (4.2 ± 0.7 vs 2.8 ± 0.9, p <.001) and PCL injuries (4.6 ± 0.7 vs 2.2 ± 1.7, p <.001) for all readers. No significant differences were observed regarding the diagnostic confidence between less and more experienced readers (Table 4).

Table 4
Diagnostic confidence and image quality of single-energy CT and dual-energy CT.

Diagnostic confidence and image quality - mean ± SD (confidence interval)	Diagnostic confidence ACL	Diagnostic confidence PCL	Image quality
SECT	2.8 ± 0.9 (2.7–2.9)	2.2 ± 1.7 (2.1–2.4)	2.8 ± 0.7 (2.7–2.8)
DECT	4.2 ± 0.7 (4.2–4.3)	4.6 ± 0.7 (4.5–4.6)	4.3 ± 0.8 (4.1–4.5)
p-value	<0.001	<0.001	<0.001

Diagnostic confidence and image quality for SECT and DECT.
Abbreviations: SECT, single-energy computed tomography. DECT, dual-energy computed tomography. ACL, anterior cruciate ligament. PCL, posterior cruciate ligament. Numbers in parentheses are confidence intervals.

The image quality was considered superior for dual-energy CT compared to single-energy CT (4.3 ± 0.8 vs 2.8 ± 0.7, p <.001). Logistic regression analysis confirmed that increased image quality contributed to correct readings with an Odds ratio of 2.4 (p <.001).

Overall agreement of dual-energy CT with MRI as the reference standard was significantly higher compared to single-energy CT (0.82 ± 0.1 vs 0.17 ± 0.12, p <.001).

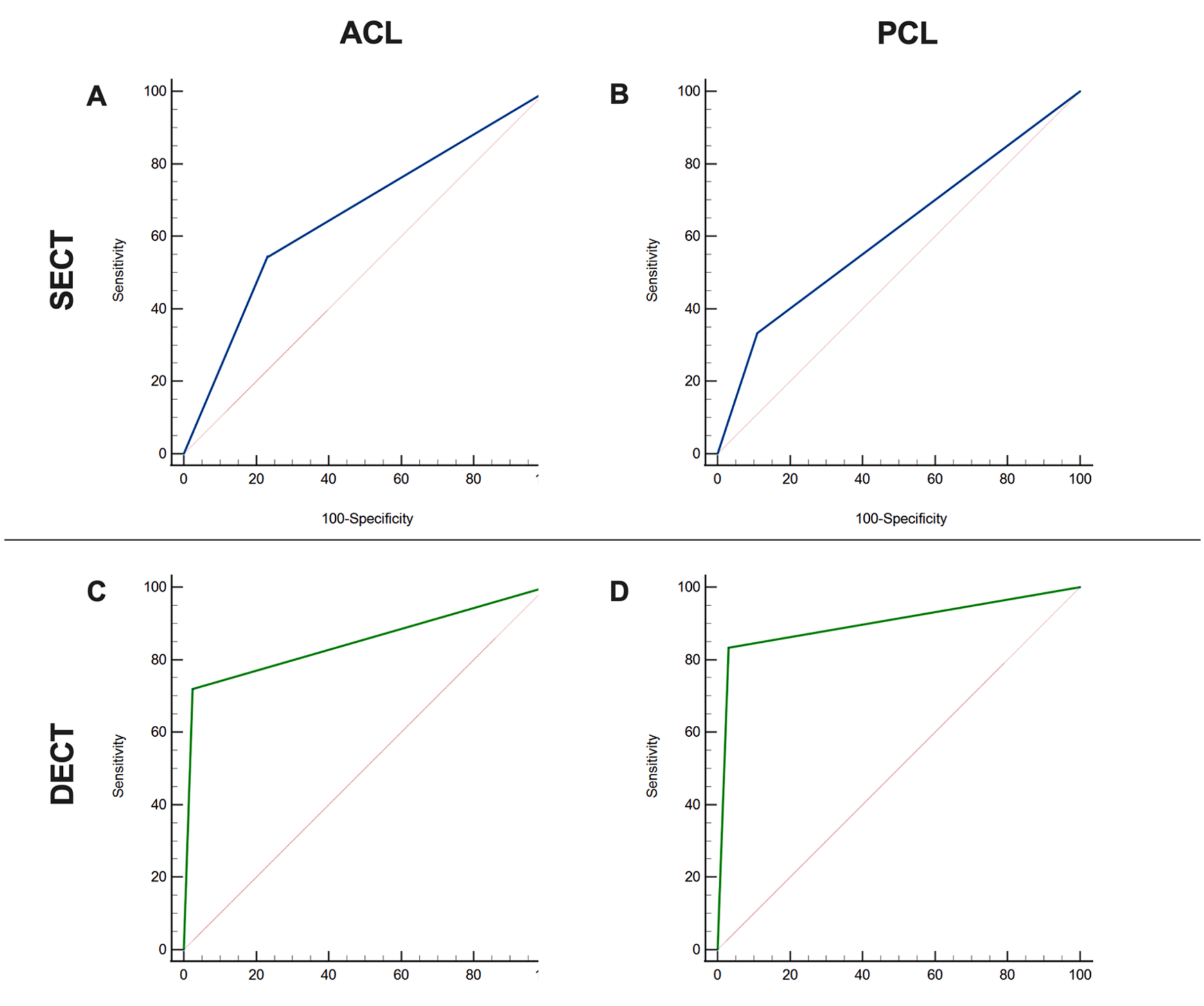

Fig. 4. ROC curve analysis for detecting cruciate ligament injury in single-energy and dual-energy CT. ROC curve analysis demonstrates increased diagnostic accuracy for detecting ACL and PCL injury in dual-energy CT (C, D) compared to single-energy CT (A, B). *Abbreviations: ROC, Receiver-operating characteristic. ACL, anterior cruciate ligament, PCL, posterior cruciate ligament. SECT, single-energy CT. DECT, dual-energy CT.*

4. Discussion

In contrast to MRI, CT is a rapid imaging technique readily accessible for evaluating musculoskeletal trauma. However, the soft tissue contrast of CT images was traditionally deemed insufficient for assessing ligamentous structures. Modern CT scanners deliver superior spatial resolution and soft-tissue contrast compared to early devices. In this study, we investigated the clinical utility of modern single and dual-energy CT for assessing the integrity of the cruciate ligaments, major stabilizers of the knee joint that are frequently injured during physical activity. Our results demonstrate that modern CT imaging is generally suitable to rapidly screen patients with acute trauma to the knee for cruciate ligament injuries, with dual-energy CT yielding superior diagnostic accuracy compared to single-energy CT.

Previous research demonstrated poor diagnostic accuracy for detecting tears of the cruciate ligaments in single-energy CT images [11]. In our study population, single-energy CT imaging yielded a higher specificity for detecting injury to the ACL and PCL (85% and 89%, respectively) than reported for earlier CT scanner generations, whereas the sensitivity was generally poor. Therefore, single-energy CT could be reliably used to rule in patients with ligamentous injury of the cruciate ligaments but was insufficient to rule out injury when imaging was negative. In a clinical context, this allows to streamline the diagnostic pathways for patients with positive imaging towards early reconstruction. In contrast, patients with negative imaging and persistent symptoms will still require MRI and do not derive additional benefit from the CT scans [5–8].

Moreover, our study confirms previous pilot studies indicating that dual-energy CT further improves the sensitivity and specificity for detecting complete ACL tears [17,18]. In a larger patient population and a more robust reference standard, we observed a significant increase in diagnostic performance for detecting ACL and PCL injuries using dual-energy CT compared to single-energy CT. Notably, in our study, the diagnostic performance further improved to an excellent level compared to both pilot studies, which can be primarily attributed to technological advancements between second and third-generation dual-energy CT systems and underlines the potential of dual-energy CT as an alternative imaging approach in situations where MRI is not available [19–22]. Additional applications of dual-energy CT, such as color-coding bone marrow edema and soft tissue structures, further emphasize this [22–24].

With around 70 μSv, the effective radiation dose of a knee CT is relatively low [25]. Nonetheless, broad CT usage for diagnostic purposes can generate undesirable stochastic effects for the predominantly young patients. Therefore, choosing CT over MRI should be limited to situations where MRI is unavailable, but prompt treatment could be initiated, such as during on-call times. In these settings, a CT scan can optimize patient flow and expedite the diagnosis and treatment of acute cruciate ligament tears. This approach could minimize the risk of subsequent injury to other soft tissue structures of the knee and effectively reduce the duration of immobilization. Consequently, it can potentially enhance patient outcomes and alleviate part of the socioeconomic burden on healthcare systems and working environments [5–7].

This retrospective study has limitations we would like to address. First, we separately evaluated patients that underwent single-energy CT and dual-energy CT. Therefore, no direct comparison of the image quality of individual patients between both devices was possible. Second, patients that underwent dual-energy CT had significantly more often injuries of the cruciate ligaments in the reference standard, and the resulting difference in pre-test probability could distort the calculated diagnostic accuracy parameters. Third, we used a mixed reference standard that included MRI and/or arthroscopic inspection. Lastly, while the adoption of dual-energy CT devices is increasing, their higher prices and primary use for research still limit their availability to selected clinics and practices. Therefore, our findings may not be immediately applicable in a broader range of healthcare facilities.

In conclusion, our study shows that modern CT can be used as a readily available screening tool for detecting injury to the cruciate ligaments in patients with acute trauma. The high diagnostic accuracy and reliable visualization provided by dual-energy CT imaging offer valuable insights into the integrity of the cruciate ligaments, aiding in timely and appropriate management decisions; however, caution should be exercised when ruling out injuries in single-energy CT, especially when symptoms persist. CT imaging can improve patient outcomes, enhance treatment planning, and reduce unnecessary procedures by providing detailed anatomical information and facilitating prompt identification of injuries.

CRediT authorship contribution statement

Leon D. Gruenewald: . **Christian Booz:** Investigation. **Simon S. Martin:** Methodology, Investigation. **Scherwin Mahmoudi:** Methodology, Investigation. **Ibrahim Yel:** Writing – review & editing. **Katrin Eichler:** Resources. **Leona S. Alizadeh:** Investigation. **Simon Bernatz:** Methodology, Investigation. **Jennifer Gotta:** Investigation. **Philipp Reschke:** Methodology, Investigation. **Christophe Weber:** Writing – review & editing. **Christof M. Sommer:** Writing – review & editing. **Tommaso D'Angelo:** Writing – review & editing. **Giuseppe Bucolo:** Writing – review & editing. **David M. Leistner:** Writing – review & editing. **Thomas J. Vogl:** Resources. **Vitali Koch:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The authors of this manuscript declare relationships with the following companies: I.Y. received a speaking fee from Siemens Healthineers. C.B. received speaking fees from Siemens Healthineers. The other authors have no conflict of interest to disclose.

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Appendix A. Supplementary data

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