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Is Caton–Deschamps Index Reliable and Reproducible in Preoperative Assessment of Patellar Height for Patellar Instability Surgery?

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Abstract: The patellar height measurement is fundamental for surgical planning in patellar instability. The Caton–Deschamps index (CDI) is a widely employed method, but a gold standard is still lacking. The aim of this study was to evaluate the reliability and reproducibility of the CDI in a patellar height assessment and to hypothesize its employment in the preoperative planning of patellar stabilization surgery. A total of 29 cases of recurrent patellar instability undergoing surgical treatment were analyzed. The preoperative and postoperative CDI were measured by six different raters (three seniors and three juniors). The interclass correlation coefficient (ICC) of the six raters was calculated to evaluate the interobserver agreement. The seniors' and juniors' measurements were compared to assess the CDI reproducibility. The Fleiss kappa was calculated among the six raters to estimate the agreement in favor of an anterior tibial apophysis (ATA) transposition surgery. This study shows excellent absolute agreement in terms of the ICC for the raters' average and for single raters as units, both preoperatively ($p < 0.001$) and postoperatively ($p < 0.001$). The agreement of the surgical choice between the six observers corresponds to "substantial agreement". This study demonstrates that the CDI is reliable and reproducible, and it could represent a valuable tool in the clinical assessment, treatment choice and pre-surgical planning of patellar instability surgery.

Keywords: patellar instability; Caton–Deschamps index; preoperative planning

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1. Introduction

The patellofemoral joint (PFJ) consists of two bony components, the patella and femoral trochlea, sharing the same joint surface [1]. It may be prone to instability, causing patellar dislocation usually on the lateral side of the knee. The incidence of primary patellar dislocation has been reported to be 5.8 cases per 100,000 in the general population, with the highest incidence occurring in the 2nd decade of life (29 per 100,000) [2]. Patellar instability can be classified as traumatic, when the dislocation is caused by an external force, or atraumatic, when the native knee anatomy predisposes to instability [1]. Non-operative treatment is usually the gold standard for the first episode of lateral patellar dislocation, except for cases with large bony avulsions or chondral fragments, and it consists of knee immobilization, physical therapy and non-steroidal anti-inflammatory drugs (NSAIDs) administration [3,4]. The recurrence rate after conservative management can be up to 15–44%, and patients with a clinical history of two or more dislocations have a 50% chance of recurrent dislocation episodes [5]. Chronic instability is a multifactorial problem that relies on limb alignment (valgus knee), the anatomy of the patella and trochlear groove and soft-tissue constraints, especially the medial patella-femoral ligament (MPFL). The management of recurrent patellar instability is still debated due to a heterogeneous patient population, skeletal immaturity, a challenging surgical approach and a lack of long-term and robust clinical outcome studies [6,7]. Radiological evaluation should investigate three main characteristics of instability: trochlear dysplasia, abnormal patellar height and a pathological tibial tubercle-trochlear groove (TT-TG) distance [8]. The patellar height can be easily evaluated through standard lateral-view knee radiographs. Several indexes have been described in the literature to calculate patellar height [9–11]. The Caton–Deschamps index (CDI) is routinely employed to measure the patellar height in patellar instability. The CDI relies upon the length of the articular surface of the patella and its distance from the anterior border of the tibial plateau [12].

The purpose of this study was to evaluate the reliability and reproducibility of the CDI and its employment in the preoperative planning of patellar stabilization surgery.

2. Materials and Methods

This retrospective, single center study was conducted at IRCCS Istituto Ortopedico Galeazzi, Milan, Italy. Approval by the Ethics Committee of IRCCS Ospedale San Raffaele, Milan, Italy (CE: 104/INT/2021, Milan, Italy 9 June 2021), was obtained in June 2021 and the study was registered on ClinicalTrials.gov (number: NCT05029505, accessed on 30 August 2021). All methods were carried out in accordance with relevant guidelines and regulations or the Declaration of Helsinki. A total of 29 cases of recurrent patellar instability, undergoing surgical treatment at our institution between March 2012 and November 2018, were selected and investigated. All procedures were performed by two senior knee surgeons. Patients ≥14 years old, affected by recurrent patellar instability (≥2 episodes of dislocation or subluxation) with surgical indication of either anterior tibial apophysis (ATA) transposition or MPFL reconstruction or both the procedures were enrolled. Specifically, 13 patients underwent both ATA transposition and MPFL reconstruction, 13 underwent only ATA transposition and 3 underwent only MPFL reconstruction. The treatment choice was based on patellar lateralization, measured with TT-TG and patellar height measured with CDI. Among patients undergoing ATA transposition, 16 underwent medialization ATA osteotomy, while 10 underwent both medialization and lowering ATA osteotomy. Exclusion criteria were less than 2 episodes of patellar dislocation or subluxation, digital radiographs not available, contraindication to surgery (ASA $\geq$ 4), knee osteoarthritis. Furthermore, because our division does not treat patients younger than 14 years, those were excluded from this study.

2.1. Radiological Assessment

The radiographic assessment was performed measuring preoperative and short-term postoperative CDI, using anterior–posterior and lateral radiographs with a 20 mm disc-shaped calibration marker [13]. CDI corresponds to a ratio of the distance between the tibial plateau anterior angle to the patellar articular surface lowest aspect, and patellar articular surface length [12]. Measurements were performed by 6 different raters to evaluate the interobserver agreement for CDI. Each rater provided a single measurement. Specifically, a half of the raters were orthopedic surgeons (seniors), and the other half were residents (juniors). For each subject, sex, age and values of preoperative and postoperative CDI have been collected. These data have been grouped into a single package and exported from the archives completely anonymized.

2.2. Surgical Technique

Depending on TT-TG and CDI, different surgical techniques were chosen. In case of patellar instability with normal TT-TG (<16 mm) and normal CDI (<1.2), only MPFL reconstruction was performed. When TT-TG was pathologic and CDI was normal, ATA medialization osteotomy was performed. When CDI was pathologic and TT-GT was normal, ATA lowering osteotomy was preferred. When both TT-TG and CDI were altered, a medialization and lowering osteotomy was performed. The patellar lowering necessary to achieve a normal CDI was calculated in millimeters, starting from the preoperative CDI measured on lateral radiographs with a 20 mm calibration marker (Figure 1).

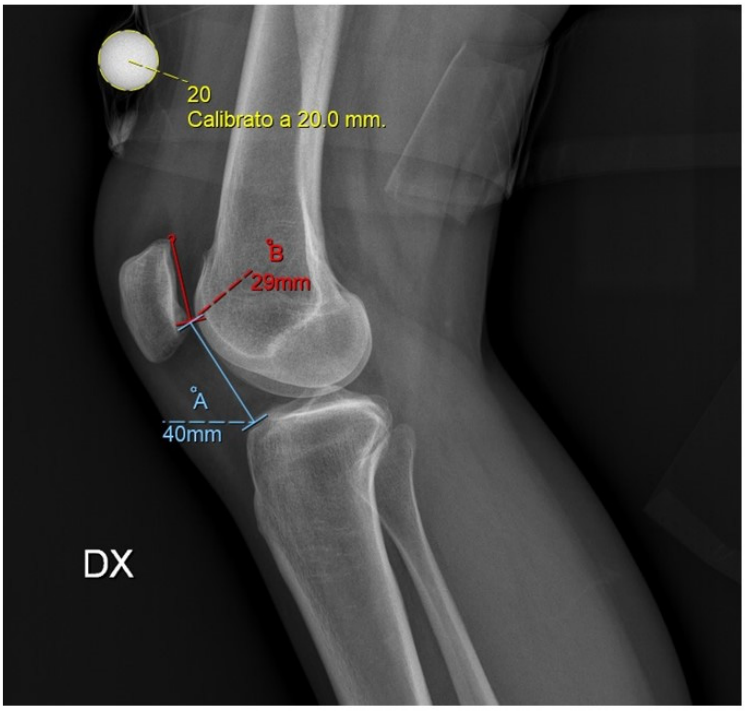

Figure 1. Caton–Deschamps index (CDI) assessed in a preoperative radiography of the knee, lateral view. In this example, CDI corresponds to 1.38, being $\frac{A}{B} = \frac{40}{29} = 1.38$, which means patella alta. Knowing that CDI should not be more than 1.2, using the proportion B x 1.2, we obtained the value B′ (29 × 1.2 = 34.8 mm) which corresponds to the maximum hypothetical length of A so that the patella does not result high. Then, with a simple subtraction, B − B′ = 40 − 34.8 = 5.2 mm, we calculated the distance of which we want to lower the bony brat during surgery. A 20 mm calibration marker is essential for making the correct lowering calculations.

MPFL reconstruction was added to ATA osteotomy when there was evidence of excessive patellar lateralization or evidence of MPFL rupture on MRI. Firstly, a diagnostic arthroscopy was routinely performed through standard medial and lateral portals to check possible chondral damages and the integrity of the trochlear groove, the anterior and posterior cruciate ligaments, as well as the medial and lateral compartments. MPFL reconstruction was performed using a gracilis muscle autograft. The gracilis muscle autograft was harvested and then prepared on a designated graft workstation (Arthrex, Inc. Naples, FL, USA). Two 2.4 mm guidewires were placed parallel on the patellar medial side at 1.5 cm from each other. A 4.5 mm cannulated drill was used to perform two bone tunnels on the patella and finally the graft ends were fixed in the tunnels using Arthrex Swivelock 4.5 mm velet system (Arthrex, Inc. Naples, FL, USA). Under fluoroscopic guidance, the femoral isometric “Schottle Point” was searched and identified using an eyelet guidewire. The Schottle point lays 2 mm anterior to the posterior cortical line, between the posterior aspect of the Blumensaat line and a parallel line which crosses the posterior transition point of the femoral condyles [14,15]. The graft loop was passed bluntly between joint capsule and vastus medialis. Subsequently, a 7 mm femoral bone tunnel was performed with a cannulated drill, through which the graft loop was passed with eyelet guidewire and fixed using an Arthrex resorbable 6 × 23 mm interference screw. When ATA transposition and MPFL reconstruction needed to be combined in the same surgical procedure, ATA transposition was performed firstly. When only ATA medialization osteotomy was necessary, an incomplete ATA osteotomy was executed leaving the distal apex of the ATA intact. When also CDI was ≥1.2, a complete osteotomy, with both medial and lowering transposition of the ATA, was performed to obtain a better correction, or just a lowering transposition if only CDI was higher than 1.2. The ATA transposition was intraoperatively measured with a ruler. The osteosynthesis was obtained with two compression screws.

2.3. Statistical Analysis

The analyses were performed using R software v4.0.3 (R Core Team, Wien, Austria) with "irr" package. Shapiro–Wilk test was used to assess the normal distribution of continuous variables. According to data distribution, parametric (unpaired Student's *t* test) or non-parametric test (Wilcoxon's test) were used to evaluate differences among the study groups. Each rater performed a single measurement. Interclass correlation coefficient (ICC) of the 6 raters was calculated in terms of absolute agreement and considering models based on both the raters' average and individual raters. These different models provide information about multiple raters' use (≥2) reliability (raters' average, RA) or individual rater (IR) reliability to determine the real index in the clinical practice. Specifically, multiple raters model assumes that ratings will be accomplished by multiple observers, mitigating possible measurement errors. Moreover, to assess CDI reproducibility, senior and junior raters' measurements were compared. Setting the threshold for surgical decision at 1.2 CDI score, a dichotomous variable was generated for each rater, either in favor of intervention (1) or not (0). Fleiss kappa was calculated among the 6 raters based on the agreement about the decision: <0 poor agreement, 0.01–0.20 slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement, 0.81–1.00 almost perfect agreement [16]. p values <0.05 were considered statistically significant.

3. Results

A total of 29 patients met the inclusion criteria and none were excluded from the statistical analysis (Figure 2).

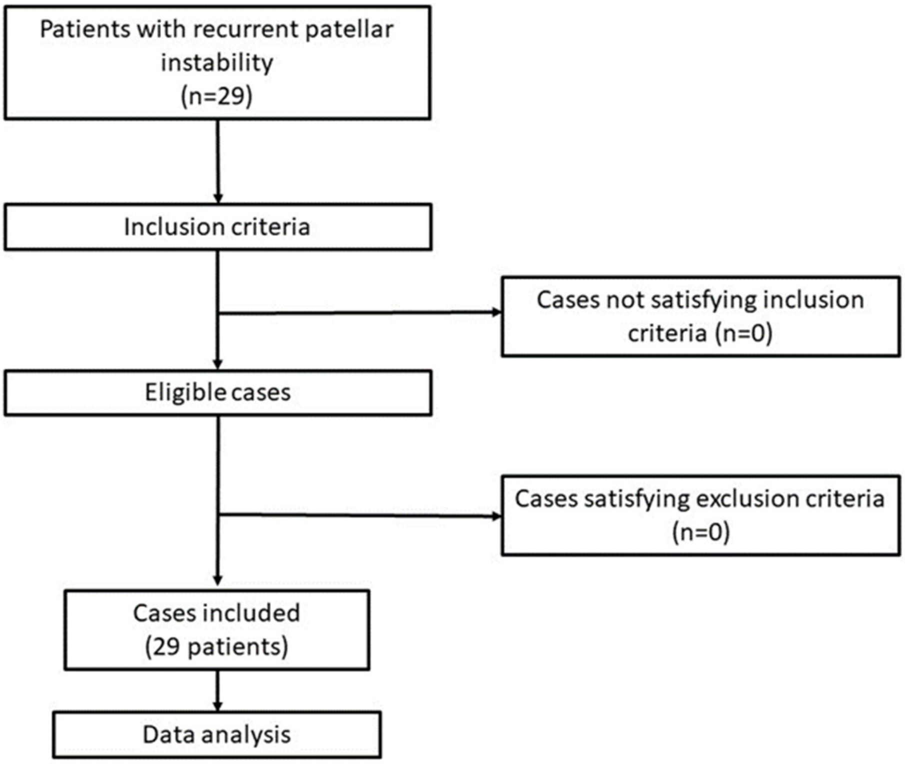

Figure 2. Study's flow chart.

A total of 6 were males, and 23 were females. The patients' ages ranged from 15 to 40 years old (average age 23.5 ± 8.2) (Table 1). Considering the raters' average, the preoperative CDI values significantly differed from the postoperative ones (pre: 1.31 ± 0.04; post: 1.22 ± 0.04; $p = 0.005$). Moreover, this difference became even more significant considering patients who underwent medialization and lowering ATA osteotomy (pre: 1.43 ± 0.12; post: 1.19 ± 0.09; $p < 0.0001$).

Table 1. Patients' demographic and surgical procedures.

Patients	N = 29
Mean age	23.5 ± 8.2
Males	6
Females	23
ATA transposition + MPFL reconstruction	13
ATA transposition	13
MPFL reconstruction	3

Concerning the preoperative CDI measurement, an absolute agreement between the six observers (meaning the tendency of raters to assign the same exact score) showed an interclass correlation coefficient (ICC) of 0.941 (CI 95%: 0.893–0.971) for the raters' average, and 0.728 (CI 95%: 0.584–0.849) for the individual raters. All these values were significantly different from 0 (meaning no agreement between the raters), showing no systematic difference between the raters' measurements ($p < 0.001$).

Considering the postoperative measures, the ICCs among the six observers were lower but remained high at 0.898 (CI 95%: 0.827–0.946) and 0.594 (CI 95%: 0.443–0.745) for the raters' average and individual raters, respectively. This could be advocated to post-surgical confounding factors with no statistical meaning. Nevertheless, the results were statistically significant ($p < 0.001$) (Table 2).

Table 2. Preoperative and postoperative interclass correlation coefficient (ICC) for raters' average (RA) and individual raters (IR) between the six raters.

	RA	IR	*p*-Value
Preoperative	0.941	0.728	<0.001
Postoperative	0.898	0.594	<0.001

The CDI ≥ 1.2 threshold was generally used to decide whether to perform an ATA transposition. The agreement between the six observers showed a Fleiss kappa of 0.636 ("substantial agreement"), significantly different from zero ($p < 0.001$) (Table 3).

Table 3. Fleiss kappa values between the six raters and between seniors and juniors separately.

	Fleiss Kappa	*p*-Value
Six raters	0.636	$p < 0.001$
Seniors	0.580	$p < 0.001$
Juniors	0.704	$p < 0.001$

Moreover, comparing the measurements between the senior and junior raters, among the senior raters, the ICC for absolute agreement had a result of 0.931 (CI 95%: 0.873–0.966, $p < 0.001$) for the raters' average and 0.819 (CI 95%: 0.696–0.903, $p < 0.001$) for the individual raters. In addition, among the junior raters, the ICC value for absolute agreement was 0.888 (CI 95%: 0.775–0.948, $p < 0.001$) for the raters' average and 0.725 (CI 95%: 0.537–0.857, $p < 0.001$) for the individual raters (Table 4).

Table 4. Seniors and juniors interclass correlation coefficient (ICC) for raters' average (RA) and individual raters (IR).

	RA	**IR**	***p*-Value**
Seniors	0.931	0.819	<0.001
Juniors	0.888	0.725	<0.001

Although the ICC values in the junior group were lower, no significant difference was detected from the seniors' measurements, because confidence intervals widely overlapped. Furthermore, concerning the Fleiss kappa, the value obtained by the senior raters was 0.580 ("moderate agreement"), while considering only the junior raters, the Fleiss kappa was 0.704 ("substantial agreement") ($p < 0.001$) (Table 3).

4. Discussion

The patellar height measurement has been shown to be a fundamental clinical tool for surgical planning in patients affected by recurrent patellar instability. Despite several methods being available, a gold standard is still lacking [17–19]. Specifically, these methods can either relate the position of the patella to the femur (direct assessment) or the position of the patella to the tibia (indirect assessment) [18]. Methods that use an indirect assessment, such as the Insall–Salvati (IS), modified Insall–Salvati (MIS), Blackburne–Peel (BP) ratio and CDI, are the most widely employed [18]. The IS consists of a ratio between the patellar tendon length and the non-articulating patellar surface length [1,18]. Due to the variability of patellar length, the clinical interpretation of the IS index can be negatively affected [1]. For that reason, Grelsamer described the MIS, which considers the patellar articular surface length rather than the patellar length [18]. However, both for the IS and MIS, the exact location of the distal patellar tendon insertion can be challenging, and it requires perfect lateral radiographs views [1]. Blackburne and Peel proposed a method consisting of the ratio between the patellar articular length and the articular cartilage lower pole height above the tibial plateau, measured on a 30-degree flexed knee lateral radiograph [9,20]. This last method has shown to be a valid tool for patellar height evaluation when applied to a total knee arthroplasty, but it does not precisely define the placement of the tibial plateau line in the case of a non-prosthetic knee [1,20]. The CDI consists of a ratio between the patellar articular surface length and its distance from the tibial plateau anterior border [1]. Generally, it is measured on a lateral radiograph with the knee flexed at 30 degrees, although for the original study by Caton–Deschamps, the knee flexion ranged from 20 to 80 degrees, suggesting how the CDI is poorly influenced by the degree of knee flexion in spite of the other indices [1,11]. Moreover, it can also be performed in children, but age correction should be applied because the patellar ossification begins at its proximal side [21]. Hence, some authors believe that the CDI may represent the best method to measure the patellar height in pre-surgical planning [1,21]. Although it has been hypothesized that the CDI could be reliable and easily reproducible, this has not been precisely clarified yet [22].

Smith et al. [23] stated that intra-observer reliability of the CDI was higher than the BP and IS. However, they suggested that intra-observer reliability of a measurement method can be likely influenced by the rater's experience, showing how the ICCs of the measurements performed by the medical student were mostly lower when compared to the orthopedic resident, the orthopedic surgeon and the radiologist. In contrast, a study conducted by Verhulst et al. [19] concluded that the IS ratio shows better intra- and inter-observer reliability than the CDI, BP and MIS ratio, measured on conventional radiographs. Seil et al. [24] evaluated the reliability and inter-observer variability of the IS, MIS, BP, CDI and Labelle–Laurin index, measured by two examiners using standard knee radiographs. A low inter-observer variability with high correlation coefficients and low mean inter-observer errors were found. Furthermore, they recommended the BP as the most reliable method among the ones examined. However, a more recent study conducted by Mortensen et al. [25] stated that the BP could be affected by the tibial slope, leading to an improper assessment of the patellar height.

The present study shows excellent absolute agreement in terms of the ICC. A decrease in the ICC can be observed considering a single rater's agreement rather than the observers average due to the greater precision required by the analysis conditions. Nevertheless, it has to be noticed that the value remains high (>0.7 meaning "good" and being very close to the threshold used for "excellent", which starts from 0.75) [26] (Tables 2 and 4). Thus, the evaluation by several raters remains the best solution, but the use of a single rater does not represent a drastic decrease in measurement accuracy. The average CDI values are very close to the decision threshold for ATA transposition surgery (1.2), so small variations can lead to a change in the surgical decision. Nonetheless, the decision agreement corresponds to a "substantial" level, as noted by Fleiss's kappa [16] (Table 3). This finding is also confirmed considering senior or junior raters separately; though, juniors show a slightly greater inter-observer agreement than seniors. Hence, our results show that the CDI is an accurate and reproducible measurement method, with a low inter-observer variability. Furthermore, this is the only study correlating the CDI measurements of six observers to the authors' knowledge, representing stronger evidence of reliability and reproducibility. Thus, we believe that the CDI may be employed to perform a quantitative evaluation in preoperative planning for ATA transposition surgery using a calibration marker, which allows for a more precise calculation of patellar lowering to achieve a normal CDI.

Limitations

Despite the encouraging results, several limitations must be addressed. First, a larger sample should be collected to avoid selection biases. Moreover, in this study, patients who underwent either ATA transposition or MPFL reconstruction or both the procedures were not completely separated in the statistical analysis. However, the purpose of the study was independent from the surgical decision, as it aims to evaluate the CDI from a descriptive point of view. Additionally, it must be noticed that a medialization of the patella leads to an unavoidable slightly inferior translation.

5. Conclusions

The authors believe that the CDI is a reliable and reproducible method to measure the patellar height in patellar instability. Indeed, it has shown an excellent agreement among different raters, and it resulted to be a trusted support for ATA transposition and MPFL reconstruction surgeries. This makes the CDI a valuable tool in the clinical assessment, treatment choice and pre-surgical planning of patellar instability surgery.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study and/or their legal guardian(s). Written informed consent has been obtained from the patient(s) and/or their legal guardian(s) to publish this paper.

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