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Original article

Femoral intercondylar notch: accuracy of a novel MRI measurement protocol

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Abstract

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Objective: The most common mechanical complication following an anterior cruciate ligament (ACL) reconstruction is joint stiffness, due in part to cyclops syndrome. A narrow intercondylar notch is an anatomical risk factor. A reliable preoperative notch measurement would help anticipate proper graft size, or plan a notchplasty during the ligament reconstruction, if necessary. No study has yet assessed the accuracy of the methods used to measure notch size.

Hypothesis: The novel measurement protocol proposed in this study would be more reproducible than the reference technique.

Methods: A total of 20 preoperative knee MRIs performed during the assessment of an ACL rupture were randomly selected. The notch size was measured using 2 methods: traditional (ratio of the notch and metaphyseal widths measured on a line drawn through the popliteal groove) and novel. The latter was measured using the same ratio but took into account the notch width in its proximal third, according to a coronal slice that passes through the ACL tibial attachment. Three orthopedic surgeons with different levels of experience (senior surgeon, junior surgeon and surgical resident) performed these measurement protocols twice on anonymized MRI scans, 10 days apart. Spearman's rank correlation coefficient was used to assess the intraobserver correlations and a concordance index was used to assess the interobserver correlations. The influence of the second MRI reading was analyzed with a bootstrap test.

Results: The mean intraobserver reliability was 0.73 for the reference method and 0.83 for the proposed method. The values of the bootstrap tests were higher for the proposed method (0.45 vs. 0.45 and 0.70; $p < .05$ for interobserver; 0.49 vs. 0.69 and 0.62; $p < .05$ for intraobserver).

Conclusion: The proposed measurement protocol showed a higher reproducibility in assessing notch size than the traditional method. This technique therefore provides a reliable assessment of the intercondylar notch width.

Level of evidence: IV; retrospective study

Keywords: intercondylar notch, magnetic resonance imaging, anterior cruciate ligament rupture, cyclops syndrome

1. Introduction

One of the most common complications following an anterior cruciate ligament (ACL) reconstruction is the persistence of a knee extension deficit [1]. This flexion deformity is most often caused by cyclops syndrome [2], occurring in 1.9% to 10.9% of cases [3]. Initially described following an ACL reconstruction with a patellar tendon graft [4]; however, all grafts are at risk of developing this complication [5]. A reoperation to excise the fibrous nodule might be necessary if rehabilitation fails [6]. This nodule is the result of a chronic inflammatory reaction caused by an intercondylar roof impingement of the ACL graft, which aggravates the flexion deformity, with a permanent loss of knee mobility. A narrow intercondylar notch (ICN) is one of the risk factors for developing this syndrome [7–9] and a notchplasty may be proposed to widen it.

Arthroscopic assessment of the notch size is not sufficiently objective or reproducible to be used as a diagnostic and therapeutic decision-making tool [10–11]. Magnetic resonance imaging (MRI) appears to be a more accurate technique to assess it, especially preoperatively [12]. Different techniques have been described for measuring ICN with an MRI [1,6,13–15], using various anatomic landmarks on preselected slices and quantification techniques.

Moreover, ACL graft impingements occur in the anterior and superior aspects of the ICN. However, the techniques for measuring ICN that are described in the literature do not take this into account. In fact, the measurements are taken in the region of the popliteal groove where the ICN is at its widest. It would be useful to have a measurement of the roof of the ICN, where the impingement is located.

The primary purpose of this study was to assess the reliability and reproducibility of a novel technique to measure ICN width on an MRI, by performing the measurement at the roof of the ICN. We hypothesized that this proposed method would be more reproducible than the reference technique.

2. Materials and methods

2.1 Study protocol

The inclusion criteria were patients between the ages of 18 and 50 who had undergone an isolated ACL reconstruction, with no history of ipsilateral limb fracture, knee arthritis or deformity, and no systemic pathology. Patients who had undergone meniscus repair in conjunction with the ACL reconstruction were excluded. A total of 20 patients with isolated ACL reconstruction were included. Surgery was performed on average 3.3 months (± 1.1) after the initial injury and an active rehabilitation program. The sex ratio (M/F) was 2.0. The mean age was 31.5 years (± 11.2). All MRIs were performed preoperatively in the same imaging department. The thickness of the slices was systematically calibrated at 3 mm and the choice of sequence was irrelevant. Each MRI was anonymized and analyzed twice, 10 days apart. The order of the measurements was changed by an independent observer before the second reading. This double reading was performed by 3 blinded orthopedic surgeons with different levels of experience: Reader 1 was a senior surgeon, Reader 2 was a junior surgeon and Reader 3 was a surgical resident. Each surgeon only performed 1 measurement at each reading.

Our proposed technique was compared to what is considered to be the reference technique [13,16]. Measurements using both techniques were recorded during each reading and sent to an independent statistician. All MRIs were analyzed with the Carestream® imaging software. Data was collected prospectively and an outside observer timed readers for each measurement protocol.

2.2 Measurement protocol (Figure 1)

2.2.1 Reference technique

The coronal slice where the popliteal groove was the most visible was selected for this measurement [13,16]. The notch width (A) and metaphyseal width (B) were defined along a line parallel to the tangent to the distal femoral condyles that passes through the popliteal groove. The A/B ratio was then inferred from this data.

2.2.1 Proposed technique

The first coronal slice where the popliteal groove was visualized starting at the ACL tibial attachment was selected for this measurement. A tangential line to the 2 distal femoral condyles was drawn. The notch height was then measured from this tangent line to the top of the intercondylar roof. This height was then divided into thirds. The A/B ratio was measured for each third.

2.3 Statistical analysis

Inter- and intraobserver associations were measured using the Spearman rank correlation coefficient. Both "intraobserver" and "interobserver" associations were measured for the 3 readers in order to investigate the linear dependence between the 2 sets of measurements. A Mann-Whitney U test was used to determine whether there were significant inter- or intraobserver differences. It compared the median of delta to a theoretical median of 0, allowing investigation of a possible systematic bias expressed by the mean of delta. The reproducibility of these measurements over time (intraobserver) and between readers (interobserver) was assessed with the intraclass correlation coefficient (ICC). The different variance component estimates required to calculate this coefficient were done using a mixed model approach. The confidence interval for the ICCs was calculated using a bootstrap method to determine whether reliability significantly changed over time.

Bland-Altman plots were produced to visually assess the reproducibility, with the mean measurement on the x-axis and the delta on the y-axis. These plots showed the bias dependency compared to the measurement values and limits of agreement – i.e. the confidence interval containing 95% of differences. All statistical analyses were performed using R software (R Foundation for Statistical Computing, Vienna, Austria).

3. **Results**

The measurements performed on each MRI took an average of 2.5 minutes (± 0.5) for the reference technique, and 4 minutes (± 1.5) for the proposed technique. Results for each reading are reported in Table 1.

The intraobserver reproducibility of the reference technique ranged from 0.50 to 0.87, depending on the reader. The overall intraobserver reliability for this method was 0.49. Descriptive data and intraobserver reliability measurements are reported in Table 2. The interobserver data were studied by first pairing the readers 2 by 2 and then as a whole. Reliability was higher at the second reading. The overall interobserver reliability for both readings was 0.45 (Table 3).

The intraobserver reproducibility was significantly better for the proposed technique ($p < .05$), ranging from 0.57 to 0.97. The values for the 2 experienced surgeons were greater than 0.75 (0.63 and 0.48, respectively), unlike those of the surgical resident. Overall reliabilities were greater than 0.5. The results were better in the proximal third than in the distal third of the ICN (0.64 vs. 0.52). Reproducibility data and intraobserver reliability measurements are reported in Table 4 and depicted in Figure 2. The correlations and the association between observers were not statistically significant. The interobserver reliabilities were higher at the second reading. The measurements had an overall reliability of 0.7 at the distal third and 0.45 at the proximal third. The interobserver reproducibility of the proposed technique is reported in Table 5.

Figure 3 represents the interobserver correlations for each technique. Reproducibility increased for both techniques at the second reading. When compared 2 by 2, readers had improved correlation results for the proposed technique at the second reading.

4. Discussion

ACL reconstruction is a technically demanding surgery with a high risk of complications [16–18]. The main complications are cyclops syndrome [3,5], graft rupture [19], anterior knee pain and extension deficit [20], which may require revision surgery. A narrow ICN is one of the possible causes of these complications. To prevent their onset, it is important to detect abnormal ICNs preoperatively, so that they can be widened during the operation or to better adapt the diameter of the ligament graft.

The ICN was initially measured on X-rays [16], but MRI now seems to be a more reliable exam, and it is systematically performed during the initial assessment of a ligament injury. Several measurement methods have been proposed. Some teams use the Blumensaat line to determine the best slice to measure ICN height [1]. Others have added to it the vertical axis and notch shape in the axial sequence [6]. The narrowest area of the notch [14] has also been used as a benchmark. Hirtler et al. [15], calculated ratios on different horizontal levels, but these were not specified. Finally, others have proposed an easy-to-use measurement technique that calculates the ratio between the ICN and metaphyseal widths on a coronal slice that pass through the popliteal groove. This measurement is performed on the MRI slice where the popliteal groove is “most visible” or at its widest [13]. However, this leaves 3 to 4 slices to choose from since there are no clear indications on how to select the most appropriate one. According to this reference measurement, a ratio of less than 0.21 would increase the risk of complications, especially an ACL graft rupture [13].

Our study proposes a more reliable and reproducible method for measuring ICN width. Moreover, this measurement is performed at the location of the potential ICN impingement of the ACL graft. As mentioned by Kulczyca et al. [18], the impingement seems to mainly occur in the anteroinferior aspect of the notch, which is why we chose the most anterior anatomical position possible and the measurement of the ICN at the proximal third, for this proposed technique. This double measurement avoids selection bias of ICN height analysis, by defining it precisely. Particularly seeing that notch shapes differ between individuals, and it is possible that this datum is also involved in bone-tendon graft impingement [21–22].

The inter- and intraobserver reliability coefficients were poor for the reference technique. We found coefficients of less than 0.5 that were statistically significant. This suggests that this method is less reproducible, probably because several MRI slices were available for the measurement. The 3 readers reported their indecisiveness in choosing between several slices, which could have influenced the ratios obtained. Regarding the proposed technique, the overall inter- and intraobserver correlation coefficients were significantly greater than 0.5. The interobserver correlation coefficients showed true superiority of the measurement results taken at the junction of the middle and distal third than the junction of the proximal and middle third. The ratios were higher than those found during the previous reading because the notch was wider than at the proximal third and the total metaphysis width did not increase much. Statistically, this would favor a greater dispersion of values.

There were superior interobserver reliability results at the second reading, thus suggesting that a familiarization period for the new measurement method is necessary and that repeated use will harmonize these results. There were significant differences between readers when analyzing the individual data. The 2 most experienced readers had intraobserver coefficients that were greater than 0.75, while the surgical resident obtained much lower results, around 0.60. The choice of MRI slice presents a bias that should be considered. A surgical resident might find it more difficult to visualize the popliteal groove and the ACL attachment site on a single slice than a more experienced reader. Therefore, the differences observed could be due to the choice of MRI slice, as the notch is more constant at its distal third in the coronal plane. Consequently, if 2 different slices were used to perform the measurements, the results could be clustered for the distal third but more spread out for the proximal third. Paradoxically, the intraobserver coefficients were better when the surgical resident used the reference method, unlike the experienced surgeons who had significantly higher coefficients with the proposed method.

The main limitation of this study was the relatively small sample size. However, significant statistical differences were demonstrated by having 3 readers with different levels of expertise perform 2 measurements using 2 different methods. This highlighted the importance of this new measurement technique. However, a larger sample size could have refined these results.

The clinical perspectives are interesting, since this is a more reliable and reproducible technique for measuring the ICN and it introduces the concept of precise measurements in areas where there is a potential for ICN impingement of the ACL graft. The measurement of the ICN width should be included in the preoperative workup of ACL reconstruction and prognosis data to anticipate treatment solutions for a narrow ICN, such as the best type of graft, smaller graft size, or intraoperative widening. This paves the way for further research. First, the concept of a narrow notch should be clarified by defining cutoff ratios for developing a cyclops syndrome. The type of graft and its diameter could then be correlated with notch size, especially since the intra-articular graft morphology seems to vary during movement [23].

5. Conclusion

The proposed measurement technique offers superior reproducibility in assessing notch size than the traditional method. Therefore, it provides a reliable assessment of ICN width. Further studies are still needed to determine its place in the preoperative workup used to identify the risk of developing complications such as a cyclops syndrome.

Conflicts of interest: Professor KHIAMI is a consultant at Mylan and Smith and Nephew, but this is unrelated to this study. None of the other authors report having any conflicts of interest.

Financing: none

Author contributions:

ROLLET M.E., KNAFO Y. and KHIAMI F. performed radiologic assessments; GRANGER B. checked the statistics; ROUGEREAU G. enrolled patients; PASCAL MOUSSELARD followed and validated the protocols.

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	Reference method		Proposed method			
	Measurement 1	Measurement 2	Proximal 1/3		Distal 1/3	
			Measurement 1	Measurement 2	Measurement 1	Measurement 2
Reader 1	0.21 ± 0.004	0.25 ± 0.021	0.18 ± 0.016	0.18 ± 0.004	0.23 ± 0.005	0.23 ± 0.006
Reader 2	0.26 ± 0.013	0.25 ± 0.041	0.21 ± 0.012	0.21 ± 0.009	0.27 ± 0.024	0.28 ± 0.036
Reader 3	0.23 ± 0.017	0.25 ± 0.028	0.17 ± 0.088	0.18 ± 0.054	0.24 ± 0.004	0.26 ± 0.008

Table 1: Mean measurements taken by each surgeon during the 2 readings*:* senior surgeon (Reader 1), junior surgeon (Reader 2) and surgical resident (Reader 3).

Studied parameters	Reader 1	Reader 2	Reader 3
Correlation coefficient between the 2 readings *(ρ)*	0.65 $p < .05$	0.86 $p < .05$	0.67 $p < .05$
Association between readings *(Mean + SD)*	-0.04 ± 0.03 $p < .05$	0.01 ± 0.01 $p > .05$	-0.01 ± 0.04 $p > .05$
Intraobserver reliability *(ICC)*	0.50 $p > .05$	0.87 $p < .05$	0.65 $p < .05$
Overall intraobserver reliability *(MICC)*	0.49		

ρ: Spearman rank correlation coefficient; SD: standard deviation; ICC: intraclass correlation coefficient; MICC: multivariate intraclass correlation.

Table 2: Descriptive data and intraobserver reliability measurements of the reference technique.

Studied parameters	Reading 1	Reading 2
Correlation coefficient between the 2 readings *(ρ)*	0.52 $p < .05$	0.58 $p > .05$
Association between readings *(Mean + SD)*	0.04 ± 0.05 $p < .05$	0.07 ± 0.05 $p > .05$
Interobserver reliability *(ICC)*	0.30 $p < .05$	0.51 $p < .05$
Overall interobserver reliability *(MICC)*	0.45	

ρ: Spearman rank correlation coefficient; SD: standard deviation; ICC: intraclass correlation coefficient; MICC: multivariate intraclass correlation.

Table 3: Descriptive data and interobserver reliability measurements for the reference technique.

Studied parameters	Reader 1		Reader 2		Reader 3	
	Proximal 1/3	**Distal 1/3**	**Proximal 1/3**	**Distal 1/3**	**Proximal 1/3**	**Distal 1/3**
Correlation coefficient between the 2 readings *(ρ)*	0.77 p <.05	0.86 p <.05	0.98 p <.05	0.96 p <.05	0.63 p <.05	0.48 p <.05
Association between readings *(Mean + SD)*	0 ± 0.02 p >.05		0 ± 0.01 p >.05		-0.02 ± 0.04 p >.05	0 ± 0.04 p >.05
Intraobserver reliability *(ICC)*	0.76 p >.05	0.90 p >.05	0.97 p <.05	0.97 p <.05	0.61 p <.05	0.57 p <.05
Overall intraobserver reliability *(MICC)*	**Proximal 1/3**: 0.64 **Distal 1/3**: 0.52					

ρ: Spearman rank correlation coefficient; SD: standard deviation; ICC: intraclass correlation coefficient; MICC: multivariate intraclass correlation.

Table 4: Reproducibility and intraobserver reliability measurements for the proposed technique.

Studied parameters	Reading 1		Reading 2	
	Proximal 1/3	Distal 1/3	Proximal 1/3	Distal 1/3
Correlation coefficient between the 2 readings ***(ρ)***	0.53 p >.05	0.53 p >.05	0.51 p >.05	0.72 p >.05
Association between readings *(Mean + SD)*	-0,02 ± 0,04 p >.05		-0,02 ± 0.03 p >.05	
Interobserver reliability *(ICC)*	0.37 p <.05	0.43 p <.05	0.43 p <.05	0.56 p <.05
Overall interobserver reliability *(MICC)*	**Proximal 1/3:** 0.45 **Distal 1/3:** 0.70			

ρ: Spearman rank correlation coefficient; SD: standard deviation; ICC: intraclass correlation coefficient; MICC: multivariate intraclass correlation.

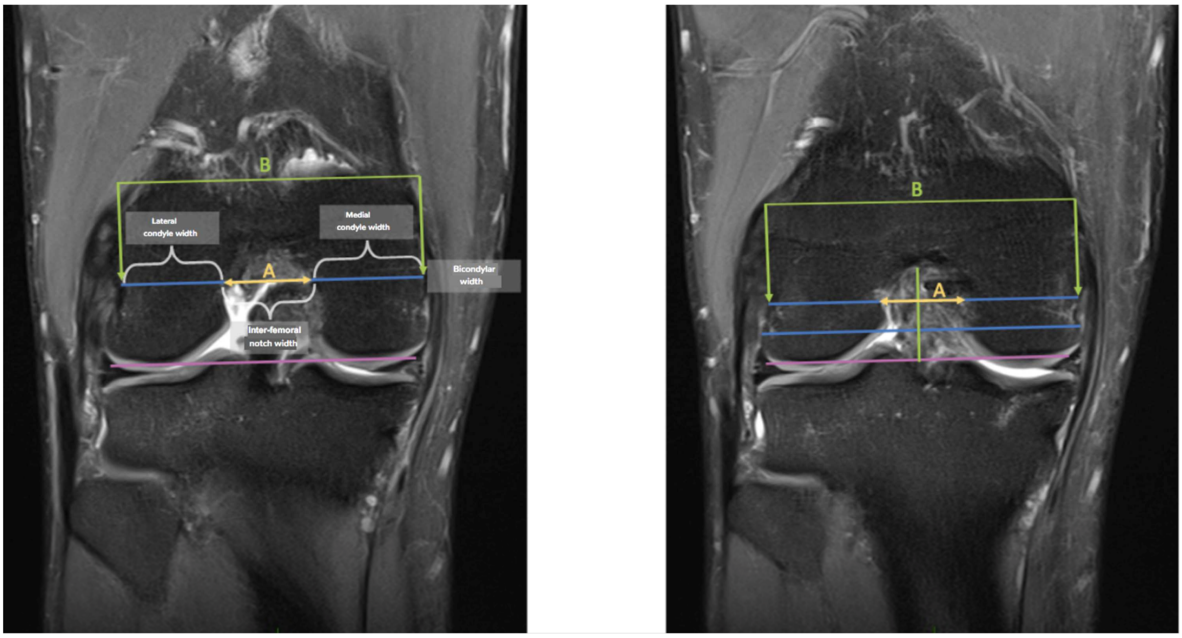
Table 5: Interobserver reproducibility data for the proposed technique

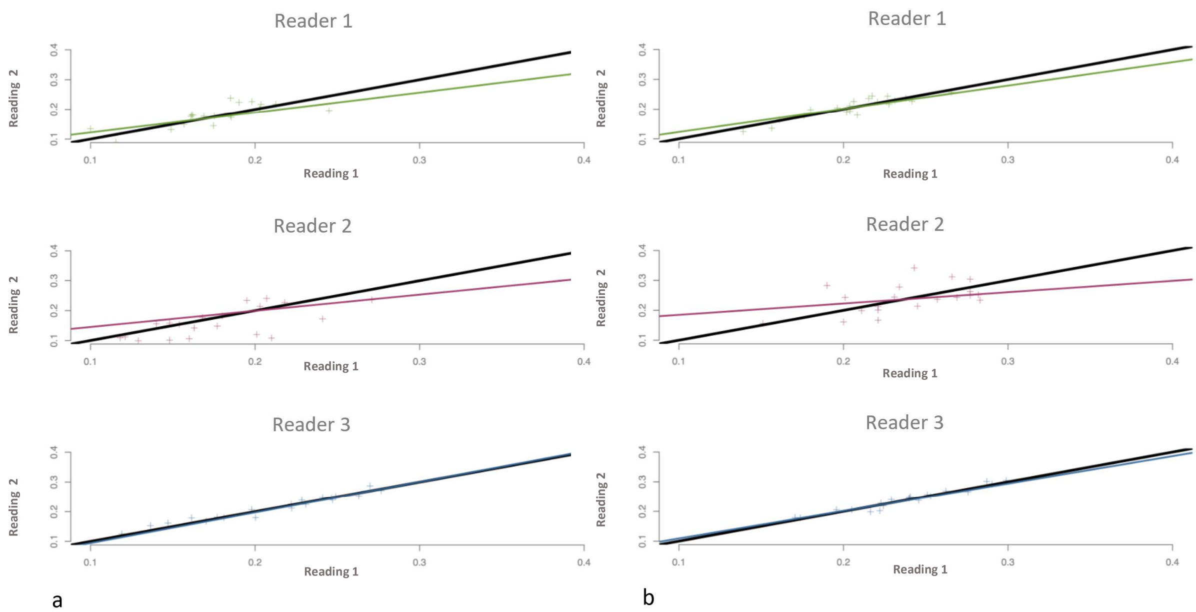
Figure legends

Figure 1: Protocol for measuring the femoral intercondylar notch on coronal MRI slices. Left: reference MRI measurement technique; the notch width is calculated with the A/B ratio. The selected slice is the one where the popliteal groove is best visualized. Right: proposed measurement technique; the same A/B ratio is calculated at the level of the 2 blue lines, which represent the proximal and distal thirds of the notch. The slice is identified by the ACL tibial attachment. The first slice where the popliteal groove appears is selected.

Figure 2: Visual representation of intraobserver correlations between the 2 readings: senior surgeon (Reader 1), junior surgeon (Reader 2) and surgical resident (Reader 3). Left: measurements at the proximal third, right: measurements at the distal third.

Figure 3: Bland-Altman plots of interobserver reproducibility for each technique. a: reference technique; b: proposed technique. FK-ME: comparison between the surgical resident and senior surgeon; FK-YK: comparison between the senior surgeon and junior surgeon; and ME-YK: comparison between the surgical resident and junior surgeon.


B
Lateral condyle width
Medial condyle width
A
Bicondylar width
Inter-femoral notch width
B
A


Reader 1
Reading 2
Reading 1
Reader 2
Reading 2
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a
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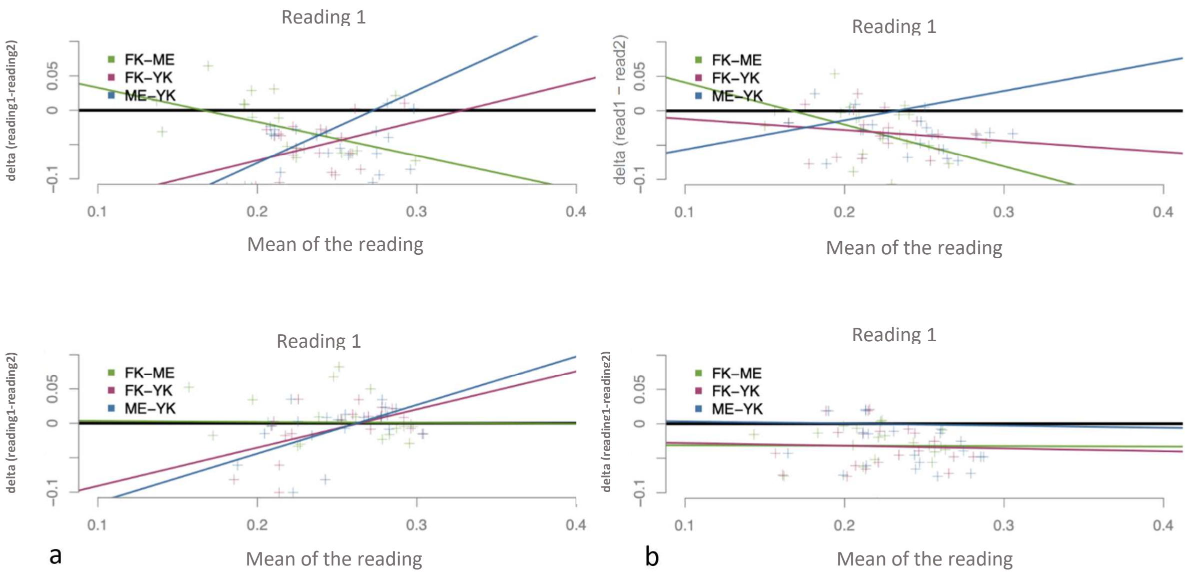
Reader 3
Reading 2
Reading 1
b



Reading 1
FK–ME
FK–YK
ME–YK
delta (reading1-reading2)
Mean of the reading
Reading 1
delta (read1 − read2)
Mean of the reading
Reading 1
delta (reading1-reading2)
Mean of the reading
Reading 1
delta (reading1-reading2)
Mean of the reading
a
b