



Original article

Axial patellar engagement index and patellar tilt after medial patello-femoral ligament reconstruction in children and adolescents[☆]Julien Roger^{a,*}, Anthony Viste^b, Maxime Cieviet-Bonfils^a, Jean-Pierre Pracros^c, Sébastien Raux^a, Franck Chotel^a^a Department of paediatric orthopaedic surgery, hôpital femme-mère-enfant de Lyon, hospices civils de Lyon, université Claude-Bernard Lyon 1, 69500 Bron, France^b Department of orthopaedic surgery, hospices civils de Lyon, centre hospitalier Lyon Sud, 69310 Pierre-Bénite, France^c Department of radiology, hôpital femme-mère-enfant de Lyon, hospices civils de Lyon, université Claude-Bernard Lyon 1, 69500 Bron, France

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ABSTRACT

Background: The medial patello-femoral ligament (MPFL) is a major patellar stabiliser whose reconstruction in adults involves graft fixation within a femoral tunnel. In skeletally immature patients, in contrast, the graft is fixed to the soft tissues to allow normal growth.

The primary objective of this prospective study was to perform computed tomography (CT) and magnetic resonance imaging (MRI) assessments of medium-term correction of patellar tilt and of the axial patellar engagement index (AEI) after a paediatric variant of MPFL reconstruction in skeletally immature patients.

Hypothesis: MPFL reconstruction, performed alone or combined with other procedures in skeletally immature patients, decreases patellar tilt and improves the AEI.

Material and methods: Eighteen children and adolescents with a median age of 14.6 years (range, 8–17 years) who underwent MPFL reconstruction on 20 knees were included in this prospective observational study. A double-strand gracilis tendon graft passed through the medial collateral ligament was used. MPFL reconstruction was performed alone in 13 knees and was combined with lateral retinaculum release, tibial tuberosity translation, and/or trochleoplasty in 7 knees. Patellar tilt and AEI values determined on preoperative and post-operative imaging studies with the quadriceps relaxed and contracted were compared. A physical examination was also performed.

Results: From baseline to last follow-up after a mean of 43 months (range, 24–63 months), patellar tilt decreased from 20° preoperatively to 9° with the quadriceps relaxed and from 33° to 15.4° with the quadriceps contracted. The AEI increased from 0.78 at baseline to 0.93 at last follow-up. No dislocation or subluxation recurrences were recorded during follow-up.

Discussion: The patellar tilt and AEI improvements seen after paediatric MPFL reconstruction confirm the study hypothesis. This is the first prospective study of patellar position in the axial plane as assessed by CT and MRI after paediatric MPFL reconstruction. In everyday clinical practice, 3D assessments of patellar tilt and the AEI should be performed to evaluate correction of the abnormalities.

Level of evidence: II, non-randomised prospective observational study.

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Abbreviations: Anterior tibial tuberosity: ATT; Axial patellar engagement index: AEI; Medial collateral ligament: MCL; Medial patello-femoral ligament: MPFL

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1. Introduction

Factors that contribute to patellar instability include trochlear dysplasia, patella alta, extensor apparatus malalignment, lower-limb rotational malalignment, and rupture of the medial patello-femoral ligament (MPFL) [1]. The MPFL is a major patello-femoral stabiliser [1–3]. Recent insights into the nosology of patellar instability in paediatric patients, combined with advances in surgical techniques, have rekindled interest in the correction of patellar instability. Because the MPFL inserts near the femoral growth plate, the MPFL reconstruction techniques used in adults would impair growth if applied to skeletally immature patients.

An MPFL reconstruction method derived from work by Deie et al. and Fithian et al. [2,3] and suitable for paediatric patients was described in 2010. The gracilis tendon is passed through the medial collateral ligament (MCL) and fixed within two patellar tunnels. This reconstruction procedure can be performed alone or combined with lateral retinaculum release, anterior tibial tuberosity (ATT) translation, and/or trochleoplasty. Radiographs are useful for identifying risk factors for patellar instability and for evaluating the postoperative outcome. Nevertheless, patellar dislocation is a dynamic event that cannot be properly evaluated on radiographs alone [4]. Magnetic resonance imaging (MRI) depicts the position of the patella in all three dimensions. Patellar height and sagittal patello-femoral engagement can be determined on sagittal views [5] and axial patellar engagement on axial views [6]. Axial patellar engagement reflects the severity of the patellar instability [6]. Computed tomography (CT) provides a dynamic assessment of patellar tilt with the knee extended and the quadriceps contracted, i.e., under conditions conducive to patellar dislocation.

No objective evaluation of the outcomes of paediatric MPFL reconstruction has been reported to date. The goal of MPFL reconstruction is correction of patellar tilt on the CT scan and correction of the axial patellar engagement index (AEI) on the MRI scan [6], as well as a sensation of patellar stability experienced by the patient.

The primary objective of this prospective study was to perform computed tomography (CT) and magnetic resonance imaging (MRI) assessments of medium-term correction of patellar tilt and of the axial patellar engagement index (AEI) after paediatric MPFL reconstruction in skeletally immature patients. The working hypothesis was that MPFL reconstruction, performed alone or combined with other procedures in skeletally immature patients, would decrease patellar tilt and improve the AEI. The secondary objectives were to assess the patellar dislocation/subluxation rate and to determine whether pre-operative patellar apprehension was eliminated post-operatively, whether the Kujala score [7] was improved by the procedure, and whether knee motion range was preserved post-operatively.

2. Material and methods

2.1. Patients

This single-centre prospective non-randomised study was performed between January 2011 and September 2014. Eligible patients were children and adolescents who underwent paediatric MPFL reconstruction to treat episodic patellar dislocation defined as any of the following:

- at least two episodes of non-traumatic patellar dislocation;

- patellar instability combined with patello-femoral pain, laxity, evidence of dysplasia, and a patellar tilt angle greater than 20 [8];
- or habitual patellar dislocation upon knee extension [9].

Non-inclusion criteria were subjective patellar instability, patellar instability in knee flexion, absence of follow-up data, and missing preoperative and/or postoperative imaging studies.

The study included 18 consecutive patients (20 knees), 11 girls and 7 boys with a median age at surgery of 14.6 years (range, 8–17 years). The preoperative patellar apprehension test was positive in every case. Patellar height was estimated by determining the Caton-Deschamps index [10,11] and trochlear dysplasia was classified according to Dejour [12]. MPFL reconstruction was performed alone in 13 (65%) knees. Concomitant procedures in the other 7 knees were as follows:

- ATT translation, 4 (20%) knees with patella alta;
- trochleoplasty, 3 (15%) knees with trochlear dysplasia;
- lateral retinaculum release, 6 (30%) knees.

The proportions of patients with each of these additional procedures differ from those seen in adult populations because trochlear remodelling can occur in skeletally immature patients if normal patellar position is achieved, notably in the axial plane.

2.2. Operative technique

The same paediatric MPFL reconstruction technique was used for all 20 knees [1]. Chassaing was the first to describe an MPFL reconstruction technique that did not involve graft fixation within a femoral tunnel [13,14]. The gracilis tendon, which is slender and therefore well suited to this procedure, is harvested. An incision is made above the medial epicondyle to expose the femoral insertion of the MCL. A small longitudinal incision is then made in the posterior third of the MCL insertion site (Fig. 1a) to serve as a femoral reflection pulley for the tendon graft, as described by Deie et al. [2]. However, the tendon graft is detached distally to allow double-strand anatomical reconstruction. The tendon graft is passed through the middle layer of the patellar retinaculum, and its two ends are threaded through a patellar tunnel and fixed (Fig. 1b). This technique provides favourable graft anisometry characteristics, as the graft is under slight tension when the knee is extended and is slack when the knee is flexed [15]. Tension was adjusted with the knee between 20° and 30° of flexion, with the goal of achieving 10% of residual patellar translation. Graft tensioning was the last step of the procedure. In patients with patella alta, either the ATT was transferred distally or, in skeletally immature children, the patellar ligament was transferred [16]. During the procedure, the

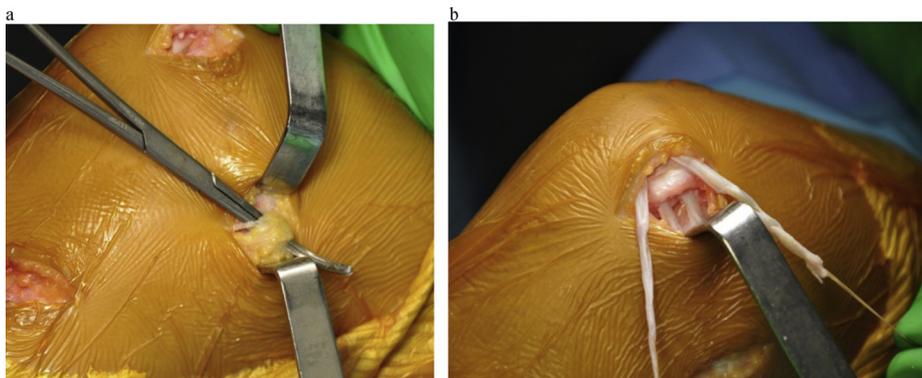


Fig. 1. Operative technique. a: the tendon graft is passed through the medial collateral ligament; b: the graft is then threaded through the patellar tunnels and fixed.

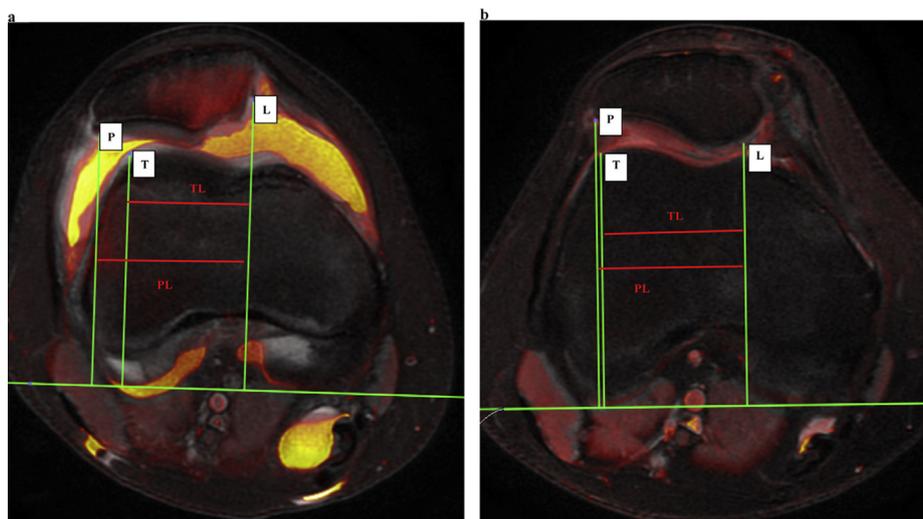


Fig. 2. Measurement of the axial patellar engagement index by magnetic resonance imaging. a: before surgery; b: after surgery. Two superimposed slices are used to identify the trochlear and patellar cartilaginous landmarks. The view on which the lateral trochlear facet is largest is selected. The posterior condylar axis (PCA) is drawn (or transferred to this view if the posterior condyles are more prominent on another view). Point T is marked as the most lateral point of the trochlear facet. The line that is perpendicular to the PCA and travels through T is drawn. The axial slice on which the patella is largest is then selected. Point L is marked as the most medial point of the patellar cartilage. The line that is perpendicular to the PCA and travels through L is drawn. The TL segment is drawn; this segment is the projected length of the patellar cartilaginous surface engaged in the trochlea. Point P is marked as the most lateral point of the patella on the slice on which the patella is largest. The PL segment is drawn; this segment is the projected length of the total patellar surface. Finally, the axial patellar engagement index is computed as the ratio of TL over PL.

surgeon tilted the patella medially and palpated the lateral patello-femoral region (medial tilt test). If no lateral patello-femoral space was felt, the lateral patellar retinaculum was released [17]. Finally, a standard rehabilitation programme was applied after the procedure.

2.3. Assessments

Each knee was evaluated before surgery and at least 24 months after surgery. Median follow-up was 38.7 months (range, 24–63 months). The assessments performed before and after surgery included a physical examination, determination of the Kujala score, radiographs, CT, and MRI (Philips, Ingenia, 1.5 T, 2-mm slices) [18]. The AEI was determined using at least two different axial slices, one through the trochlea and the other through the patella (Fig. 2). Cartilaginous landmarks seen on MRI scans are more accurate than bony landmarks [6]. The AEI is normally close to 1. Patellar tilt was assessed on CT views obtained with the quadriceps relaxed then in maximum isometric voluntary contraction (Fig. 3). In 3 cases, MRI was not performed and both the AEI and patellar tilt were evaluated on the MRI views. Measurements were performed using OsiriX software Osirix® (Pixmeo, Bernex, Switzerland).

The Hospices Civils de Lyon institutional review board approved the study protocol (#17-01). Informed consent was obtained from each patient before study inclusion.

2.4. Statistical analysis

R software (<http://www.r-project.org/>) was used on a Macintosh computer for the statistical analyses. Distribution of quantitative variables was assessed using the Kolmogorov-Smirnov test; when distribution was normal, comparisons were with the independent-samples *t* test. Comparisons of qualitative variables relied on the Chi² test or, when the required conditions were not met, Fisher's exact test. Based on preliminary data, we estimated the required sample size by assuming that the minimal clinically significant AEI change was 0.1. With the alpha risk set at 0.05, 20 knees were required to detect such a change with 90% power.

3. Results

Table 1 reports the median patellar tilt and AEI values before and after surgery. No correlation was found between the preoperative patellar tilt and AEI values.

A trend towards greater patellar tilt improvement was noted in the subgroup of knees managed with lateral retinaculum release (+14.75° with the quadriceps relaxed and +16° with the quadriceps contracted).

No recurrent dislocations were recorded during the median postoperative follow-up of 38.7 months (range, 24–63 months). After surgery, the patellar apprehension test was negative for 19 (95%) knees, and lateral patellar translation was also normal for 19 knees. The median Kujala score improved from 53.4 pre-operatively to 91.4 (range, 84–99) postoperatively ($p < 0.001$). For 19 knees, postoperative range of motion was identical to that of the normal knee (0°–0°–130° [130° minimum]).

4. Discussion

This study reports the outcomes of an MPFL reconstruction procedure suitable for paediatric patients. Both patellar tilt and the AEI were substantially improved after surgery. In addition to objective improvements, good clinical patellar stability was noted with no recurrent dislocation events and with a marked decrease in patellar apprehension. These findings confirm the working hypothesis.

4.1. Position of the patella

The median preoperative AEI of 78% reflects the severity of the patellar instability in the study patients. The AEI improved by 15%, in keeping with the findings in the control group of the study by Guilbert et al. [6]. In addition, MPFL reconstruction decreased patellar tilt to values below 20° in 70.6% of patients with the quadriceps contracted and in 82.4% of patients with the quadriceps relaxed. Similarly, the amount of patellar tilt correction in previous studies of adult and paediatric patients ranged from 9° to 17° [15,19]. Few studies have reported patellar tilt values with the quadriceps relaxed and contracted, and data on patellar tilt

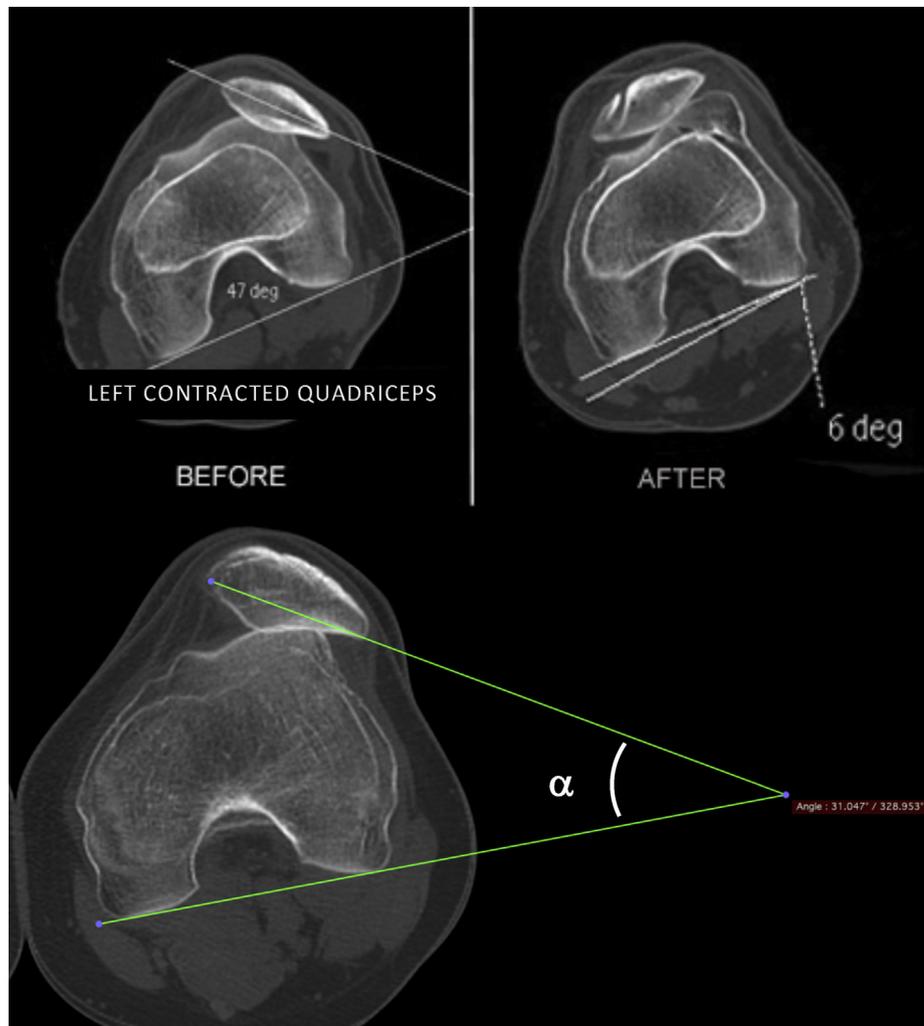


Fig. 3. Computed tomography measurement of patellar tilt (alpha: α).

after MPFL reconstruction are scant. In addition, to our knowledge, this study is the first to assess AEI after MPFL reconstruction in paediatric patients. Guilbert et al. reported a mean pre-operative AEI value of 84% in patients who had surgery for patellar instability, compared to 94% in controls [6]. The MPFL is a triangular sheet of fibrous tissue that controls patellar tilt and translation, particularly between 0° and 30° of knee flexion [20]. Impairment of the capsule and ligaments, including the MPFL, explains 83% of cases of episodic patellar dislocation. Patellar tilt as measured using CT is an objective criterion for determining whether MPFL reconstruction is in order. Values below 20° are considered abnormal. In addition,

patellar tilt is useful for monitoring postoperative outcomes. Voluntary contraction of the quadriceps is used to replicate the effects of the quadriceps contraction produced during weight bearing. The AEI reflects the percentage of the patella that is engaged within the trochlear groove; a normal value indicates complete side-to-side engagement. A major advantage of the AEI is independence from both gender and body habitus. Charles et al. demonstrated that most of the patello-femoral parameters previously measured by CT can be obtained from MRI views [21,22]. The PEI is not yet widely used as its assessment requires postoperative MRI. Furthermore, the lateral part of the trochlea may be difficult to assess in patients

Table 1
Patellar tilt and axial patellar engagement index values measured by computed tomography and magnetic resonance imaging before and after paediatric medial patello-femoral ligament reconstruction.

	Patellar tilt, QR, mean \pm SD (range)	Patellar tilt, QC, mean \pm SD (range)	APEI
Before surgery	20 \pm 12.9 (2.5–53)	33 \pm 11.6 (3.1–52)	0.78 \pm 0.19
After surgery	9 \pm 9.5 (2–35)	15.4 \pm 13.9 (2–58.9)	0.93 \pm 0.08
Difference	11	14.6	0.15
p value	0.002	0.006	0.001
	Percentage		
Tilt > 20° before surgery	52.6	88.9	
Tilt > 20° after surgery	17.6	29.4	
p value	0.019	0.0005	

QR: quadriceps relaxed; QC: quadriceps contracted; APEI: axial patellar engagement index; SD: standard deviation.

with severe trochlear dysplasia or a fracture of the lateral patellar border, neither of which occurred in our study.

4.2. Recurrent patellar dislocation

No dislocation recurrences were recorded during our study. Similarly, in a study of 21 patients managed by anatomical MPFL reconstruction, Nelitz et al. recorded no recurrences during 2 years of prospective follow-up [23]. Failure rates of surgery for habitual patellar dislocation in paediatric patients vary between 10% and 30%. However, in the medium term, 80% of knees are asymptomatic. Outcomes of surgery for episodic patellar dislocation in paediatric patients are good in 75% to 80% of cases. The surgical strategy is tailored to each patient, with combinations of procedures being performed as needed. Consequently, the contribution of each procedure to the outcome is difficult to assess. Nevertheless, the failure rate of the paediatric procedure described here can be estimated at less than 5% [1].

4.3. Patellar apprehension test

Patellar apprehension persisted for a single knee (1/20, 5%). In a comparison of MPFL reconstruction plus medial retinaculum plication, MPFL reconstruction plus lateral retinaculum release, and medial retinaculum plication plus lateral retinaculum release, Du et al. found that outcomes were best after MPFL reconstruction plus lateral retinaculum release [24]. This last method produces the best joint congruence as assessed by 3D reconstruction and the best knee function scores.

4.4. Kujala score

Kujala score values are heavily influenced by pain and motion range. In our study, postoperative patello-femoral pain was noted in a single knee (5%). Tendon graft tensioning is one of the most challenging steps of the surgical procedure. The goal is to achieve the ideal degree of tension that produces normal patello-femoral kinematics and joint constraints. Excessive tension is a devastating event that can require section of the graft to relieve the pain [25]. When surgery included lateral retinaculum release, this procedure was performed before graft tensioning, possibly explaining the absence of AEI or patellar tilt overcorrection in our patients. Furthermore, graft fixation to a soft-hard system (MCL and patella) may explain the low frequency of postoperative pain.

4.5. Study limitations

The study limitations include the small number of patients. MPFL reconstruction is uncommonly performed in paediatric patients, and the available population was further decreased by the use of stringent non-inclusion criteria. Another point that deserves discussion is the inclusion of knees managed by isolated MPFL reconstruction and of knees for which other procedures were performed also. These other procedures affect patellar tilt and the AEI. More specifically, the AEI is influenced not only by the condition of the MPFL, but also by trochlear dysplasia [6]. However, the study objective was to assess axial parameter correction after surgery tailored to the needs of each individual knee. Correlations between the AEI and trochlear dysplasia were not investigated, as trochlear dysplasia may be difficult to evaluate in paediatric patients. Outcomes were evaluated at least 24 months after surgery. However, the time to last postoperative imaging varied widely, from 24 to 63 months. Furthermore, the absence of MRI for 3 (15%) knees may have influenced the findings, since CT is less accurate than MRI for determining the AEI. However, this proportion of only 15% of patients without MRI is acceptable. Dejour et al. described the

measurement of sagittal patello-femoral engagement by MRI [5]. Evaluation of sagittal patellar engagement in the trochlea adds to the information provided by patellar height measurement. This parameter can help to identify inadequate patellar engagement in patients without patella alta, and the results may lead to a reappraisal of the need for ATT osteotomy. Sagittal patello-femoral engagement was not assessed in our study. Taking this parameter into account in future work may provide a more extensive picture of the corrected abnormalities in the three dimensions.

5. Conclusion

Paediatric MPFL reconstruction performed alone or in combination with other procedures is effective in correcting patellar tilt and the AEI and provides good clinical outcomes. Consequently, it is a technique of choice for the treatment of episodic patellar dislocation in children and adolescents. In everyday clinical practice, patellar tilt should be assessed concomitantly with the AEI on imaging studies obtained before and after surgery. Given the objective evidence of improved patellar positioning in the axial plane, this paediatric procedure is recommended, in combination with corrective procedures targeting other causes of patellar instability if needed, as it spares the growth plates and provides anatomical reconstruction.

Disclosure of interest

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The other authors declare that they have no competing interest.

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Contributions

JR provided outpatient follow-up to the patients, reviewed the computed tomography and magnetic resonance imaging scans, performed the statistical analysis, and drafted the manuscript.

AV contributed to draft the manuscript.

MC participated in the design of the study, called the patients, and examined the patients during follow-up outpatient visits.

JPP is a radiologist and performed the imaging studies.

SR contributed to conceive the study.

FC conceived the study, contributed to coordinate the study and to draft the manuscript, and examined the patients during outpatient visits.

All authors read and approved the final version of the manuscript.

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