Correlation Between Trochlear Groove Depth and Patellar Position During Open and Closed Kinetic Chain Exercises in Subjects With Anterior Knee Pain

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The purpose of this study was to correlate the trochlear shape and patellar tilt angle and lateral patellar displacement at rest and maximal voluntary isometric contraction (MVIC) exercises during open (OKC) and closed kinetic chain (CKC) in subjects with and without anterior knee pain. Subjects were all women, 20 who were clinically healthy and 19 diagnosed with anterior knee pain. All subjects were evaluated and subjected to magnetic resonance exams during OKC and CKC exercise with the knee placed at 15, 30, and 45 degrees of flexion. The parameters evaluated were sulcus angle, patellar tilt angle and patellar displacement using bisect offset. Pearson’s $r$ coefficient was used, with $p < .05$. Our results revealed in knee pain group during CKC and OKC at 15 degrees that the increase in the sulcus angle is associated with a tilt increase and patellar lateral displacement. Comparing sulcus angle, patellar tilt angle and bisect offset values between MVIC in OKC and CKC in the knee pain group, it was observed that patellar tilt angle increased in OKC only with the knee flexed at 30 degrees. Based on our results, we conclude that reduced trochlear depth is correlated with increased lateral patellar tilt and displacement during OKC and CKC at 15 degrees of flexion in people with anterior knee pain. By contrast, 30 degrees of knee flexion in CKC is more recommended in rehabilitation protocols because the patella was more stable than in other positions.

Keywords: anterior knee pain, patellar kinematics, magnetic resonance imaging, exercise

Anterior knee pain (AKP) is defined as a diffuse intermittent pain in the anterior region of the knee (Collado & Fredericson, 2010) that increases during functional activities such as walking upstairs and downstairs, squatting, and sitting for long periods (Powers, 2000; Cowan et al., 2002), becoming a limitation in activities of daily living, thus reducing the quality of life of these patients (Carry et al., 2010). This dysfunction affects mainly young sedentary women (Cowan et al., 2001, 2002).

Although AKP has a multifactor and controversial etiology (Collado & Fredericson, 2010), alterations in patellar kinematics have been constantly discussed in literature as one of the main etiologic factors of AKP (Sheehan et al., 2009; Lin et al., 2008; Powers et al., 2003). Therefore, knowledge of patellar kinematics is crucial both for diagnosis and the indications of exercises for patients with AKP.

Patellar kinematics can be altered by morphological differences in the patellar surface and the femoral trochlea (Powers, 2000; Harbaugh et al., 2010), since subjects with AKP demonstrate reduced femoral trochlear surface depth compared with individuals with no AKP (Keser et al., 2008). Moreover, reduction in trochlear groove depth could increase patellar lateral tilt and patellar height (Harbaugh et al., 2010). However, these authors only analyzed open kinetic chain (OKC) exercises, and OKC exercises are currently known for causing an increase of the patellar lateral displacement (Sheehan et al., 2009; Powers et al., 2003; Powers, 2000; McNally et al., 2000). On the other hand, there are no studies in literature that address the influence of patellofemoral shape and patellar kinematics during closed kinetic chain (CKC) exercises.
Exercises in OKC and CKC are broadly used in treatments for individuals with AKP; however, both exercises could lead to an increase in the patellar lateral displacement and tilt, and this increase in the patellar movement is not recommended for these patients (Powers et al., 2003). Although some authors criticize OKC exercises (Powers, 2000; Wilk & Reinold, 2001; Bakhtiary and Fatemi, 2008) because they cause an increase in the lateral displacement of the patella and increase the compressive force of the patellofemoral joint close to total knee extension (Steinkamp et al., 1993; Escamilla et al., 1998). Other authors report that both OKC and CKC exercises must be used in the treatment for individuals with AKP, as long as they do not enhance the pain status of these patients (Witvrouw et al., 2004; Escamilla et al., 2009).

Open and closed kinetic chain exercises have specific behaviors regarding patellofemoral compressive force and knee movements, ranging according to the position of the knee and the type of kinetic chain (Steinkamp et al., 1993; Escamilla et al., 1998). According to Powers et al. (2003), other factors also affect the rehabilitation program for individuals with AKP, including patellar kinematics. Therefore, the comparison of patellar kinematics in OKC and CKC exercises would help to reach a better understanding about patellar behavior and in prescribing these exercises during all stages of rehabilitation in AKP patients.

Only Powers et al. (2003) compared patellar kinematics during OKC and CKC exercises and found that exercises in OKC increase the lateral tilt of the patella compared with CKC exercises, but these authors evaluated women with patellar subluxation associated to AKP. Therefore, understanding patellar kinematics not only during OKC exercises, but also during CKC, besides comparing the exercises could provide better support for the rehabilitation evaluation and its indications for individuals with AKP.

Thus, the aim of this research was to correlate femoral trochlear depth measurements and patellar tilt and lateral displacement during OKC and CKC exercises in individuals with AKP, and to compare patellar kinematics between maximal voluntary isometric contraction (MVIC) in OKC and CKC.

Hence, this present study’s hypothesis is that a decreased femoral trochlea depth, especially in individuals with AKP, can lead to an increase in the patellar displacement and lateral tilt in both exercises.

**Methods**

In this present study, 39 female volunteers who fit the inclusion/exclusion criteria for the control group and the AKP group (Table 1) were evaluated. Both groups were composed of sedentary women so that a possible physical training would not affect the patellar kinematic response. Out of these 39 volunteers, 20 were included in the control group and 19 were included in the AKP group (Table 2). The volunteers were informed about the procedures of this study and signed a free and informed consent form, in accordance to the norms of the institution’s Research Ethics Committee (process number: HCRP 4250/2005).

All volunteers underwent magnetic resonance (MR) exams during rest and MVIC during OKC and CKC exercises. Images were obtained using 1.5 T Siemens equipment, Magnetom Vision (Erlangen, Germany), and a coil measuring 52 × 21 cm. The center of the coil was aligned to the center of the patella. Images were obtained at a rate of one image per 3 s, using the following parameters: repetition time (TR), 15 ms; echo time (TE), 6 ms; matrix size, 512 × 128; slice thickness, 7 mm. Acquisition time for the 6 frames of each evaluated situation, rest and MVIC was 18 s and the average time for each examination was 50 min.

The exam was done with the volunteers’ knees placed at 15, 30 and 45 degrees of flexion during OKC and CKC exercises and all exercise were randomized. To achieve the maximal voluntary isometric contraction (MVIC) during whole exercises the volunteers were requested through verbal encouragement (“Go! Go! Go! Keep it going! Keep it going!”) (Coqueiro et al., 2005); however, the force made during the exam was not controlled because of an interference generated on MR imaging by the metallic devices used to make the

**Table 1 Inclusion and exclusion criteria for the control and the anterior knee pain (AKP) groups**

<table>
<thead>
<tr>
<th>Control Group</th>
<th>AKP Group</th>
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<tr>
<td><strong>Inclusion Criteria</strong></td>
<td><strong>Inclusion Criteria</strong></td>
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<tr>
<td>Maximum presence of two signs indicating AKP observed on the functional evaluation (Felicio et al., 2010).</td>
<td>Minimum presence of three signs indicating AKP observed on the functional evaluation (Coqueiro et al., 2005).</td>
</tr>
<tr>
<td>Absence of pain verified through Visual Analog Scale (VAS) in the last month.</td>
<td>Presence of pain of at least 3 cm on VAS in the last month (Cowan et al., 2001).</td>
</tr>
<tr>
<td>—</td>
<td>Account of pain in at least two functional activities (Cowan et al., 2001, 2002; Powers et al., 2003).</td>
</tr>
<tr>
<td><strong>Exclusion Criteria</strong></td>
<td><strong>Exclusion Criteria</strong></td>
</tr>
<tr>
<td>History of lesion or surgery on the bone/joint/muscle system of the hip and ankle and individuals with neurological, cardiovascular and rheumatologic illnesses.</td>
<td>Presence of patella dislocation episodes.</td>
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force measurement. There was a 2 min rest between contractions. Data collection was made in three repetitions for each activity and the mean value was computed for statistical analysis. A wood support with hinges made of nonmetallic material for setting the knee angles was used to perform the exercises, thus not causing interferences on the MR images (Figure 1A). Belts were used to stabilize the hip, ankle and foot. The images were achieved on the axial plan of the patellofemoral joint, with a relaxed quadriceps and during MVIC in OKC and CKC for each knee angle (Figure 1B). The selected image for analysis among the 6 frames was the one with the largest patellar mediolateral diameter (Felicio et al., 2010; Powers, 2000). The analysis of the sulcus angle (SA), patellar tilt angle (PTA) and patellar displacement using bisect offset (BO) was done using the e-Film Medical software, version 1.8.3 (Milwaukee, USA).

The parameters observed through the MR were SA, PTA and BO (Figure 2). The sulcus angle (SA) is formed between the lateral and medial facets of the femoral

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control ($n = 20$)</th>
<th>AKP ($n = 19$)</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>21.5 ± 2.16</td>
<td>23.47 ± 3.24</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>160.75 ± 5.23</td>
<td>161.63 ± 2.24</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>54.44 ± 5.23</td>
<td>57.89 ± 6.91</td>
</tr>
<tr>
<td>Kujala score (out of 100)</td>
<td>99.0 ± 2.3*</td>
<td>77.9 ± 8.8</td>
</tr>
<tr>
<td>Visual Analog Pain Scale (out of 100)—during step up/down</td>
<td>—</td>
<td>22 ± 18</td>
</tr>
<tr>
<td>Length of pain (months)</td>
<td>—</td>
<td>60.6 ± 27.2</td>
</tr>
<tr>
<td>Q-angle (degrees)</td>
<td>17.9 ± 1.4</td>
<td>20.1 ± 4.2*</td>
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</table>

Note. Only Kujala score and Q angle were significantly different between groups. $t$ Student test ($*p < 0.05$).

Figure 1 — Custom-made nonferromagnetic support (A) used during voluntary isometric contraction in OKC (c) and CKC (d) at angles 15°, 30°, and 45° (B). The arrow represents the direction of force made by the volunteer.

Figure 2 — Magnetic resonance images showing (A) SA—sulcus Angle, (B) PTA—patellar tilt angle, (C) BO—bisect offset.
trochlea (Powers, 2000; Harman et al., 2002), the patellar tilt angle (PTA) is formed by the intersection between the line parallel to the posterior femoral condyles and the line formed by the medial and lateral borders of the patella (Powers, 2000; Powers et al., 2003; Ward et al., 2002) and the bisect offset (BO), measured by drawing one line connecting the posterior femoral condyles and then projecting a perpendicular anterior line through the deepest point of the femoral groove and another line connecting the medial and lateral borders of the patella, and measuring the distance between the lateral border of the patella and the vertical line (Harman et al., 2002; Powers et al., 2003; Ward et al., 2002). These anatomic points were visually determined in the software on the selected slide.

The intraclass correlation coefficients (ICC) of SA, PTA and BO measurements in both groups were applied to analyze intraexaminer reliability, which were done with an interval of 7 days. The ICC was done through PROC GLM of the Statistical Analysis System software (SAS, San Diego, California), version 8. The ICC values were classified as follows: <0.4 poor reliability, between 0.4–0.75 moderate reliability and >0.75 excellent reliability (Fleiss et al., 2003).

The comparisons of SA, PTA and BO measurements between exercises in OKC and CKC were performed using the mixed effects linear model (McLean et al., 1991), with significance level at 5%. After the construction of models, a residue analysis was performed to check the associated suppositions. This adjustment was performed through the mixed procedure (PROC MIXED) of the SAS version 8 for Windows software.

The SA, PTA and BO data were correlated in each group during rest and the two types of exercises. To set the correlation coefficient (r value), the Pearson correlation coefficient was used, with p < .05. The correlation strength was analyzed according to Chan (2003), in which r values greater than 0.5 were considered clinically relevant (Harbaugh et al., 2010). For r values greater than 0.5, the slope values were calculated.

**Results**

The measurements of SA, PTA and BO showed excellent levels of intraexaminer reliability (ICC > 0.75) for both groups and all exercises.

When comparing the types of exercise in the control and AKP groups, it was observed that, during MVIC in OKC with the knee flexed at 15 degrees, the patella articulates with a shallower femoral trochlea in AKP subjects compared with exercise in CKC (Figure 3).

Regarding patellar tilt angle (PTA), a greater lateral tilt was observed in the AKP group with the knee flexed at 30 degrees during exercises in OKC compared with exercises in CKC (Figure 3).

In the control group, the correlation coefficient (r value) between SA and PTA demonstrated a negative and significantly fair correlation level during CKC with the knee positioned at 30° of flexion. As for the correlation between SA and BO, it was positive with the knee at 15° of flexion during MVIC in CKC. The degree of association between BO and PTA was positive and considered fair and fairly strong for all positions of the knee except at 15° of flexion (Table 3).

The correlation between SA and PTA measurements in the AKP group, demonstrated positive and significant values with the knee positioned at 15 degrees of flexion for all situations, resting, MVIC in OKC and CKC, varying between fair and fairly strong. With the knee at 15 degrees of flexion, the correlation between SA and BO, in OKC and CKC, demonstrated positive and significant values, also varying between fair and fairly strong levels (Table 4). The correlation between SA and BO during MVIC in OKC at 45 degrees of flexion was negative and significant, with a fair correlation level (Table 4).

The slope values calculated based on the graph of the dispersion between SA and PTA measurements with the knee flexed at 15 degrees in the AKP group showed similar values between and during MVIC in OKC (0.47) and CKC (0.48) and a smaller slope was observed at rest (0.38). Nevertheless, the opposite occurs when the slope of the SA measurements and the lateral displacement of the patella (BO) are observed for the same knee position in individuals with AKP: the MVIC in CKC (0.41) and in OKC (0.47) show a smaller slope in relation to rest (0.56) (Figure 4).

**Discussion**

In the current study it was observed that lateral patellar tilt increase in OKC with the knee flexed at 30 degrees in the AKP group, compared with the exercise in CKC. Though Powers et al. (2003) evaluated individuals with lateral subluxation, they did not find differences regarding patellar lateral tilt in CKC and OKC exercises. Nevertheless, these authors did verify that patellar lateral displacement was greater in OKC from 30 to 12 degrees of knee flexion compared with CKC. In the current study, however, no statistical difference in BO was found, but it was observed that the lateral displacement of the patella was greater during OKC, and, according to Powers 2000, lateral patellar displacement may be associated with patellar tilt.

The femoral trochlea morphology was analyzed through SA and correlated with the patellar kinematic measurements, as the patellar lateral tilt and displacement. According to the data in this study, it is observed that, especially for the AKP group with the knee at 15° of flexion, a reduced femoral trochlea surface depth is associated with an increase both in tilt and in lateral displacement of the patella. These data were also observed by Keser et al. (2008) and Powers (2000).

Although we observed that during MVIC in OKC with the knee flexed at 30 degrees the patella articulates with a shallower trochlea compared with MVIC in CKC, it appears that the relationship between femoral trochlea depth does not affect the correlation with the parameters of patellar kinematics, considering that this correlation is not related to the type of exercise performed, if during OKC or CKC.
Our data indicate that femoral morphology is an important factor to evaluate in AKP patients because it is associated with alterations in the patellar kinematic, mainly in the last degrees of the extension, which could be the causing factors of AKP (Sheehan et al., 2009; Lin et al., 2008; Powers et al., 2003).

The slope values for the AKP group with the knee flexed at 15 degrees showed that femoral trochlea depth may affect patellar lateral displacement and tilt regardless of the type of exercise. According to Powers (2000) and Witvrouw et al. (2004), caution is needed when performing exercises that favor patellar lateral displacement and tilt. Therefore, although exercises in CKC with the knee flexed at 15 degrees produce low patellofemoral compressive forces (Steinkamp et al., 1993), they should be indicated in a later stage of treatment for AKP.

Considering the knee position at 30 and 45 degrees in OKC and CKC exercises, the trochlea morphology is demonstrated as not correlates to patellar lateral tilt and displacement in both exercises. According to Felicio et al. (2010) and Manske and Davies (2003), in these angulations of the knee, the patella is better positioned in the trochlear groove, hence with better patellar lateral tilt and displacement and less patellofemoral stress (Steinkamp et al., 1993). According to Steinkamp et al. (1993), exercises in CKC from 45 to 0 degrees of knee flexion produce low compressive patellofemoral force; however, not only patellofemoral stress must be considered, but also pain and patellar lateral displacement and tilt when recommending exercises for AKP patients.

According to Witvrouw et al. (2004), a conservative treatment for individuals with AKP should include OKC and CKC exercises during all stages of treatment; however, different knee position associated with these exercises can cause an increase in patellofemoral stress.
(Steinkamp et al., 1993); hence, exercises that may increase compressive forces should be used in the final stages of treatment of AKP patients.

Our data reveal that with the knee positioned at 15 degrees of flexion, the femoral trochlea morphology influences patellar kinematic both in OKC and CKC exercises.

These results partially confirm the hypothesis, since only with the knee positioned at 15 degrees, independently of the type of exercise; a reduced femoral trochlea surface depth is associated with an increase in patellar lateral tilt and displacement, despite this reduced femoral trochlea depth not being a criterion for trochleoplasty, that is, an SA greater than 145 degrees (Schöttle et al., 2005).

Although exercises in OKC do not produce axial load, some studies suggest that these exercises recruit the quadriceps muscle selectively and with more intensity, especially the vastus medialis obliquus and vastus lateralis obliquus, which are the main stabilizers of the patella (Bevilaqua-Grossi et al., 2004, Escamilla et al., 1998). Exercises in CKC, in the other hand, favor muscular synergism of the lower limbs, as they are related with the presence of axial load, besides simulating functional activities (Stensdotter et al., 2003, Escamilla et al., 1998). Hence, both exercises should be included throughout the rehabilitation program of individuals with AKP (Witvrouw et al., 2004).

As the effects of muscle contraction are yet to be studied, the indication for these exercises during a

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**Figure 4** — Graphs of linear correlation ($r$ value) for SA, PTA and BO in open and closed kinetic chain.
Table 3 Correlation values ($r$) between sulcus angle (SA), patellar tilt angle (PTA) and bisect offset (BO) in the 15, 30 and 45 degrees of knee flexion for the control group ($n = 20$)

<table>
<thead>
<tr>
<th></th>
<th>SA $\times$ PTA</th>
<th>SA $\times$ BO</th>
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<tbody>
<tr>
<td><strong>15° of Knee Flexion</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>0.15</td>
<td>0.36</td>
</tr>
<tr>
<td>OKC</td>
<td>0.14</td>
<td>0.31</td>
</tr>
<tr>
<td>CKC</td>
<td>0.26</td>
<td>0.5*</td>
</tr>
<tr>
<td><strong>30° of Knee Flexion</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>–0.16</td>
<td>–0.26</td>
</tr>
<tr>
<td>OKC</td>
<td>–0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>CKC</td>
<td>–0.54*</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>45° of Knee Flexion</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>–0.29</td>
<td>–0.42</td>
</tr>
<tr>
<td>OKC</td>
<td>–0.37</td>
<td>–0.34</td>
</tr>
<tr>
<td>CKC</td>
<td>–0.54</td>
<td>–0.29</td>
</tr>
</tbody>
</table>

* $p < 0.05$.

strength protocol should be performed with caution, because muscle contraction is an important patellar dynamic stabilizer, especially at the end of the knee extension, which has not been evaluated in this paper. Another aspect to be considered is that due to the limitations of the MR equipment, it was not possible to control the force load during the evaluated exercises, or to perform the dynamic contraction during image recording. Shellock (2003) had reported that recording images during MVIC reduced the presence of movement artifacts. Furthermore, isometric exercises, especially of the quadriceps muscle, are routinely used in programs to increase muscular strength in individuals with AKP (Hart, 2010).

Hence, we may conclude that exercises with the knee positioned at 30 and 45 degrees of flexion do not demonstrate correlation between trochlear anatomy and patellar kinematic in both exercises; however, exercises in CKC demonstrate a more stable patella, and they can be indicated for physiotherapeutic rehabilitation throughout all phases in subjects with AKP without patellofemoral maltracking.

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References


