**ORIGINAL ARTICLE**

# Jumper's knee mechanical consequences in professional basketball players: the "Camel's Back curve"

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## Abstract

**Purpose** Jumper's knee is characterized by an anterior knee pain during tendon palpation and can be classified in overuse pathologies, secondary to repetitive jumps. The prevalence is high in professional basketball players. It is responsible for an alteration of the motor control inducing a strength deficit of the quadriceps. We aimed to describe an isokinetic curve anomaly, a double-humped curve called "Camel's Back curve", consequence of a jumper's knee history.

**Methods** 170 Professional basketball players were enrolled ($24.8 \pm 4.6$ years; $91.8 \pm 12.0$ kg, $194 \pm 9.0$ cm). All players performed isokinetic tests of the knee extensors on a concentric mode at the angular speed of 60°/s and 180°/s.

**Results** 43 players had a jumper's knee history and 35 (81%) had a "Camel's Back curve" at 60°/s. The sensitivity and the specificity of this curve were 81.3% and 100%, respectively. The minimum torque of strength was decreased from 12 to 18% compared to the 2 maximal peaks. Yet, the strength measured every 5° of ROM was significantly different between the players with "Camel's Back curve" and those with normal curve.

**Conclusions** "Camel's Back curve" had never been described in that context. It may be secondary to a protective inhibitory mechanism which could alter jumping. The presence of a "Camel's Back curve" would enable clinicians to adapt physical preparation, knee rehabilitation, and trainings to improve players performances.

**Keywords** Patellar tendon · Jump · Quadriceps · Basketball · Isokinetic

## Abbreviations
ANOVA  Analysis of variance
LSI  Limb symmetry index
PM&R  Physical medicine and rehabilitation
ROM  Range of motion

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## Introduction

Patellar tendinopathy known as jumper's knee was reported for the first time in 1973 (Blazina et al. 1973). Jumper's knee is characterized by anterior knee pain during tendon palpation and can be classified in overuse pathologies, secondary to repetitive jumps and changes of direction (Balčiūnas et al. 2006; Van der Worp et al. 2014, 2016; Rosso et al. 2015). Indeed, during basketball practice, players realize 50–60 changes of direction and 40–60 jumps per match (Van der Worp et al. 2016). Jumper's knee prevalence in basketball players is estimated at about 32% (Lian et al. 2005). Clinically, Jumper's knee is responsible for a control motor alteration inducing a strength deficit of the quadriceps, either because of a protection mechanism or an inhibition induced by pain (Dvir 1991; Cook and Purdam 2009; Visnes et al. 2013; Rudavsky and Cook 2014; Rio et al. 2016; Cook et al.

2016). Jumper's knee treatment always includes a phase of muscle strength recovery at different knee ranges of motion (Rudavsky and Cook 2014).

In case of jumper's knee, muscle strength is rarely measured with isokinetic dynamometer, whereas strength deficit can be easily and precisely measured with this reproducible method (Dvir 1991; Impellizzeri et al. 2008). In jumper's knee history, we have already reported isokinetic quantitative strength deficit of the knee extensors of $25 \pm 10\%$ at an angular speed of 60°/s in high-level basketball players (Dauty et al. 2007). Sometimes, an association with an abnormal aspect of the isokinetic curve was highlighted (a double-humped curve). This abnormal curve called "Camel's Back curve" is rarely described. However, it could reflect a mechanical consequence of jumper's knee, explaining a loss of athletic performance. Very few authors have described the "Camel's Back curve" (Croisier and Crielaard 1999; Ayalon et al. 2002). Ayalon et al. (2002) showed that 2 independent examiners were able to identify 3 different types of abnormal curves including the "Camel's Back curve" and normal "inverted U-shape" curves in 28 knees of 14 operated patients (kappa coefficient: 0.946 [0.864–1.028]; $p < 0.0001$). Moreover, the "Camel's Back curve" has been used to develop rehabilitation programs (Rudavsky and Cook 2014). In these rehabilitation programs, quadriceps strengthening exercises are performed only at limited angular knee range of motion (between 0° and 30° of knee flexion) or at a fast isokinetic speed, in order not to cause the occurrence of a Camel' back Curve. Croisier and Crielaard described also this type of curve at specific angular speeds in a few cases during the follow-up after anterior cruciate ligament reconstruction (Croisier and Crielaard 1999), but it has never been described in population at risk of jumper's knee such as basketball players.

As "Camel's Back curve" is often found in association with a quantitative strength deficit in professional basketball players during isokinetic testing, the first aim of this study was to describe precisely this curve anomaly and the second one was to study its link with a jumper's knee history.

## Methods

### Subjects

We included all the professional basketball players of a French second division male team evaluated at the beginning of 15 sport seasons, from 2002 to 2017 (Fig. 1). Exclusion criteria were the incapacity to practice basketball either during training or during pre-season exhibition matches because of an injury. We also excluded players with a history of serious knee injury or thigh muscular injury, if they had an isokinetic quadriceps strength deficit superior
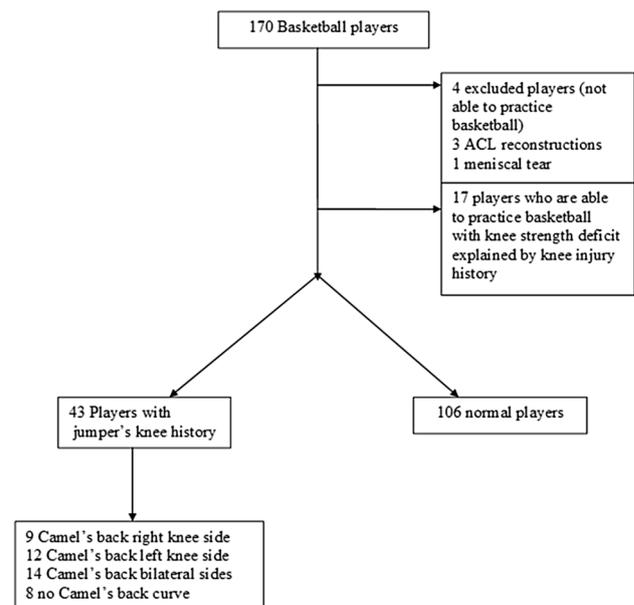


**Fig. 1** Flow chart

to 10% considered as a sequel of previous injuries (Grace et al. 1984; Schiltz et al. 2009). All the players with jumper's knee history were interviewed on the severity of their current symptoms with the Victorian Institute of Sport Assessment Score-Patella (VISA score) (Visentini et al. 1998). All these patients had an ultrasound imaging of the patellar tendon with signs of tendinopathy: tendon thickening and/or a hypo-echogenic area and/or intra-tendinous calcifications, especially close to the apex of the patella (Cook et al. 2001; Gisslèn et al. 2005; Visnes et al. 2015).

### Procedures

All the tests were performed at the beginning of the sport seasons using a CybexNorm® isokinetic dynamometer (Lumex Inc. Ronkonkoma, NY, USA). Every session was preceded by a 10-min ergocycle warm up (70 rpm at 100 W) and stretching exercises. Each subject was seated with the hip angle flexion of 85°. The mechanical axis of the dynamometer was aligned with the lateral epicondyle of the knee. The trunk and the thigh were stabilized with belts. The knee range of motion (ROM) was 100° (100° to 0° = full knee extension). Torque was gravity-corrected at 45° of knee flexion and the dynamometer recalibration was monthly performed in accordance with the manufacturer's instructions.

After familiarization with the isokinetic movements (three submaximal followed by two maximal movements), the basketball players were tested over three repetitions at the angular speed of 60°/s followed by five repetitions at 180°/s in concentric mode. A 30-s recovery period was

allowed between both series. The two knees were evaluated in a random order after instruction and with verbal encouragement and visual feedback. All evaluation tests were conducted by the same physician specializing in physical medicine and rehabilitation according to the method previously described by Dauty et al. (2007). Isokinetic strength was normalized to the body mass. The knee extensors and flexors Limb Symmetry Index (LSI) of the maximal strength and of the total work (area under the curve was calculated with the formula: non-dominant limb/dominant limb) for healthy players (Schiltz et al. 2009) and with the formula: limb with jumper's knee history/limb without jumper's knee history for players with a history of jumper's knee. The dominant limb was defined as the one used preferably in a single-legged jump (Zakas et al. 1995).

A "Camel's Back curve" was defined by a double hump curve with two peak torques separated by a local minimum value (a drop of curve superior to 10%), constantly present during all the repetitions (Dvir 1991). Two types of "Camel's Back curve" were identified depending on whether the first peak was greater than the second (type 1) or inversely (type 2). More precisely, isokinetic strength of the extensors was extracted every 5° of the knee ROM from 100° to 0° (full knee extension) at an angular speed of 60°/s for each basketball player. Data sampling frequency was 200 Hz and data analysis was done in increments of 5° knee joint angles, starting from 100° to 0° knee extension (the data processing was performed by the Cybex software, Lumex Inc. Ronkonkoma, NY, USA and the data extraction with Excel 2010, Microsoft Corporation). The strength parameters were the angle-specific torque at each increment. Reproducibility of concentric isokinetic measures is excellent with an intraclass correlation coefficient from 0.93 to 0.98 (Drouin et al. 2004; Impellizzeri et al. 2008).

## Statistical analyses

Statistical analyses were performed with SPPS 23.0 software (IBM corp. Dublin, Ireland). In the studied population, jumper's knee prevalence was calculated as well as the sensitivity and the specificity of the "Camel's Back curve" in case of jumper's knee history. The players with a "Camel's Back curve" were then compared to the healthy ones and those with a history of jumper's knee without "Camel's Back curve" for anthropometric parameters, for the peak torque and for total work of knee extensors (quadriceps) and flexors (hamstring) LSI (ANOVA test and T3 post-hoc test of Dunnet). Players with bilateral symptoms were excluded for the LSI comparison because the first analysis was performed taking patients as units. A $\chi^2$ test was performed (3 populations $\times$ 3 playing positions) to compare results according to the playing position on the court : Guard, Forward and Center (Köklü et al. 2011).

As some players had bilateral "Camel's Back curves", we performed a second statistical analysis taking legs as units with a $t$ test (Bahr and Holme 2003). The strength measured at the drop of the curve was compared with the two maximal peaks (double hump) with an ANOVA. Two types of "Camel's Back curve" were compared depending on whether the first peak was greater than the second (type 1) or inversely (type 2). Results were considered significant for $p < 0.05$.

## Results

170 basketball players were evaluated. 43 had jumper's knee history with a mean evolution time of $36 \pm 6$ months. The severity according to the VISA score was $74 \pm 6$ points. 35 players out of 43 (81%) had "Camel's Back curve" only at the angular speed of 60°/s (Fig. 2).

A "Camel's Back curve" was characterized by a maximal peak either at the beginning of the knee extension ($81° \pm 5$) in 21 cases (Type 1) or at the end of the knee extension ($43° \pm 10$) in 14 cases (Type 2) (Table 1; Fig. 2a, b). On average, the minimum torque was decreased of $12\% \pm 3$ and $18\% \pm 3$ compared to the 2 maximal peaks. No significant difference was found between type 1 and type 2 of "Camel's Back curve". The strength measured every 5° of ROM was, on average, significantly different between the players with "Camel's Back curve" and the 106 players with normal "inverted U-shape curves", from 90° to 5° of knee ROM (Fig. 3).

Jumper's knee history prevalence was 25.2% [95% IC: 18.7–31.7]. There was no difference concerning age, height and playing position on the court between players with jumper's knee history and those without (Table 2). Yet, a significant difference was found concerning body mass and knee extensors LSI after exclusion of 14 players because of a bilateral "Camel's Back curve" (Table 2). When taking limbs as units, the players with jumper's knee history had a maximal strength and total work of the quadriceps significantly decreased compared to the 106 healthy players (Table 3). The strength and the total work of the knee flexors also decreased significantly at 60°/s, when normalized to the body mass.

A "Camel's Back curve" was found in 9 players on the right side, in 12 players on the left side and in 14 players on both sides. The 8 other players had asymmetrical curves (differences superior to 10%) with irregular anomalies but without an aspect of double hump. The sensitivity and the specificity of the "Camel's Back curve" was 81.3% and 100%, respectively. Indeed, no "Camel's Back curve" was found in absence of jumper's knee history.

**Fig. 2** Type I (**a**) and II (**b**) "Camel's Back curves" depending from the peak torque



**a** Type I Camel's Back curve
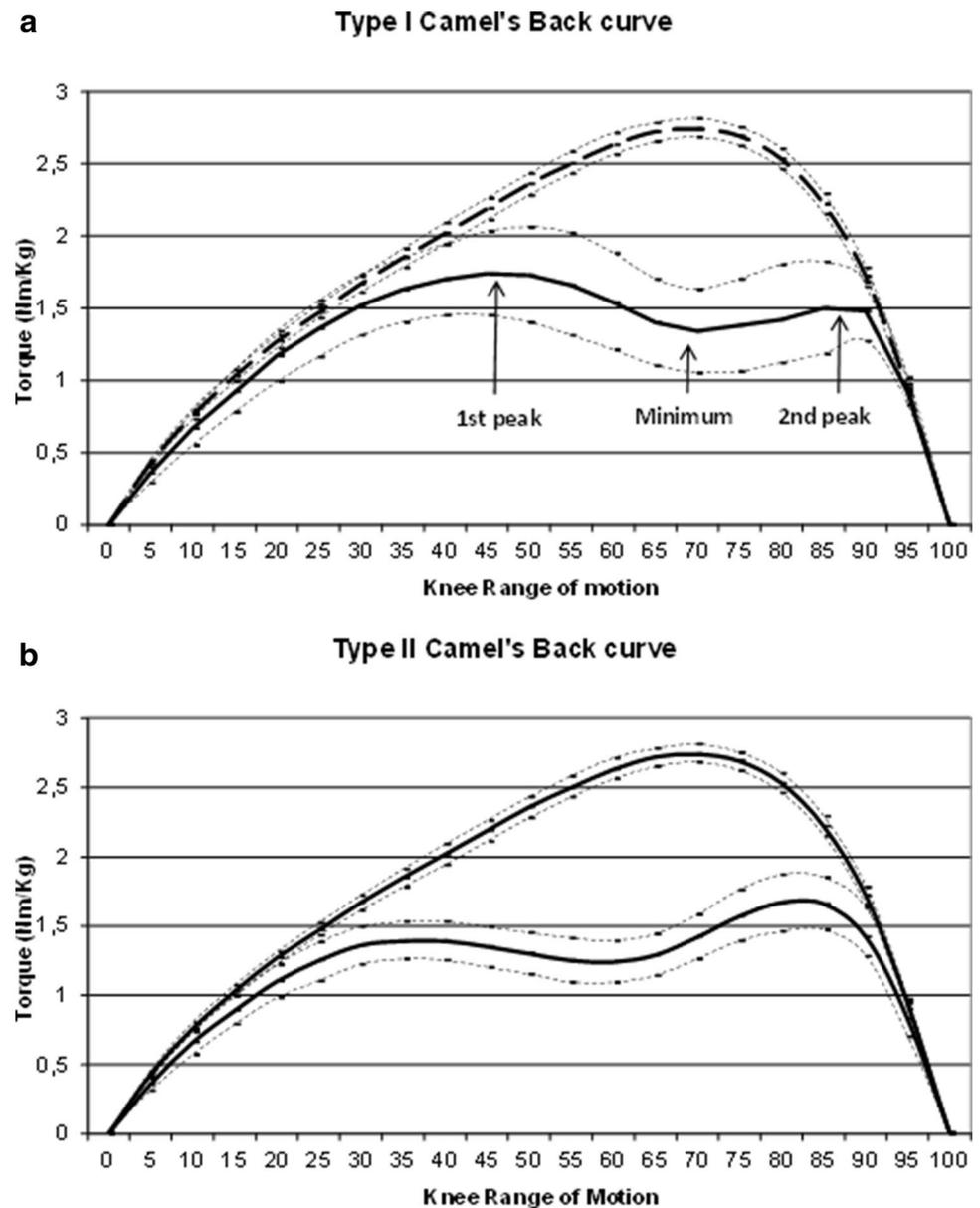
**b** Type II Camel's Back curve

**Table 1** Strength characteristics of the different types of "Camel's Back curves"

| Curves | First peak torque (Nm/Kg) (ROM) | Minimal peak torque (Nm/Kg) (ROM) | Second peak torque (Nm/Kg) (ROM) |
|---|---|---|---|
| Type I Camel's Back ($n=21$) | $1.74 \pm 0.53$[a] | $1.34 \pm 0.38$[a, b] | $1.50 \pm 0.54$[b] |
| | $(81° \pm 5)$ | $(63° \pm 6)$ | $(43° \pm 10)$ |
| Type II Camel's Back ($n=14$) | $1.39 \pm 0.17$[a] | $1.24 \pm 0.32$[a, b] | $1.67 \pm 0.43$[b] |
| | $(46° \pm 9)$ | $(69° \pm 11)$ | $(83° \pm 4)$ |
| Average Camel's Back ($n=35$) | $1.51 \pm 0.49$[a] | $1.33 \pm 0.37$[a, b] | $1.60 \pm 0.50$[b] |
| | $(70° \pm 17)$ | $(65° \pm 8)$ | $(56° \pm 20)$ |

Type I: maximal peak torque at the beginning of knee extension. Type II: maximal peak torque at the end of knee extension

*ROM* range of motion

ANOVA and T3 of Dunnet post-hoc test: [a]Significant difference between first peak torque end minimal peak torque; [b]significant difference between second peak torque end minimal peak torque
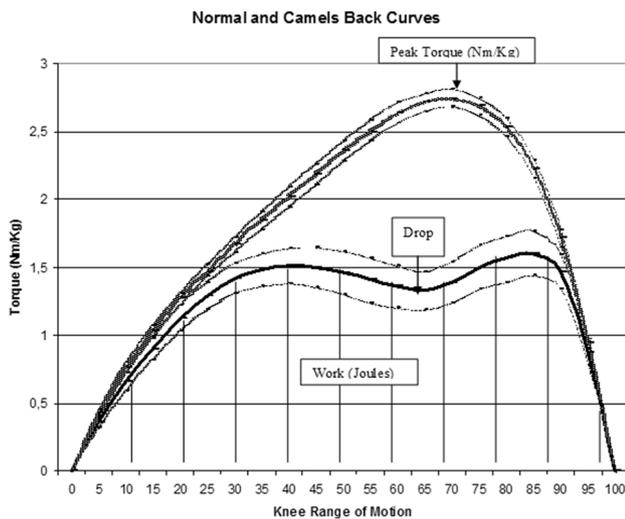
**Fig. 3** Normal "U inverted curve" ($n = 212$) and "Camel's Back curve" ($n = 35$)

## Discussion

We showed that "Camel's Back curve" is often identified during isokinetic assessments at the angular speed of 60°/s, in association with jumper's knee history in professional basketball players. Indeed, we found 35 patients with "Camel's Back curves" out of 43 patients with a jumper's knee history. This curve is characterized by 2

peak torques separated by a minimum torque between $12\% \pm 3$ and $18\% \pm 3$. This anomaly is responsible for a knee extensor LSI deficit (Table 2).

Few studies have described isokinetic strength in male basketball players. Generally, no difference was found in terms of quadriceps peak torque whatever the playing position on the court or the level of practice in national division, when isokinetic strength was normalized to body mass (Zakas et al. 1995; Schiltz et al. 2009; Metaxas et al. 2009; Köklü et al. 2011; Hadzić et al. 2013; Boone and Bourgois 2013). Schiltz et al., found no difference of strength according to the dominant or non-dominant limb in players without history of knee injury, as it was the case for our 106 healthy players (Schiltz et al. 2009).

Only one study reported the mechanical consequences of jumper's knee by isokinetic torque measurement in 15 professional basketball players (Dauty et al. 2007). In this study, the quadriceps LSI was of 0.75 and hamstring LSI of 0.95 at 60°/s, which is close to our results. More than this asymmetry of strength, the interest and the originality of our study were the qualitative description of the knee extensor curve, with a "Camel's Back" aspect in professional basketball players with a jumper's knee history, as it had never been described previously in that sport. However, this type of curves had been shown before, during active open chain extension of the knee in isokinetic assessment (Ayalon et al. 2002). This curve is found only at low speed (60°/s) and disappears at fast speed (Croisier and Crielaard 1999). It is easily recognizable because it is significantly different from

**Table 2** Comparison (variance analyses) of the isokinetic strength deficit between the normal population and the population with a jumper's knee history (with and without "Camel's Back curve")

| | Normal population ($n = 106$) | Jumper'knee history without CBC ($n = 8$) | Jumper's knee history with CBC ($n = 35$) | $p$ value |
|---|---|---|---|---|
| Age (year) | $24.8 \pm 4.6$ | $24 \pm 4.2$ | $24.4 \pm 4.4$ | 0.85 |
| Body mass (Kg) | $91.8 \pm 12.0^a$ | $92.5 \pm 15.2$ | $97.0 \pm 13.1^a$ | 0.03 |
| Height (cm) | $194 \pm 9.0$ | $194.8 \pm 810$ | $197 \pm 8.4$ | 0.058 |
| Playing position | | | | 0.19* |
|   Point and shooting guard | 38 | 4 | 10 | |
|   Small and power forward | 53 | 3 | 19 | |
|   Center | 9 | 2 | 7 | |
| VISA score | $100 \pm 0$ | $75 \pm 7$ | $74 \pm 6$ | 0.73** |
| Q LSI 60°/s | $0.99 \pm 0.12^a$ | $0.84 \pm 0.09^a$ | $0.76 \pm 0.22^a$ | < 0.0001 |
| Q LSI 180°/s | $1.01 \pm 0.12^a$ | $0.92 \pm 0.09$ | $0.85 \pm 0.17^a$ | < 0.0001 |
| H LSI 60°/s | $1.00 \pm 0.13$ | $0.95 \pm 0.12$ | $0.93 \pm 0.17$ | 0.10 |
| H LSI 180°/s | $1.00 \pm 0.10$ | $0.97 \pm 0.18$ | $0.94 \pm 0.22$ | 0.23 |
| WQ LSI 60°/s | $1.00 \pm 0.13^a$ | $0.92 \pm 0.14$ | $0.72 \pm 0.13^a$ | < 0.0001 |
| WQ LSI 180°/s | $1.00 \pm 0.09$ | $1.00 \pm 0.20$ | $0.83 \pm 0.16^a$ | < 0.0001 |
| WH LSI 60°/s | $1.00 \pm 0.13$ | $0.96 \pm 0.14$ | $0.90 \pm 0.13$ | 0.08 |
| WH LSI 180°/s | $1.00 \pm 0.10$ | $0.96 \pm 0.13$ | $0.91 \pm 0.13$ | 0.17 |

Exclusion of 14 basketball players for LSI because of bilateral "Camel's Back curve"

*CBC* Camel's Back curve, *Q LIS* quadriceps limb symmetry index, *H LSI* Hamstring limb symmetry index, *WQ LSI* quadriceps work limb symmetry index ANOVA (T3 of Dunnett): [a]difference with normal population; *$\chi^2$ test ($3 \times 5$); **$t$ test after Levene test

**Table 3** Isokinetic strength leg-to-leg deficit according to the normal population and the population with a jumper's knee history and a "Camel's Back curve"

|  | Normal legs ($n=233$) | Jumper'knee history with CBC ($n=49$) | $p$ value |
|---|---|---|---|
| Q 60°/s (Nm/Kg) | 2.65 ± 0.41 | 1.81 ± 0.46 | < 0.0001 |
| Q 180°/s (Nm/Kg) | 1.91 ± 0.26 | 1.54 ± 0.31 | < 0.0001 |
| H 60°/s (Nm/Kg) | 1.64 ± 0.27 | 1.49 ± 0.31 | 0.0001 |
| H 180°/s (Nm/Kg) | 1.25 ± 0.20 | 1.18 ± 0.19 | 0.04 |
| WQ 60°/s (J/Kg) | 2.83 ± 0.49 | 1.95 ± 0.47 | < 0.0001 |
| WQ 180°/s (J/Kg) | 2.18 ± 0.32 | 1.76 ± 0.38 | < 0.0001 |
| WH 60°/s (J/Kg) | 2.00 ± 0.34 | 1.80 ± 0.39 | < 0.0001 |
| WH 180°/s (J/Kg) | 1.53 ± 0.26 | 1.45 ± 0.32 | 0.07 |

*CBC* Camel's Back curve, *Q* quadriceps, *H* hamstring, *W* work, *Nm/Kg* Newton meter per kilogram, *J/Kg* Joules per kilogram

a normal "inverted U-shape curve" (Ayalon et al. 2002), as shown in our study. Yet, its diagnostic interest remains controversial because it is the mechanical consequences of a knee extension dysfunction, which is not necessarily secondary to a jumper's knee (Croisier and Crielaard 1999; Rochcongar 2004). Indeed, it has been described in knee anterior cruciate ligament (ACL) reconstruction but it can also be present in the healthy population (Croisier and Crielaard 1999; Ayalon et al. 2002). Croisier et al. described this type of curve in 4% of non-operated patients and in 14% of patients with patellar tendon graft reconstruction of the ACL (Croisier and Crielaard 1999). In the present study, the "Camel's Back curve" was present in 81% of professional basketball players with jumper's knee history, that is to say 5 times more frequent than after ACL reconstruction (Croisier and Crielaard 1999). It explains the good sensitivity and specificity we found in case of jumper's knee history. Yet, how can we explain that some healthy subjects had "Camel Back curve"? Some subjects may have practiced sports with many jumps responsible for a non-disabling jumper's knee history, and consequently did not report it (Clarsen et al. 2013).

On a mechanical point of view, the "Camel's Back curve" may be due to a knee extensor dysfunction, secondary to an inhibition of the quadriceps contraction in a specific angular sector (Croisier and Crielaard 1999), which could be secondary to a femoropatellar syndrome (Rochcongar 2004). In that context, irregular curves on eccentric mode, called "break curves", were reported with a strength deficit from 30 to 40% (Nordgren et al. 1983; Dvir et al. 1990; Dvir 1991; Dvir and Halperin 1992). These curves were 4 times more frequent than in control subjects (Anderson and Herrington 2003). However, the authors reported no curve abnormality

on concentric mode in control subjects. No "Camel's Back curve" was described contrary to our results (Anderson and Herrington 2003). Rauschning et al. found that after patellar luxation surgery, curve abnormalities were secondary to a nociceptive muscle inhibition, because of residual pain (Rauschning et al. 1983). The physiopathological explanation of the "Camel's Back curve" seems to be different because no pain is reported during the active isokinetic extension of the knee. It may be a protective inhibition so as to limit knee constrains due to patellar tendon tensioning. When quadriceps contraction increases, mechanoreceptors discharge frequency also increases until an activation threshold that, when exceeded, inhibits the movement as a circuit breaker of the quadriceps contraction to protect the tendon and the muscle (Chalmers 2002). This phenomenon could well explain the origin of the "Camel's Back curve" during isokinetic assessment at a slow speed (60°/s). Indeed, mechanically, more the angular speed increases (180°/s) and more the external strength produced decreases (Mileusnic and Loeb 2009). In case of jumper's knee history, the activation threshold of the circuit breaker from the mechanoreceptors could decrease because of the joint position according to the constrains on the patellar tendon. Jumping and direction changing could be altered. The restoration of a normal curve by selecting knee range of motion or by choosing adapted angular speed could improve the quadriceps strength and then, athletic performances.

Our series of cases has several limits, especially the variability of the clinical expression of the jumper's knee at a specific time of its evolution that is to say at the beginning of the sport season. Indeed, return to sport is known to reactivate tendon pains (Cook and Purdam 2009; Cook et al. 2016). Moreover, we found no significant difference between type 1 and type 2 "Camel's Back curve", maybe because of an insufficient number of cases despite the evaluation of 170 players. A multicentric study could be interesting to confirm that difference, which seems to be obvious when looking at the curves (Fig. 2). The physiopathological explanation of the difference between the 2 types of "Camel's Back curve" may be secondary to more complex and subtle mechanisms.

## Conclusion

Thanks to these isokinetic evaluations, we may assume that "Camel's Back curve" seems to be specific of jumper's knee history (81% of jumper's knee cases). This anomaly has a prevalence of 25.2% in male professional basketball players. It depicts a strength deficit between 90° and 5° of knee ROM, with 2 peaks of strength separated by a drop, measured between 12% ± 3 and 18% ± 3. It is identified only at the angular speed of 60°/s and disappears when the angular speed increases at 180°/s. The presence of a "Camel's Back

curve" associated with a strength deficit is the indicator of patellar tendon malfunction.

## Compliance with ethical standards

## References

Anderson G, Herrington L (2003) A comparison of eccentric isokinetic torque production and velocity of knee flexion angle during step down in patellofemoral pain syndrome patients and unaffected subjects. Clin Biomech Bristol Avon 18:500–504

Ayalon M, Barak Y, Rubinstein M (2002) Qualitative analysis of the isokinetic moment curve of the knee extensors. Isokinet Exerc Sci 10:145–151

Bahr R, Holme I (2003) Risk factors for sports injuries—a methodological approach. Br J Sports Med 37:384–392

Balčiūnas M, Stonkus S, Abrantes C, Sampaio J (2006) Long term effects of different training modalities on power, speed, skill and anaerobic capacity in young male basketball players. J Sports Sci Med 5:163–170

Blazina ME, Kerlan RK, Jobe FW et al (1973) Jumper's knee. Orthop Clin North Am 4:665–678

Boone J, Bourgois J (2013) Morphological and physiological profile of elite basketball players in Belgian. Int J Sports Physiol Perform 8:630–638

Chalmers G (2002) Do Golgi tendon organs really inhibit muscle activity at high force levels to save muscles from injury, and adapt with strength training? Sports Biomech 1:239–249. https://doi.org/10.1080/14763140208522800

Clarsen B, Myklebust G, Bahr R (2013) Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. Br J Sports Med 47:495–502. https://doi.org/10.1136/bjsports-2012-091524

Cook JL, Purdam CR (2009) Is tendon pathology a continuum? A pathology model to explain the clinical presentation of load-induced tendinopathy. Br J Sports Med 43:409–416. https://doi.org/10.1136/bjsm.2008.051193

Cook JL, Khan KM, Kiss ZS et al (2001) Asymptomatic hypoechoic regions on patellar tendon ultrasound: a 4-year clinical and ultrasound followup of 46 tendons. Scand J Med Sci Sports 11:321–327

Cook JL, Rio E, Purdam CR, Docking SI (2016) Revisiting the continuum model of tendon pathology: what is its merit in clinical practice and research? Br J Sports Med 50:1187–1191. https://doi.org/10.1136/bjsports-2015-095422

Croisier JL, Crielaard JM (1999) Exploration isocinétique: analyse des courbes. Ann Réadapt Méd Phys 42:497–502. https://doi.org/10.1016/S0168-6054(00)87704-1

Dauty M, Dupré M, Potiron-Josse M, Dubois C (2007) Identification of mechanical consequences of jumper's knee by isokinetic torque measurement in elite basketball players. Isokinet Exerc Sci 15:37–41

Drouin JM, Valovich-mcLeod TC, Shultz SJ et al (2004) Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. Eur J Appl Physiol 91:22–29. https://doi.org/10.1007/s00421-003-0933-0

Dvir Z (1991) Clinical applicability of isokinetics: a review. Clin Biomech Bristol Avon 6:133–144. https://doi.org/10.1016/0268-0033(91)90024-K

Dvir Z, Halperin N (1992) Patellofemoral pain syndrome: a preliminary model for analysis and interpretation of isokinetic and pain parameters. Clin Biomech Bristol Avon 7:240–246. https://doi.org/10.1016/S0268-0033(92)90007-Q

Dvir Z, Shklar A, Halperin N et al (1990) Concentric and eccentric torque variations of the quadriceps femoris in patellofemoral pain syndrome. Clin Biomech Bristol Avon 5:68–72. https://doi.org/10.1016/0268-0033(90)90040-D

Gisslèn K, Gyulai C, Söderman K, Alfredson H (2005) High prevalence of jumper's knee and sonographic changes in Swedish elite junior volleyball players compared to matched controls. Br J Sports Med 39:298–301. https://doi.org/10.1136/bjsm.2004.014290

Grace TG, Sweetser ER, Nelson MA et al (1984) Isokinetic muscle imbalance and knee-joint injuries. A prospective blind study. J Bone Jt Surg Am 66:734–740

Hadzić V, Erculj F, Bracic M, Dervisević E (2013) Bilateral concentric and eccentric isokinetic strength evaluation of quadriceps and hamstrings in basketball players. Coll Antropol 37:859–865

Impellizzeri FM, Bizzini M, Rampinini E et al (2008) Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer. Clin Physiol Funct Imaging 28:113–119. https://doi.org/10.1111/j.1475-097X.2007.00786.x

Köklü Y, Alemdaroğlu U, Koçak F et al (2011) Comparison of chosen physical fitness characteristics of Turkish professional basketball players by division and playing position. J Hum Kinet 30:99–106. https://doi.org/10.2478/v10078-011-0077-y

Lian OB, Engebretsen L, Bahr R (2005) Prevalence of jumper's knee among elite athletes from different sports: a cross-sectional study. Am J Sports Med 33:561–567. https://doi.org/10.1177/0363546504270454

Metaxas TI, Koutlianos N, Sendelides T, Mandroukas A (2009) Preseason physiological profile of soccer and basketball players in different divisions. J Strength Cond Res 23:1704–1713. https://doi.org/10.1519/JSC.0b013e3181b3e0c5

Mileusnic MP, Loeb GE (2009) Force estimation from ensembles of Golgi tendon organs. J Neural Eng 6:036001. https://doi.org/10.1088/1741-2560/6/3/036001

Nordgren B, Nordesjö LO, Rauschning W (1983) Isokinetic knee extension strength and pain before and after advancement osteotomy of the tibial tuberosity. Arch Orthop Trauma Surg Arch Orthopadische Unf-Chir 102:95–101

Rauschning W, Nordesjö LO, Nordgren B (1983) Isokinetic knee extension strength and pain before and after correction of recurrent patellar dislocation. Arch Orthop Trauma Surg Arch Orthopadische Unf-Chir 102:102–106

Rio E, Kidgell D, Moseley GL et al (2016) Tendon neuroplastic training: changing the way we think about tendon rehabilitation: a narrative review. Br J Sports Med 50:209–215. https://doi.org/10.1136/bjsports-2015-095215

Rochcongar P (2004) Isokinetic thigh muscle strength in sports: a review. Ann Readaptation Med Phys Rev Sci Soc Francaise Reeducation Fonct Readaptation Med Phys 47:274–281. https://doi.org/10.1016/j.annrmp.2004.05.013

Rosso F, Bonasia DE, Cottino U et al (2015) Patellar tendon: From tendinopathy to rupture. Asia-Pac J Sports Med Arthrosc Rehabil Technol 2:99–107. https://doi.org/10.1016/j.asmart.2015.07.001

Rudavsky A, Cook J (2014) Physiotherapy management of patellar tendinopathy (jumper's knee). J Physiother 60:122–129. https://doi.org/10.1016/j.jphys.2014.06.022

Schiltz M, Lehance C, Maquet D et al (2009) Explosive strength imbalances in professional basketball players. J Athl Train 44:39–47. https://doi.org/10.4085/1062-6050-44.1.39

Van der Worp H, de Poel HJ, Diercks RL et al (2014) Jumper's knee or lander's knee? A systematic review of the relation between jump biomechanics and patellar tendinopathy. Int J Sports Med 35:714–722. https://doi.org/10.1055/s-0033-1358674

Van der Worp H, van der Does HTD, Brink MS et al (2016) Prospective study of the relation between landing biomechanics and jumper's knee. Int J Sports Med 37:245–250. https://doi.org/10.1055/s-0035-1555858

Visentini PJ, Khan KM, Cook JL et al (1998) The VISA score: an index of severity of symptoms in patients with jumper's knee (patellar tendinosis). Victorian Institute of Sport Tendon Study Group. J Sci Med Sport 1:22–28

Visnes H, Aandahl H, Bahr R (2013) Jumper's knee paradox–jumping ability is a risk factor for developing jumper's knee: a 5-year prospective study. Br J Sports Med 47:503–507. https://doi.org/10.1136/bjsports-2012-091385

Visnes H, Tegnander A, Bahr R (2015) Ultrasound characteristics of the patellar and quadriceps tendons among young elite athletes. Scand J Med Sci Sports 25:205–215. https://doi.org/10.1111/sms.12191

Zakas A, Mandroukas K, Vamvakoudis E et al (1995) Peak torque of quadriceps and hamstring muscles in basketball and soccer players of different divisions. J Sports Med Phys Fitness 35:199–205

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