# Relationship Between Spinal-Pelvic Sagittal Balance and Pelvic-Femoral Injuries in Professional Soccer Players.

Antoine Ferenczi, Antoine Moraux, Franck Le Gall, André Thevenon, Valérie Wieczorek

*Original Research*

# Relationship Between Spinal-Pelvic Sagittal Balance and Pelvic-Femoral Injuries in Professional Soccer Players

Antoine Ferenczi,*† MD, Antoine Moraux,‡§ MD, Franck Le Gall,‖ MD, André Thevenon,† MD, PhD, and Valérie Wieczorek,† MD

*Investigation performed at the University Hospital Center of Lille, France*

**Background:** Pelvic-femoral injuries are a common problem in football (soccer) players. However, the risk factors for these injuries are unclear. Our knowledge of spinal-pelvic sagittal balance has increased considerably over the past few years, notably as a result of new radiographic techniques such the EOS radiographic imaging system.

**Purpose:** To investigate the link between spinal-pelvic sagittal balance on EOS imaging and the incidence of pelvic-femoral injuries.

**Study Design:** Cohort study; Level of evidence, 2.

**Methods:** Players in a League 1 professional soccer team were observed for 5 consecutive seasons. All players included in the study underwent EOS radiographic imaging. All acute and microtraumatic injuries to the pelvic-femoral complex were recorded prospectively: hamstrings, psoas, quadriceps, adductors, obturators, and pubic symphysis. We analyzed the relationship between injury incidence and key radiographic parameters involved in pelvic balance.

**Results:** A total of 61 players were included (mean age, 24.5 years; n = 149 injuries; mean pelvic tilt, 9.08° ± 5.6°). A significant link was observed between the incidence of pelvic-femoral injuries and pelvic tilt ($P = .02$). A significant link was also observed between the incidence of acute pelvic-femoral injuries and pelvic tilt ($P = .05$). In both cases, a high pelvic tilt was associated with a low incidence of injuries.

**Conclusion:** In professional soccer players, a low pelvic tilt was associated with a high incidence of all pelvic-femoral injuries as well as acute pelvic-femoral injuries. These results could lead to new preventive methods for these musculotendinous injuries through physical therapy.

**Keywords:** EOS imaging; spinal-pelvic sagittal balance; pelvic tilt; pelvic-femoral injury; acute injury; hamstrings; quadriceps; obturators, adductors

On average, a professional football (soccer) player will miss approximately 12% of a single season because of injury. This equates to roughly 37 days of matches and training per season.[10] Muscle damage is the most common type of injury, representing 31% of all traumatic accidents.[9] Among these injuries, 96% are intrinsic in origin, resulting from abnormal stretching or forced contraction, usually during an eccentric movement or a position of maximal elongation; this mechanism stands in contrast to extrinsic injuries, which result from direct trauma.[9] The majority (92%) of intrinsic injuries affect the leg muscles.[9] The Union of European Football Associations (UEFA) has recently standardized the definition and characterization of muscle injuries in soccer players.[12] The main criterion for injury severity is the total number of days a player misses training or playing in matches. The 4 main intrinsic risk factors identified for muscle damage are age, history of muscle injury, muscle imbalance, and fatigue.[5,11,20,30]

*Address correspondence to Antoine Ferenczi, MD, Service de Médecine du Sport et de Médecine Physique et de Réadaptation, CHU Lille, France (email ferenczi.antoine@gmail.com).

†Service de Médecine du Sport et de Médecine Physique et de Réadaptation, CHU Lille, France.

‡Hôpital Privé La Louvière, Lille, France.

§Imagerie Jacquemars Giélée, Lille, France.

‖Olympique de Marseille, Marseille, France.

Final revision submitted September 26, 2019; accepted September 28, 2019.

The authors declared that there are no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval was not sought for the present study.

The Orthopaedic Journal of Sports Medicine, 8(1), 2325967119894962
DOI: 10.1177/2325967119894962

Over the past few years, our knowledge of the spinal-pelvic sagittal balance has increased through use of the EOS radiographic imaging system (EOS Imaging) to acquire a digital radiographic image of the entire skeleton.[6,7,31] The EOS imaging system can provide a digital radiographic image of bones with a very low radiation dose. This allows one to obtain a single image of a large field of view, as wide as the full skeleton. The simultaneous capturing of spatially paired anteroposterior and lateral radiographic images is also a feature of EOS imaging, which further provides secondary 3-dimensional (3D) (volumic) reconstruction of skeletal images.[6,7,31]

The EOS system has provided insights into the key parameters involved in pelvic balance, namely pelvic incidence, pelvic tilt, and sacral slope.[8] These parameters have been studied widely but have not been linked directly to injuries in athletes. Our objective in the current study was to investigate the link between spinal and pelvic angles, as measured by EOS imaging, and the incidence of acute and microtraumatic injuries to the pelvic-femoral complex in soccer players. Establishing such a link would help to identify the morphotypes most at risk of injury and to modify the sagittal balance by preventive physical therapy.

## METHODS

### Study Design and Patients

This was a retrospective, single-center study of data collected prospectively. The study participants were soccer players in a League 1 professional soccer team between the start of the 2011-2012 season and end of the 2015-2016 season. In total, 76 players were on the team over the 5 seasons. The inclusion criteria were age older than 18 years and EOS imaging carried out during the 5 seasons. Scoliotic players with a Cobb angle greater than 10° on EOS images were excluded; this was justified because a high Cobb angle can cause 3D deformations of the spine that could affect the spinal-pelvic sagittal balance.[17] All participants gave their informed consent to take part in the study.

### Data Collection

All data were collected by the same physician (F.L.G.). In this study, the laterality of the player corresponds to the dominant leg for kicking, and the age of the players corresponds to the age at which they underwent EOS imaging. The playing times were recorded by the team's fitness trainer during all League 1, Europa league, and Championnat National 2 (CFA) matches. Playing time in the national team was not included since the players involved were managed by other medical and paramedical staff.

### EOS Imaging

During 1 of the 5 seasons, an EOS imaging examination was performed on each player at the hospital and university center to which the team was attached. The players were summoned in groups of 5, spread out according to the availability of the machine during the 5 seasons. Imaging was performed away from games and training.

The EOS has an open cabin with a square base of 2 m and a height of 2.70 m. The player remained in a standing position, with the upper limbs in anteflexion of the shoulders at 90° and with the elbows and forearms resting against the wall opposite. The feet were spaced about 20 to 25 cm apart. The apparatus is controlled from a console close to the cabin, separated by a leaded screen.

All radiographic measurements necessary to calculate the following parameters were carried out by the same operator in the medical radiology department: lumbar lordosis L1-S1, thoracic kyphosis T4-T12, pelvic obliquity, pelvic incidence, pelvic tilt, sacral slope, axial rotation of the pelvis, torsion of the right and left femurs, and difference in overall leg length (Figures 1-4).

### Injuries and Diagnosis

All injuries occurring during the 2011-2012 to 2015-2016 seasons were noted by the team doctor, who recorded the date of the injury, side of the injury, age of the player at the time of the injury, intrinsic or extrinsic mechanism of the injury (contact injuries were not included), number of days of absence before resuming training with the team, occurrence of the injury during training or a match (which were not differentiated in this study), and diagnosis of the injury via a clinical examination by the team doctor, associated systematically with an on-the-spot ultrasonographic examination. The muscles considered in our study were the hamstrings, quadriceps, psoas, and internal and external obturators and adductors.

The ultrasound machine used was a SonoSite/Fujifilm, X-Porte model, and linear probes were used with frequencies ranging from 6 to 15 MHz. The diagnosis was confirmed by magnetic resonance imaging (MRI) if necessary, carried out 48 to 72 hours after the injury, and always at the same radiology center. We used a Siemens Aera 1.5-T MRI machine. The protocol for producing the MRI scans included at least 1 coronal sequence (frontal), which was T2-weighted with fat signal saturation, and 2 axial sequences, which were T1- and T2-weighted with fat signal saturation.

Acute muscle injuries were divided into 3 levels of severity. Level 1 entailed aches and cramps. Level 2 included benign lesions, corresponding to mild, minor, and moderate stages of the UEFA classification, requiring the player to stop playing from 1 to 27 days, or corresponding to stage 1 or 2 of the MRI classification by O'Donoghue.[25] Only injuries that required players to stop playing for at least 24 hours were recorded in the database used in this study. Level 3 entailed severe muscle injuries, corresponding to the major stage of the UEFA classification, requiring the player to stop playing for more than 28 days, or corresponding to stage 3 of the MRI classification of O'Donoghue.[25]

We recorded 149 injuries. In our retrospective analysis as part of our study, we observed a discordance between initial diagnosis of severity and the number of days a player missed training and matches in 30 cases. In 20 of the 30 cases (66%

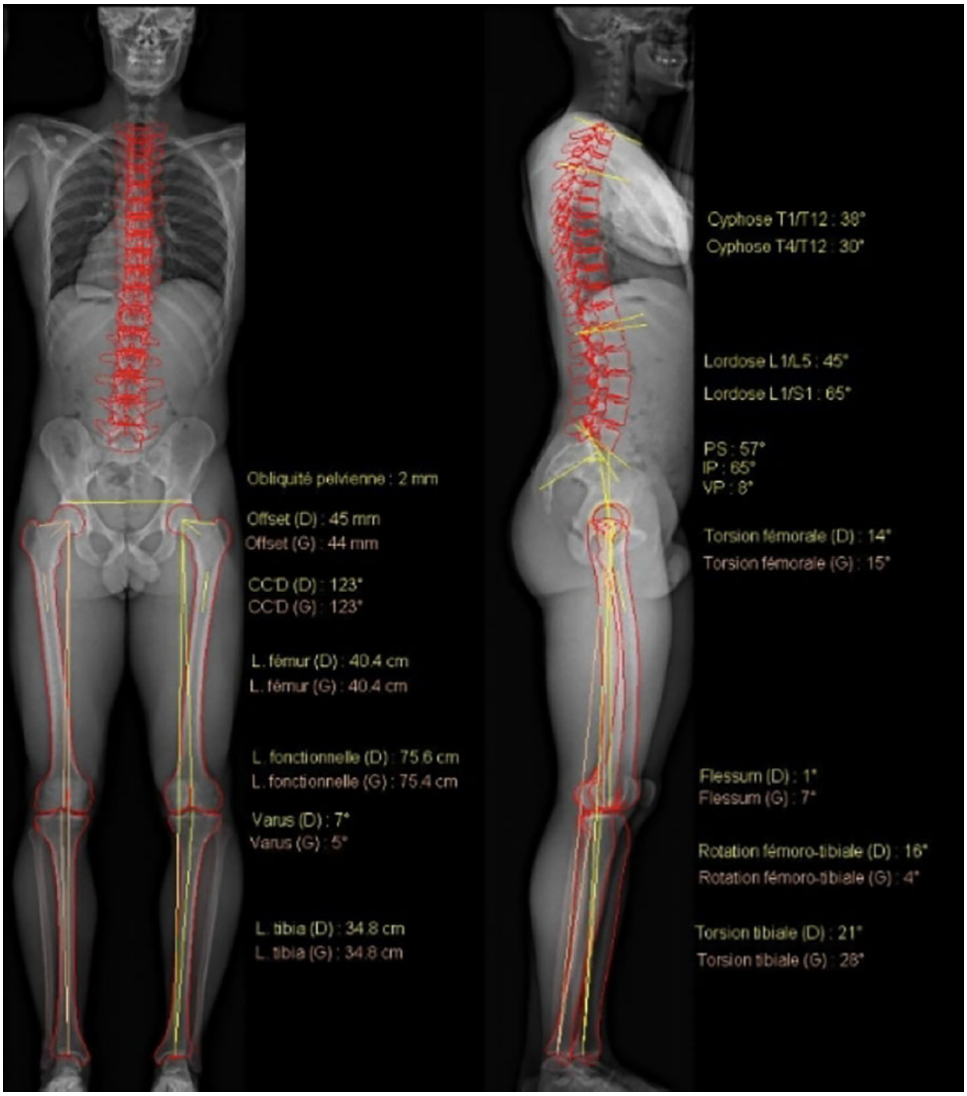


**Figure 1.** Full spine contouring on paired frontal and lateral views on an EOS radiograph, with appropriate manually placed landmarks and automatically provided angles.

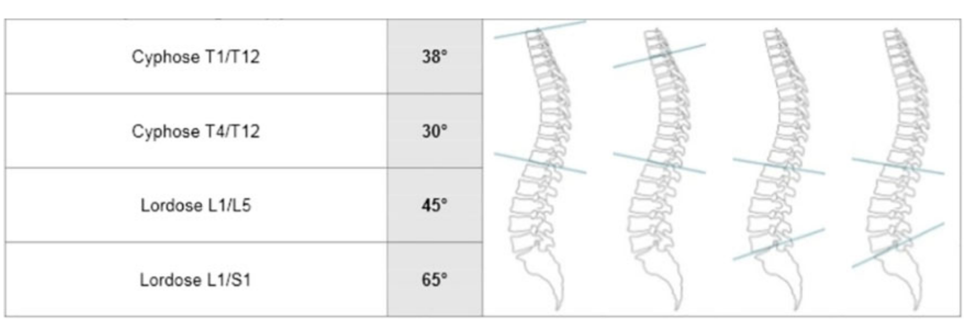


**Figure 2.** Schematics of spine parameters used in this study obtained through the EOS system with appropriate landmarks. To assess spine parameters, angles were measured through use of the Cobb method (angles formed by the tangent lines to the endplates of the extreme vertebrae limiting a given curvature). Thoracic kyphosis ("cyphose") T1/T12 is the angle between the upper vertebral tray of T1 and lower tray of T12. Thoracic kyphosis T4-T12 is the angle between the upper vertebral tray of T4 and lower tray of T12. Lumbar lordosis ("lordose") L1/L5 is the angle between the upper vertebral tray of L1 and lower tray of L5. Lumbar lordosis L1/S1 is the angle between the upper vertebral tray of L1 and sacral endplate.

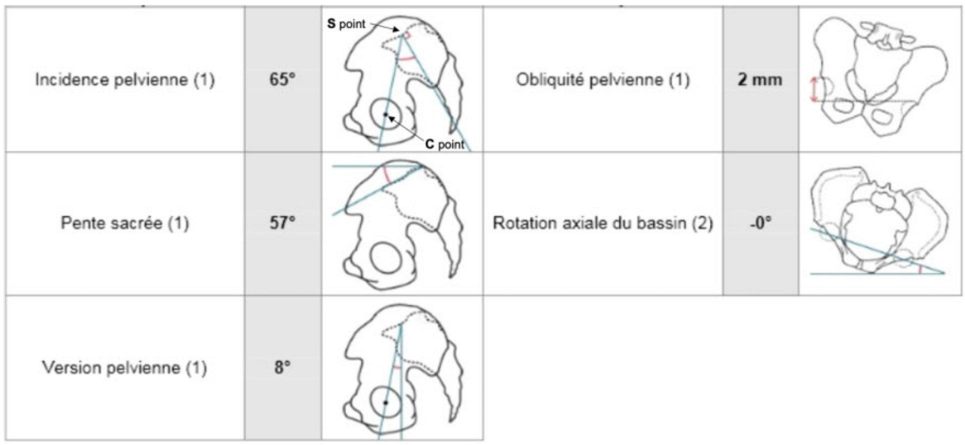


**Figure 3.** Schematics of pelvic parameters used in this study obtained through the EOS system with appropriate landmarks. To assess the 3 sagittal pelvic parameters, it was necessary to draw different points and lines on sagittal views: the center of the femoral heads (C point); the midpoint of the sacral endplate (S point); the CS line; a vertical line passing through the C point; a line tangent to the sacral endplate; a line perpendicular to this tangent, passing through the S point; and a horizontal line cutting this tangent. Pelvic incidence ("incidence pelvienne") is the angle that is between CS and perpendicular to the tangent at the sacral endplate; sacral slope ("pente sacrée") is the angle between the tangent at the sacral endplate; and horizontal and pelvic tilt ("version pelvienne") is the angle between vertical and the CS line.

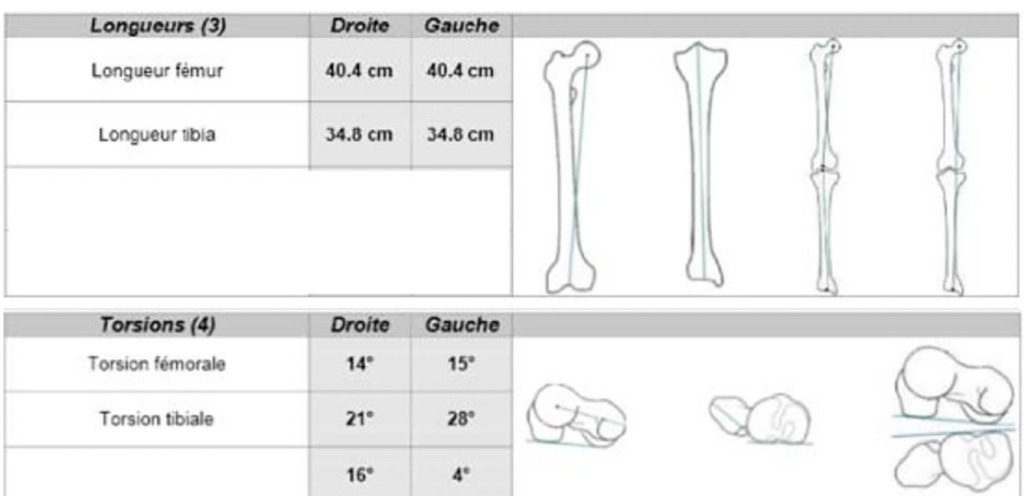


**Figure 4.** Schematics of knee parameters used in this study obtained through the EOS system with appropriate landmarks. Femoral length ("longueur femur") is the distance between the center of the femoral head and the center of the trochlea. Tibial length ("longueur tibia") is the distance between the center of the tibial spine (intercondylar eminence) and the center of the ankle joint. Femur torsion ("torsion fémorale") is the angle between the femoral neck axis and posterior condylar line. Difference in overall leg length between the right ("droite") and left ("gauche") sides was also calculated.

of cases), we were able to reanalyze the MRIs of the players made at the time of their injuries, enabling the injury to be diagnosed precisely. After rereading by a blinded bone-joint radiologist (A.M.) who had 9 years of experience and was not involved in the care of the patients, concordance was eventually found between the number of days of missed training or matches and the MRI classification in 11 of these injuries (52% of cases). For the remaining 9, the number of days of missed training or matches was taken to determine injury severity.

## Statistical Analysis

All statistical analyses were performed by the biostatistics group of the university hospital center of Lille. Continuous variables are presented as means and standard deviations and categorical variables as number and percentage. The incidence of injuries was calculated by dividing the total number of injuries by the sum of the total match play time for each player. Incidence is expressed as number of injuries per 1000 hours of play. For analysis of the link between

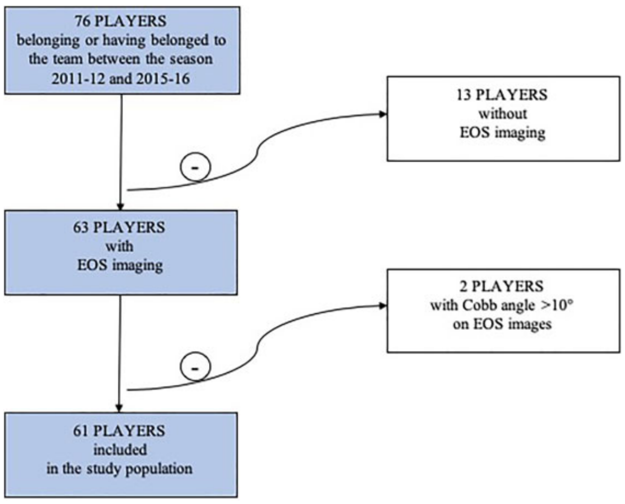


**Figure 5.** Flowchart of the study population.

radiographic parameters and incidence of injuries, a negative binomial regression model was used and adjusted because the data did not favor the Poisson distribution. $P < .05$ was considered to represent statistical significance.

## RESULTS

### Study Population

Among the 76 players, 63 underwent EOS imaging; 2 players had scoliosis with a Cobb angle greater than 10° and were excluded from the study. In total, 61 players who belonged to the team during 1 of the 5 seasons were included in the study population (Figure 5).

The demographic characteristics of these 61 players are summarized in Table 1. Mean age was 24.5 ± 4.9 years (range, 18-32 years), and mean body mass index was 23 ± 1.6 kg/m$^2$. The distribution of field positions was representative of a typical soccer team. The majority of players (93%) were right-footed. Three-fourths of the players (78%) were white or black. The average total playing time counted for each player throughout the 5 consecutive seasons was 83.6 ± 73.5 hours (Table 1).

### Sagittal Radiographic Parameters

The sagittal parameter characteristics on EOS images are shown in Table 2.

### Injuries

A total of 149 injuries were recorded over the 5 seasons, with a mean of 2.4 injuries per player (Figure 6). The majority (94.6%) of injuries were due to acute trauma, and 5.4% were due to microtrauma. Among the traumatic injuries, 39% were aches or cramps, 46% were benign lesions, and 10% were severe injuries.

TABLE 1
Demographic Characteristics of the Study Population (N = 61)[a]

| Characteristic | Value |
|---|---|
| Age, y | 24.5 ± 4.9 |
| Body mass index, kg/m$^2$ | 23 ± 1.6 |
| Position | |
| Attack | 20 (33) |
| Defense | 19 (31) |
| Mid-field | 16 (26) |
| Goalkeeper | 6 (10) |
| Ethnic origin | |
| Caucasian | 24 (39) |
| African | 24 (39) |
| North African | 3 (5) |
| West Indian | 4 (6.5) |
| Réunion | 2 (3) |
| Central American | 1 (1.5) |
| South American | 4 (6.5) |
| Dominant side | |
| Right | 57 (93) |
| Left | 4 (7) |
| Playing time over the 5 seasons, h | 83.6 ± 73.5 |

[a]Data are expressed as mean ± SD or n (%).

TABLE 2
Sagittal Radiographic Parameters of the Players[a]

| Parameter | Value |
|---|---|
| Kyphosis T4-T12, deg | 30.8 ± 7.9 |
| Lordosis L1-S1, deg | 57.5 ± 10.6 |
| Pelvic incidence, deg | 54.6 ± 10.8 |
| Pelvic tilt, deg | 9.08 ± 5.6 |
| Sacral slope, deg | 45.4 ± 8.8 |
| Pelvic obliquity, mm | 4.4 ± 4.1 |
| Axial rotation of the pelvis, deg | 0.6 ± 4.0 |
| Right femur torsion, deg | 17.4 ± 8.8 |
| Left femur torsion, deg | 17.8 ± 9.8 |
| Difference in leg length, cm | 0.6 ± 0.4 |

[a]Data are expressed as mean ± SD.

The most frequently involved muscles were the hamstrings, with a total of 63 injuries (42.5% of all injuries and 44.7% of acute injuries); 19 of these injuries (30%) were aches or cramps, 36 were benign lesions (57%), and 8 were severe injuries (12.5%).

The second most common location was the muscles and tendons of the adductors, with a total of 47 injuries (31.7% of all injuries). Among these injuries, 40 were acute, of which 22 were aches or cramps (47%), 15 were benign lesions (32%), and 3 were severe injuries (6.5%). A further 7 injuries were microtraumatic lesions.

We recorded 25 injuries to the quadriceps muscles, corresponding to 17% of all injuries and 17.7% of acute injuries. Of these 25 injuries, 12 injuries were aches or cramps (48%), 12 were benign lesions (48%), and 1 was a severe injury (4%).

We found that 9 injuries involved the psoas muscle (6% of all injuries and 6.4% of acute injuries), of which 4 were

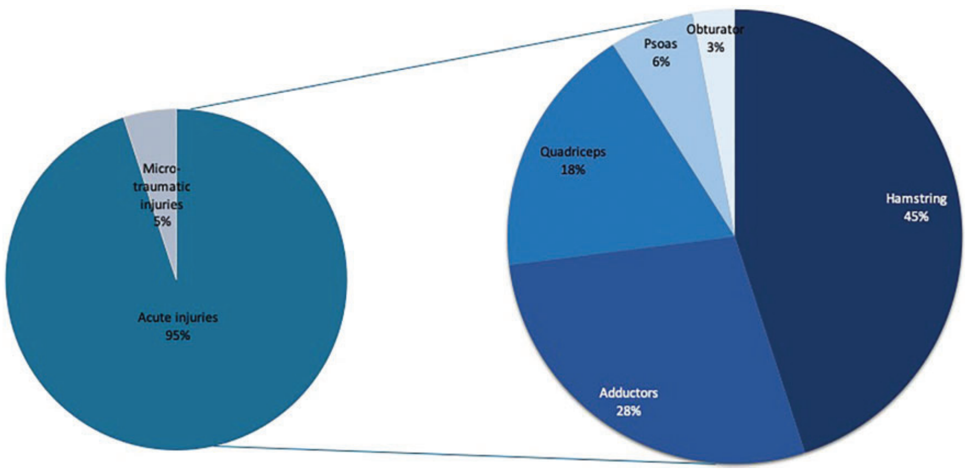


**Figure 6.** Distribution of injuries. Left, total injuries; right, acute injuries.

TABLE 3
Relationship Between Sagittal Radiographic Parameters and Global Incidence of Injuries

| Variable | Coefficient | SE | *P* Value |
|---|---|---|---|
| T4-T12 | 0.02 | 0.016 | .19 |
| L1-S1 | –0.03 | 0.025 | .20 |
| Pelvic incidence | 0.03 | 0.030 | .25 |
| Pelvic tilt | –0.09 | 0.040 | .02[a] |
| Pelvic obliquity | 0.01 | 0.033 | .82 |
| Axial rotation of pelvis | –0.04 | 0.028 | .17 |
| Difference in leg length | 0.11 | 0.307 | .71 |

[a]Statistically significant.

aches or cramps (44%), 4 were benign lesions (44%), and 1 was a severe injury (11%).

We noted that 4 of the injuries concerned the internal and external obturator muscles (2.7% of all injuries and 2.8% of acute injuries), of which 1 was an ache or cramp (25%), 1 was a benign lesion (25%), and 2 were severe injuries (50%). In addition, 1 pubic arthropathy was noted, which was microtraumatic in origin.

The incidence of injuries was 32.4 per 1000 hours of combined training and match play. Among these, there was an incidence of 3 severe injuries per 1000 hours of combined training and match play. The incidence of injuries in left foot–dominant players was 15 per 1000 hours of combined training and match play versus 14 per 1000 hours of combined training and match play for right-footed players.

## Link Between Sagittal Radiographic Parameters and Incidence of Acute Injuries of the Pelvic-Femoral Complex

The results concerning the relationship between radiographic parameters and overall incidence of injuries are presented in Table 3. A significant link was observed between pelvic tilt and incidence of all injuries ($P = .02$) with a negative coefficient in the regression at –0.09. High pelvic tilt was associated with a decrease in the incidence of injuries. No link was found with the spinal parameters T4-T12 and L1-S1 ($P = .19$ and $P = .20$, respectively), other pelvic parameters (pelvic incidence, pelvic obliquity, axial rotation of the pelvis), or difference in leg length.

TABLE 4
Relationship Between Sagittal Radiographic Parameters and Incidence of Acute Musculotendinous Injuries

| Variable | Coefficient | SE | *P* Value |
|---|---|---|---|
| T4-T12 | 0.03 | 0.02 | .09 |
| L1-S1 | –0.04 | 0.03 | .18 |
| Pelvic incidence | 0.04 | 0.04 | .27 |
| Pelvic tilt | –0.10 | 0.05 | .05[a] |
| Pelvic obliquity | –0.04 | 0.04 | .35 |
| Axial rotation of pelvis | –0.04 | 0.04 | .26 |
| Difference in leg length | 0.45 | 0.40 | .27 |

[a]Statistically significant.

TABLE 5
Relationship Between Sagittal Radiographic Parameters and Incidence of Psoas Muscle Injuries

| Variable | Coefficient | SE | *P* Value |
|---|---|---|---|
| T4-T12 | 0.05 | 0.06 | .44 |
| L1-S1 | –0.08 | 0.09 | .32 |
| Pelvic incidence | 0.12 | 0.09 | .06 |
| Pelvic tilt | –0.26 | 0.14 | .06 |
| Pelvic obliquity | –0.01 | 0.11 | .90 |
| Axial rotation of pelvis | –0.09 | 0.10 | .39 |
| Difference in leg length | 0.23 | 1.21 | .85 |

The results concerning the link between radiographic parameters and incidence of acute injuries are shown in Table 4. A significant link was found between pelvic tilt and the incidence of acute musculotendinous injuries ($P = .05$) with a negative coefficient in the regression at –0.10. High pelvic tilt was associated with a decrease in the incidence of acute injuries. In contrast, no link was found between pelvic tilt and incidence of microtraumatic injuries ($P$ = .10).

No link was found between EOS parameters and the incidence of musculotendinous injuries of the hamstrings, quadriceps, adductors, or obturators taken independently muscle by muscle. Only a nonsignificant tendency was found between pelvic tilt and the incidence of psoas muscle injuries ($P$ = .06) and between pelvic incidence and the incidence of psoas muscle injuries ($P$ = .06) (Table 5).

## DISCUSSION

In this study of professional soccer players, a significant link was found between the incidence of all injuries to the pelvic-femoral complex and pelvic tilt ($P$ = .02) and between the incidence of acute injuries to the pelvic-femoral complex and pelvic tilt ($P$ = .05). In both relationships, a high pelvic tilt was associated with a lower incidence of injuries.

In contrast, no significant link was found between pelvic tilt and the incidence of acute injuries taken independently muscle by muscle. Only a nonsignificant tendency was found between pelvic tilt and the incidence of psoas muscle injuries and between pelvic incidence and the incidence of psoas muscle injuries ($P$ = .06). The absence of significance of these results can be explained by a lack of power, as only 9 of the 149 injuries recorded concerned the psoas muscle.

A relationship between pelvic tilt and acute injuries has not been demonstrated previously. However, previous studies have revealed close links between spinal-pelvic parameters and spinal-pelvic-femoral musculotendinous structures. Contraction of these muscles will change the position of the pelvis. Pelvic anteversion is brought about by antagonistic muscle contractions between the flexor muscles of the hips and the erector muscles of the spine.[16,23,28,29] Pelvic retroversion is brought about by antagonistic muscle contractions between the extensor muscles of the hips and the abdominal muscles.[1,16,23,28] The balance between the forces exerted by the flexor and extensor muscles of the hips appears to have a major role in sagittal stability of the pelvis.[23]

The effect of muscle suppleness on pelvic balance has been studied only for the hamstrings, where a decrease in suppleness led to an increase in pelvic retroversion.[3,4,19,21,22] This relationship is significant during major flexion of the spine but appears less important during limited anteflexion of the trunk and upright posture.[2,18,24] The effect of suppleness of the flexor muscles of the hips on pelvic balance has not been reported.

The consequences of pelvic tilt on pelvic-femoral musculotendinous tension was described in a cadaveric study by Harvey et al,[13] who demonstrated an increase in tension of the hamstring muscles during flexion of the hips and retroversion of the pelvis.

The pelvic-trochanteric muscles, including the obturator muscles, play a role in maintaining the position of the pelvis.[29] These muscles bring about external rotation of the hips. This action is particularly important in soccer during quick changes of direction, during which these muscles join forces with eccentric contraction of the internal rotator muscles of the hip, including the adductors. This abrupt co-contraction of the adductor muscles could be the origin of injuries.[23]

### Mechanisms for Lower Injury Incidence

The mechanisms behind the lower incidence of injuries in players with a high pelvic tilt have not been identified. These mechanisms could include (1) a better balance of muscular forces, with more effective coupling of the extensor forces of the hips and abdominal muscles, or (2) satisfactory suppleness of the flexor muscles of the hips. Whatever the causal mechanism, it would be interesting to carry out a clinical study in patients with low pelvic tilt, to look for a muscular deficit of the extensor muscles of the hips or a lack of suppleness of the flexor muscles of the hips, in order to correct such factors through physical therapy.

The role of pelvic tilt in the pathogenesis of microtraumatic injuries such as groin strain has already been suggested. The morphotype “anteversion of the pelvis” appears to increase the forces on the pubic symphysis, which make the symphysis more sensitive to shearing forces, which are strong in soccer.[14,26,27] Rolland[27] identified a population at risk consisting of sports participants with low pelvic tilt and excessive anteversion.

### Limitations

Our study has several limitations. The participants included were professional soccer players, and therefore the results cannot be generalized to amateur sports participants. Furthermore, only 61 patients were included, which limits the statistical power. We divided the injuries into acute and microtraumatic injuries; recurring injuries were considered to be acute injuries. Only 5.4% of injuries were microtraumatic, compared with more than 25% of injuries in the literature.[10,15,32] Our results therefore essentially concern acute muscle injuries. This is because only injuries that required players to stop playing for at least 24 hours were recorded in the database. Microtraumatic injuries cause pain, which may hinder performance but does not necessarily stop players from participating in soccer.[32] It is therefore likely that some players with microtraumatic injuries were able to continue playing while receiving care. This may have led to an underestimation of the number of microtraumatic injuries.[32] The small number of microtraumatic injuries is also explained by the fact that many affected players did not undergo EOS imaging and were therefore excluded from the study.

EOS imaging was performed only once per player, and injuries were recorded over the 5 consecutive seasons. It is possible that some sagittal radiological parameters, other than pelvic tilt, which is fixed, could have changed over the course of time. EOS imaging performed annually could have resulted in better statistical correlations.

## CONCLUSION

This study is a first step in exploring whether there is a relationship between sagittal balance and sport-related trauma. We demonstrated a link between sagittal pelvic balance and the incidence of all injuries (acute and microtraumatic) and acute injuries of the pelvic-femoral complex. However, no relationship was observed between spinal-pelvic sagittal parameters and the incidence of injuries to specific muscles. Further studies with higher statistical power will be necessary to demonstrate this link. These developments could lead to the emergence of new preventive physical therapy protocols.

## ACKNOWLEDGMENT

The authors thank the participating soccer club, including players and medical staff.

## REFERENCES

1. Busquet L. *Les Chaînes Musculaires: Lordoses, Cyphoses, Scolioses et Déformations Thoraciques*. Vol 2. Paris: Frison-Roche; 1992.
2. Cho M, Lu Z, Lee C. Influence of hamstring tightness in pelvic, lumbar and trunk range of motion in low back pain and asymptomatic volunteers during forward bending. *Asian Spine J*. 2015;9(4):535-540.
3. Congdon R, Bohannon R, Tiberio D. Intrinsic and imposed hamstring length influence posterior pelvic rotation during hip flexion. *Clin Biomech (Bristol, Avon)*. 2005;20(9):947-951.
4. Cristóbal RV, Miñarro PAL, Cárceles FA, Ros FE. Efectos del método Pilates sobre la extensibilidad isquiosural, la inclinación pélvica y la flexión del tronco. *Nutr Hosp*. 2015;32(5):1967-1986.
5. Croisier J-L, Ganteaume S, Binet J, Genty M, Ferret J-M. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. *Am J Sports Med*. 2008;36(8): 1469-1475.
6. Delin C, Silvera S, Bassinet C, et al. Ionizing radiation doses during lower limb torsion and anteversion measurements by EOS stereoradiography and computed tomography. *Eur J Radiol*. 2014;83(2): 371-377.
7. Deschênes S, Charron G, Beaudoin G, et al. Diagnostic imaging of spinal deformities: reducing patients' radiation dose with a new slot-scanning X-ray imager. *Spine*. 2010;35(9):989-994.
8. Duval-Beaupère G, Legaye J. Composante sagittale de la statique rachidienne. *Revue du Rhumatisme*. 2004;71(2):105-119.
9. Ekstrand J, Hägglund M, Waldén M. Epidemiology of muscle injuries in professional football (soccer). *Am J Sports Med*. 2011;39(6): 1226-1232.
10. Ekstrand J, Hägglund M, Waldén M. Injury incidence and injury patterns in professional football: the UEFA injury study. *Br J Sports Med*. 2011;45(7):553-558.
11. Fousekis K, Tsepis E, Poulmedis P, Athanasopoulos S, Vagenas G. Intrinsic risk factors of non-contact quadriceps and hamstring strains in soccer: a prospective study of 100 professional players. *Br J Sports Med*. 2011;45(9):709-714.
12. Fuller CW. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Br J Sports Med*. 2006;40(3):193-201.
13. Harvey MA, Singh H, Obopilwe E, Charette R, Miller S. Proximal hamstring repair strength: a biomechanical analysis at 3 hip flexion angles. *Orthop J Sports Med*. 2015;3(4):2325967115576910.
14. Journée de traumatologie du sport de la Pitié-Salpêtrière. *Pathologie du Complexe Pelvi-Fémoral du Sportif*. Issy-les-Moulineaux, France: Elsevier Masson; 2009.
15. Junge A, Engebretsen L, Mountjoy ML, et al. Sports injuries during the Summer Olympic Games 2008. *Am J Sports Med*. 2009;37(11): 2165-2172.
16. Kamina P, Gouazé A. *Anatomie Clinique: Tome 1, Anatomie Générale, Membres*. 4th ed. Paris: Maloine; 2009.
17. Legaye J, Duval-Beaupère G, Hecquet J, Marty C. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. *Eur Spine J*. 1998;7(2):99-103.
18. Li Y, McClure PW, Pratt N. The effect of hamstring muscle stretching on standing posture and on lumbar and hip motions during forward bending. *Phys Ther*. 1996;76(8):836-845.
19. López-Miñarro PA, Alacid F. Influence of hamstring muscle extensibility on spinal curvatures in young athletes. *Sci Sports*. 2010;25(4): 188-193.
20. McCall A, Carling C, Davison M, et al. Injury risk factors, screening tests and preventative strategies: a systematic review of the evidence that underpins the perceptions and practices of 44 football (soccer) teams from various premier leagues. *Br J Sports Med*. 2015;49(9): 583-589.
21. Muyor J, Alacid F, López-Miñarro P. Influence of hamstring muscles extensibility on spinal curvatures and pelvic tilt in highly trained cyclists. *J Hum Kinet*. 2011;29:15-23.
22. Nakamura M, Hasegawa S, Umegaki H, et al. The difference in passive tension applied to the muscles composing the hamstrings—comparison among muscles using ultrasound shear wave elastography. *Man Ther*. 2016;24:1-6.
23. Neumann DA. *Kinesiology of the Musculoskeletal System: Foundations for Physical Rehabilitation*. St Louis, MO: Mosby; 2002.
24. Norris CM, Matthews M. Correlation between hamstring muscle length and pelvic tilt range during forward bending in healthy individuals: an initial evaluation. *J Bodyw Mov Ther*. 2006;10(2):122-126.
25. O'Donoghue D. Principals in the management of specific injuries. In: O'Donoghue D, ed. *Treatment of Injuries to Athletes*. 4th ed. Philadelphia, PA: Saunders; 1984:39-91.
26. Rochcongar P, Rolland J, Menou P. Influence de l'antéversion du bassin sur les contraintes de la symphyse pubienne. *Médecine Sport*. 1981;55:338-340.
27. Rolland E. L'équilibre lombo-pelvi-fémoral: de la physiologie à la pathologie. *J Traumatol Sport*. 2006;23(3):153-156.
28. Rouvière H, Delmas A. *Anatomie Humaine Descriptive, Topographique et Fonctionnelle: Tome 3: Membres, Système Nerveux Central*. 11th ed. Paris: Masson; 1974.
29. Simon B, Gouilly P, Peverelly G. Le psoas: synthèse de 12 actions musculaires. *Kinésithérapie Cah*. 2001:73-78.
30. Small K, McNaughton L, Greig M, Lovell R. The effects of multidirectional soccer-specific fatigue on markers of hamstring injury risk. *J Sci Med Sport*. 2010;13(1):120-125.
31. Wybier M, Bossard P, Laredo JD. Le système EOS. *L'Actualité Rhumatol*. 2012;13:179-194.
32. Yang J, Tibbetts AS, Covassin T, Cheng G, Nayar S, Heiden E. Epidemiology of overuse and acute injuries among competitive collegiate athletes. *J Athl Train*. 2012;47(2):198-204.