Archives of Orthopaedic and Trauma Surgery (2019) 139:1771–1777
https://doi.org/10.1007/s00402-019-03266-9

ARTHROSCOPY AND SPORTS MEDICINE

Radiographic analysis of lower limb alignment in professional football players

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Received: 19 December 2018 / Published online: 28 August 2019

Abstract

Introduction To radiographically analyze lower limb alignment in adult asymptomatic professional football players and to correlate these values to clinical measurements.

Materials and methods Twenty-four asymptomatic players [24.2 (3.6) years] were enrolled. Standard bilateral lower limb anteroposterior weight-bearing radiographs were acquired and clinical measurement of intercondylar/intermalleolar (ICD/IMD) distance was performed. Coronal plane mechanical alignment was assessed by five angles: leg mechanical axis (LMA), lateral proximal femoral angle (LPFA), lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), and lateral distal tibial angle (LDTA). Their values were compared to the reference values for adult population. An inter-individual comparison between right/left and dominant/non-dominant leg was added. The sum of bilateral LMA was correlated against ICD/IMD and against ICD/IMD adjusted for body height.

Results Football players presented with ICD/IMD of 46.5 (19.8) mm. Two, out of five, lower leg coronal angles showed significant differences ($p < 0.001$) compared to reference data from literature: LMA 5.8 (3.0)° vs.1.2 (2.2)° and MPTA 83.5 (2.6)° vs. 87.2 (1.5)°. No significant differences between left/right leg and dominant/non-dominant leg were established. Summed up bilateral LMA showed a high correlation to IMD/ICD ($r = 0.8395$; $R^2 = 0.7048$), and even higher to ICD/IMD adjusted for body height ($r = 0.8543$; $R^2 = 0.7298$).

Conclusions This study was radiographically confirming increased varus of elite football players toward general population. Apex of the varus deformity was located in the proximal tibia. Clinical measurement of ICD/IMD adjusted for body height highly correlated with the radiographic values of coronal alignment; therefore, it may be used in population studies.

Keywords Lower limb · Alignment · Coronal plane · Mechanical axis · Bowlegs · Deformity · Football

Introduction

Football is undoubtedly the most popular and globally played sport, [1]. Sport participation provides fun, satisfaction, and it is perceived positively for healthy development. However, it also poses an increased risk for musculoskeletal injuries [2, 3]. Football is ranked amongst sports with the highest risk for injuries [3–5]. Besides acute injuries, the footballers are notorious for their bowlegs. Chantraine et al. have proven that varus axial deviation of lower limbs occurs more frequently in football players than in the general population, and up to 73% of retired footballers presented with genu varum [6]. It was shown that physical activity of athletes during growth results in an increased varus of lower limbs, particularly among football players, compared to their non-athletic peers [7–10]. Varus leg alignment predisposes athletes to overuse and traumatic lesions of the knee joints: higher strain on the anterior cruciate ligament, patellofemoral pain syndrome, meniscal lesions, and medial tibial stress syndrome [7, 9, 11, 12]. A long-term effect of vigorous football activity and numerous injuries is development of early osteoarthritis [13].

It is generally accepted that "normal mechanical axis" of lower limb which is considered as Hip-Knee-Ankle angle in neutral (180°) or slight varus or valgus (up to 3°)

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position [14, 15]. Bellemans et al. [14] and Shetty et al. [15] reported that approximately, one-third of male adult population presented with constitutional knee varus of 3º or more. The normality values of coronal plane alignment have been defined through systematic radiographic analysis of healthy individuals under standardized anteroposterior (AP) full weight-bearing conditions [14–18]. The axial analysis of standardized full-leg weight-bearing radiographs not only defines general leg alignment, but it can also locate the apex of deformity. While varus deviations in football players have been confirmed clinically, the systematic radiographic studies on this matter are lacking. The aim of this study on asymptomatic professional football players was: (a) to analyze their coronal alignment on standard full leg weight-bearing radiographs; (b) to define the potential apex of deformity on these radiographs; and (c) to corroborate whether most commonly used clinical measure for coronal alignment in population studies, intra-condylar or intra-malleolar distance (ICD/IMD), correlates with the radiographically measured leg mechanical alignment.

Materials and methods

Subjects

The study was designed as retrospective case series, and its protocol was approved by the National Medical Ethics Committee (approval no. 86/02/13). The work was conducted in accordance with the Declaration of Helsinki (1964). The alignment analysis in coronal plane was performed clinically and radiographically on adult professional football players from football club NK Maribor, Slovenia. Full-length weight-bearing radiographs were performed previously, either during routine medical screening before contracting or due to acute or overuse knee injuries (Fig. 1a). Thirty-five bilateral standardized AP lower leg radiographs of professional soccer players were identified between the years 2012–2017. These players were invited to give their informed consent for study participation. They were additionally asked to provide basic personal data, playing position, leg dominance, and history of lower leg injuries. History of lower leg fracture, growth plate injury, or major lower leg surgeries was an exclusion criterion for study participation. Players were asked to complete Knee Osteoarthritis Outcome Score (KOOS) taking into account the current condition of a more symptomatic knee. The "asymptomatic" players needed to reach at least 95 points of cumulative KOOS score (maximum value is 100). Clinical measurements of lower limb mechanical alignment were conducted in a weight-bearing position with a caliper, as previously described (Fig. 1c) [8, 10, 19]. The results were given as intermalleolar/intercondylar distance (ICD/IMD). Positive numbers indicate increased intercondylar distance (varus), while negative values indicate increased intermalleolar distance (valgus). The final study comprised of 24 asymptomatic players with the following personal characteristics (provided at the time of informed consent): age 24.2 (3.6) years, height 178.2 (5.9) cm and weight 74.2 (5.5) kg. According to the playing positions, there were 7 strikers, 9 midfielders, and 8 defensive players. Seventeen of them declared as being right-leg dominant (defined as the leg that is used for kicking), and seven were left-leg dominant.

Radiographic analysis

Standard bilateral full-length AP weight-bearing radiographs were used for the coronal plane deformity analysis: radiographs are taken barefoot in standing position with the back against the radiographic table, the whole lower limb from femoral head to the ankle mortise should be included, and both knees are in full extension with patellae facing forward [14, 17, 20, 21]. All radiographs in our study were acquired on the Philips MD Eleva device (Eindhoven, the Netherlands) with settings following the manufacturer's recommendations. Distance between radiographic tube and the detector was 125 cm. The subject was positioned directly to the detector. X-ray beam was directed against the patient and it moved from hips to ankles acquiring 32–36 scans (depending on subject's height). These scans were assembled into one image of the whole lower limb by the original software ViewForum R4.1 (Philips MD Eleva device, Eindhoven, the Netherlands) at the assembled into the desired image of the entire lower limb.

All radiographic measurements were performed in consensus of both co-authors. The coronal alignment diagnostics was performed according to the protocol of Paley et al. [17] (Fig. 2). First, the centers of hip (concentric template over femoral head), knee (intersection of the midline between the femoral condyles and the intercondylar eminences of tibia), and ankle joint (mid-width of the talar dome) were determined. Next, the mechanical axes of femur, tibia, and the whole lower limb were drawn over the radiographs. According to these reference lines, five lower leg coronal angles were measured (Fig. 1b) [14, 17]:

- Leg Mechanical Axis (LMA) is defined as the angle between mechanical axis of femur and mechanical axis of tibia expressed as a deviation from 180° with a positive value for varus and a negative value for valgus deviation;
- Lateral Proximal Femoral Angle (LPFA) is defined as the angle between mechanical axis of femur and the line connecting trochanteric apex and the center of femoral head.

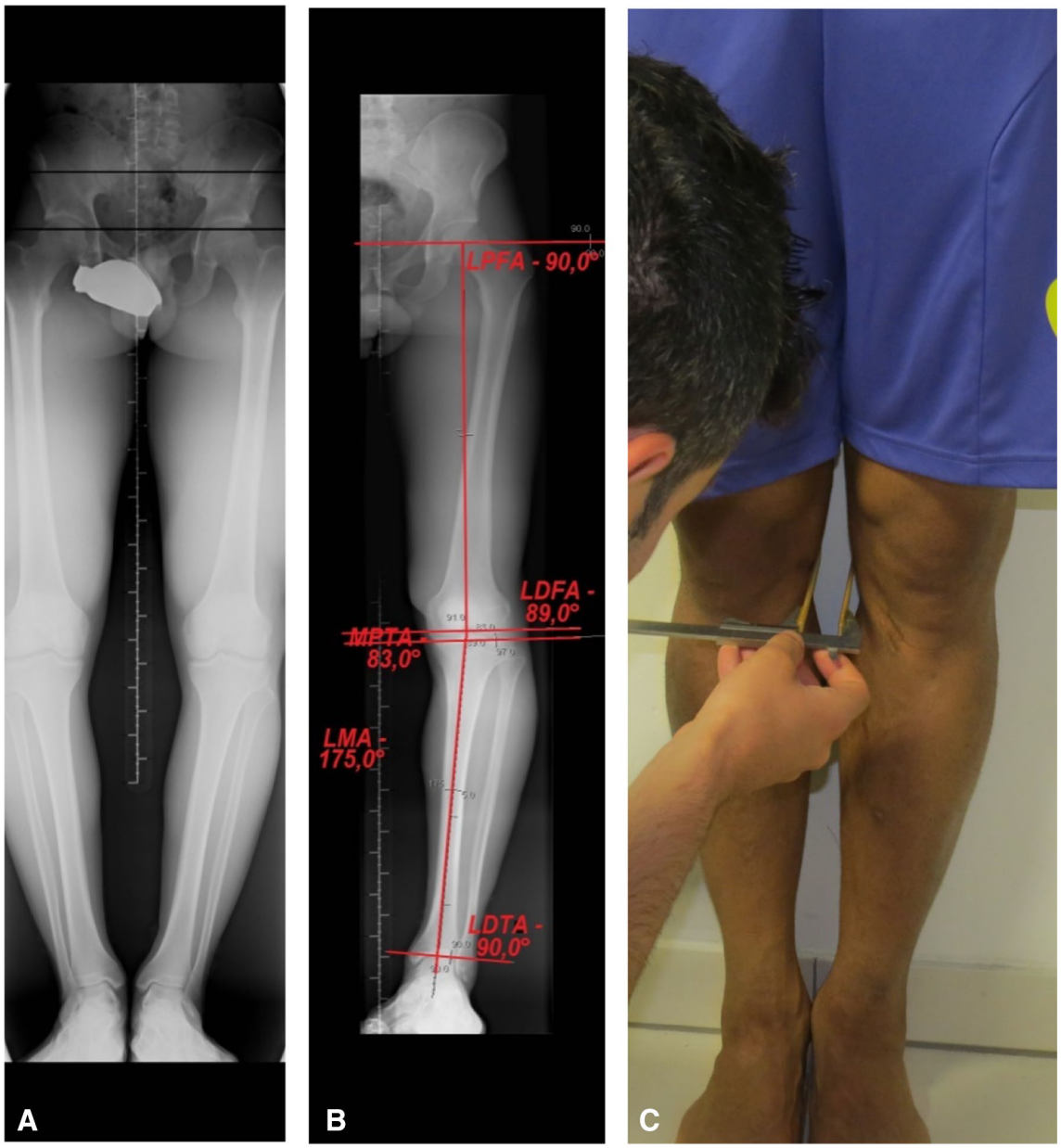

Fig. 1 Bilateral full-leg weight bearing radiograph of a football player (**a**) with radiographic analysis of axis and lower limb mechanical angles (**b**), and an example of the ICD/IMD clinical measurement with a caliper (**c**)

- Lateral Distal Femoral Angle (LDFA) is defined as the lateral angle formed between the mechanical axis of femur and the knee joint line of femoral condyles.
- Medial Proximal Tibial Angle (MPTA) is defined as the medial angle formed between the mechanical tibial axis and the knee joint line of tibial plateau.
- Lateral Distal Tibial Angle (LDTA) is defined as the lateral angle formed between the mechanical axis of tibia and the ankle joint line of distal tibia.

The extent of tibio-femoral osteoarthritis was graded by a five-level Kellgren–Lawrence (KL) grading system, which is the most frequently used reference scale for this purpose since 1963 [22].

Statistical analysis

All the data are presented as means and standard deviations (SD). Standard coronal angles (LMA, LPFA, LDFA,

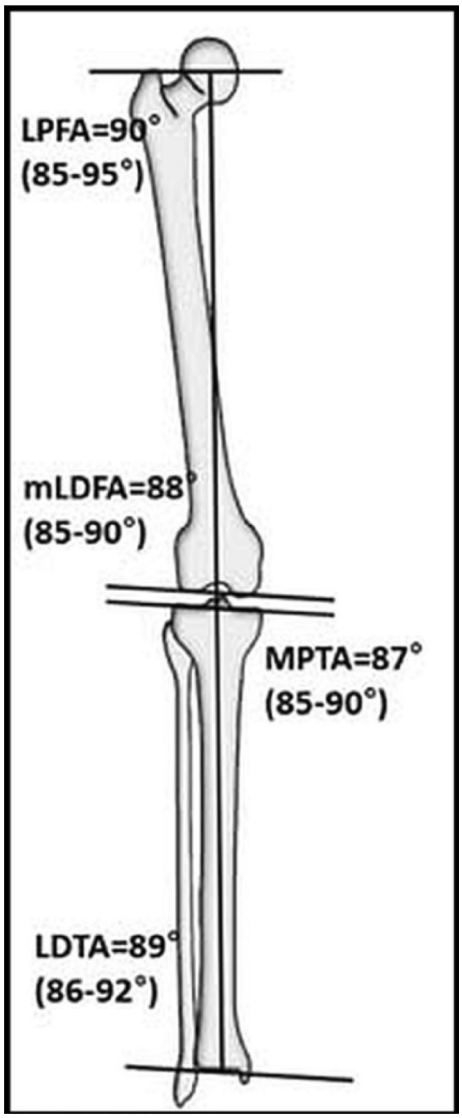

Fig. 2 Normal values of coronal lower limb mechanical angles that were used for the evaluation of radiographs of football players (*LPFA* lateral proximal femoral angle, *LDFA* lateral distal femoral angle, *MPTA* medial proximal tibial angle, *LDTA* lateral distal tibial angle) Adapted according to [17]

MPTA, LDTA) from radiographic analysis of lower legs were compared to the literature referencing values of Paley et al. and Hsu et al. via *t* test for non-paired samples [16, 17]. These angles were also compared for possible inter-individual differences between left to right legs and dominant to non-dominant legs using *t* test for paired samples. The sum of bilateral LMA was correlated against ICD/IMD and also against ICD/IMD adjusted for body height using a Spearman coefficient. The level of statistical significance was set at $P < 0.05$. The analysis was performed by computer software InStat (GraphPad, La Jolla, CA, USA).

Table 1 Comparison of lower limb coronal mechanical angles between football players in current study and reference data from Paley et al. and Hsu et al. [16, 17]

Mechanical lower limb angles	Football players ($N=48$)	Paley et al. ($N=25$) Hsu et al. ($N=120$)
LPFA	89.6° (1.0)	89.9° (5.2)
LDFA	88.8° (1.1)	87.8° (1.6)
MPTA[a]	83.5° (2.7)	87.2° (1.5)
LDTA	89.9° (0.8)	88.6° (3.8)
LMA[a]	5.8° (3.0)	1.2° (2.2)

Data is shown as average values in degrees with standard deviation (SD)

LPFA lateral proximal femoral angle, *LDFA* lateral distal femoral angle, *MPTA* medial proximal tibial angle, *LDTA* lateral distal tibial angle, *LMA* leg mechanical axis

[a]Statistical significant differences

Results

There were 24 players, i.e., 48 lower limbs analyzed. Players had an average ICD/IMD measured with the caliper of 46.5 (19.8) mm. Five lower leg coronal angles in comparison with reference values of Paley et al. and Hsu et al. showed statistically significant differences for the two of them: LMA—5.8° vs.1.2° ($p < 0.001$), and MPTA—83.5° vs. 87.2° ($p < 0.001$). These two differences confirmed increased lower limb varus in football players, with the apex of varus deformity located in the proximal tibia. Details are given in Table 1. We could not detect any significant differences of the five coronal plane angles between left and right legs neither between dominant and non-dominant legs. Details are presented in Table 2. Five knees were graded with mild osteoarthritis (Kellgren-Lawrence 1), while the other 43 knees showed no radiographic signs of osteoarthritis. Summed up bilateral LMA showed a high correlation to IMD/ICD ($r = 0.8395$; $R^2 = 0.7048$), and even higher to ICD/IMD adjusted for body height ($r = 0.8543$; $R^2 = 0.7298$).

Discussion

The most important findings of this lower limb coronal alignment study in active elite football players were: radiographically confirmed increased varus angulation toward the general population with apex of deformity in the proximal tibia, and high correlation between clinical measurements ICD/IMD adjusted for body height toward radiographic values of leg mechanical axis.

Lower limb axial alignment is predominately developing during growth at the level of growth plates [23]. During the rapid growth phase, changes on bones occur along with typical physiological processes in the growth plate [24].

Table 2 Comparison of coronal lower limb mechanical angles between right/left leg and dominant/non-dominant leg of football players

Mechanical lower limb angles	Right leg ($N=24$)	Left leg ($N=24$)	Dominant leg ($N=24$)	Non-dominant leg ($N=24$)
LPFA	89.5° (1.1)	89.7° (1.0)	89.6° (1.1)	89.6° (1.0)
LDFA	89.0° (1.1)	88.5° (1.1)	88.8° (1.2)	88.8° (1.1)
MPTA	83.5° (2.8)	83.5° (2.6)	83.7° (2.8)	83.8° (2.7)
LDTA	90.2° (0.9)	89.7° (0.7)	89.9° (0.9)	90.0° (0.8)
LMA	6.0° (3.0)	5.6° (3.0)	5.7° (3.1)	5.9° (2.9)

Data is shown as average values in degrees with standard deviation (SD)

LPFA lateral proximal femoral angle, *LDFA* lateral distal femoral angle, *MPTA* medial proximal tibial angle, *LDTA* lateral distal tibial angle, *LMA* leg mechanical axis

The growth plate is especially vulnerable due to specific changes and a variety of hormonal stimuli occurring during the growth spurt [25]. When the musculoskeletal system, including the growth plates, is exposed to repeated supramaximal loading, the tolerance limits of tissue regeneration processes may be exceeded, resulting in an overuse syndrome. Overload of long bones growth plates may lead to long-term, even lifelong disability [24, 25]. It has been established that increased intensity of sport activities during the growth spurt has an effect on increased varus incidence in a subgroups of adolescent boys; in particular in football players, who are exposed to specific trainings on a daily basis [7–10]. Chantraine et al. established that 81% of the knees of retired football players showed radiological varus deviation [6]. Varus deviation of 3° or more in professional footballers in our study was found in 87.5% of their lower limbs. On contrary, the constitutional varus of 3° or more occurs only in one-third of general adult male population [14, 15]. Golden standard for the evaluation of coronal alignment in most of the studies on growing children or athletes is clinical measurement of ICD/IMD [7–9]. Using this method, an increased knee varus deviation among adolescent soccer players was confirmed. The average intercondylar distance by the end of growth phase (16 years) in non-sporting teens was 5–15 mm [7, 23], compared to 22–32 mm in football players of same age [7–9]. Normality values for the adult lower limb alignment were defined from the lower limb radiographs of general population [14, 16–18].

The literature review revealed that there are currently no radiographic data on axial lower limb alignment of active elite football players available [12, 14, 16, 17, 26]. The results of our study were consistent with the results on general population in three (LPFA, LDFA, and LDTA) out of five standard alignment parameters. The values of MPTA (83.52°) and the mean LMA (5.79° of varus) showed significant differences compared to reference data from the literature [16, 17]. Smaller MPTA and comparable other parameters suggest that apex of deformity is located in the proximal tibia. With the radiological analysis of selected parameters of the lower limbs of football players, we confirmed the emphasized varus knee deformation in footballers. Bellemans et al. [14] find constitutional varus in 32% of the male knees with the average LMA 1.87°of varus and MPTA 86.50° in Caucasian subjects. His results are comparable to Asian adult male population, where authors noticed slightly greater varus deformation with LMA 2.8° and MPTA 86.7° [15]. Their data are comparable also to reference data from other studies [16, 17]. Bellemans et al. [14] and Colyn et al. [12] established a strong association between constitutional varus and increased sport activity in the period of growth. They attributed more frequent incidence of varus to the consequence of Heuter-Volkmann`s law which states that increased pressure retards the physeal growth, while decreased pressure promotes it. Colyn et al. [12] in their study additionally analyzed the influence of sport intensity in growing age on the lower limb alignment. Mean LMA was in increasing varus deviation as follows: low–activity male athletes 1.27°, high-activity male athletes 2.63°, and football players 3°. Active elite football players in our study revealed with even higher varus with an average LMA of 5.8°. All this data support the hypothesis that vigorous intensive football training directly impact on the greater varus angulation of the knees.

Comparing the influence of leg dominance on radiological measured parameters, there was no significant difference between the dominant and non-dominant leg in our group of footballers. Therefore, we can conclude that kicking the ball, which was mentioned as a possible reason for the occurrence of bowleg between footballers [7, 9], in our group of football players did not have an effect on a possible one-side greater varus appearance. Upon analysis of radiographs, we did not find evident radiological signs of knee osteoarthritis by football players in the study. This is probably attributed to the inclusion criteria, as we tried to capture only healthy players [27, 28]. Players in our study were measured also for ICD/IMD to check whether most commonly used clinical measure for coronal alignment in population studies, ICD/IMD, correlates with the radiographically measured leg mechanical alignment. The average ICD/IMD of players included in the study measured with the caliper was 46.5 (19.8) mm. This was

significantly higher in comparison to ICD/IMD 22–32 mm measured by 16-year-old football players, as described in the literature [7–10]. Once the growth plate is closed, further bone remodeling in football players occurs due to external forces, as referred to in the Hueter–Volkmann law: growth is retarded by increased compression and accelerated by decreased compression [29, 30], which might be a possible explanation for this phenomenon of continuation of varus angulation, changing the shape of the bone and the lower limb axial alignment also later in life due to physiologic bone remodeling under the influence of external and internal factors throughout the entire life. Kicking the ball and tackling maneuvers may have a prominent role in the development of bowlegs by footballers due to the influence of the increased adduction moment on the medial joint part of the knee, taking into account the law of remodeling [9]. There are currently lack of data on lower limb alignment adaptations and shifting in adults after the cessation of skeletal growth.

Limitations of the current study include possible errors involved in measuring parameters on radiographs. The use of full-leg standing radiography—a method which was well validated in literature, despite the greatest effort of proper positioning of subject's legs, allows the possibility of incorrect positioning of lower limbs that might influence the results. This can be especially true for athletes with a great varus angulation with additional rotation of the limbs. However, with the correct patellar positioning facing forward, we minimized this possible error. Usage of CT or MRI could be a better choice to prevent rotational mistakes, but weight-bearing 3D imaging of the entire lower limbs is currently not possible. The recognized drawbacks for ICD/IMD measurements should be exposed nevertheless: it is a bilateral measure which cannot be applied when one leg only is outstanding, and this measurement was not adapted for body height or leg length by the others authors [7–9, 31]. We have confirmed that adjustment for body height further improves ICD/IMD correlation with LMA. We would, therefore, suggest that body height adjusted ICD/IMD measurement is used in the future studies. Clinical measurements become less reliable also in obese population, which was not the case in our football players. When more detailed axial analysis is conducted, a single leg measurement with goniometer is more accurate. Nevertheless, radiography remains gold standard for axial analysis when surgical planning in required. Finally, there was no ethnical diversity of subjects in our study, so the results could have been different for other populations.

Conclusion

This study has radiographically confirmed an increased varus lower limb deviation of active elite football players compared to the general population. With the measurements of axis and angles of the lower limb of football players, we confirmed that the center of lower limb deformity is located in the proximal part of the tibia. The study has established adequate correlation between radiographically measured LMA and clinical measurements ICD/IMD, but adjustment of ICD/IMD for body height has further improved this correlation. We would, therefore, support the usage of ICD/IMD adjusted for body height in population studies on lower limb alignment.

Acknowledgements The authors are indebted to University Medical Centre Maribor (institutional research funding Grant Number IRP-2012/02-02) for financial support. We are very grateful to Martin Golob (Department of Radiology, University Medical Centre Maribor, Slovenia), for collaborating the study using software ViewForum R4.1 (Philips MD Eleva device). The authors thank also to all the participants—football players of NK Maribor, Slovenia.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interests in relation to the presented work.

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