PhD Thesis

The 3D reconstruction based examination of the lower limbs' anatomical and biomechanical parameters in childhood, adolescence and young adulthood

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Abbreviations used

CD angle – collodiaphyseal angle,

CT – computed tomography,

FM-FS – femoral mechanical axis-femoral shaft angle,

FMA – femoral mechanical angle,

LDX – low-dose X-ray,

MRI – magnetic resonance imaging,

mTFA – mechanical tibiofemoral angle,

sTFA – sagittal tibiofemoral angle,

TMA – tibial mechanical angle,

US – ultrasound.

I. Introduction

The period from infancy through childhood and into early adolescence is a time of unprecedented growth. During this time height increases almost 3.5 times, weight grows almost 20 fold and the ratio between our body parts changes significantly. Our bony skeleton undergoes and adapts to these changes with alterations in its' longitudinal and volumetric parameters.

I.1. Importance of lower limb anatomical and biomechanical parameters

Dysfunction of this developmental process can lead to a wide variety of orthopaedic diseases, which may manifest themselves in childhood or in later life. Changes in the sensitive biomechanical balance may lead to numerous orthopaedic disorders. Axis deviation of the lower limb in childhood increases the risk of knee osteoarthritis five-fold. Abnormal collodiaphyseal angles (the angle between the femoral neck axis and the proximal diaphysis axis),femoral torsions (the angle between the femoral neck axis and the posterior condylar line projected on a plane perpendicular to the mechanical axis of the femur), or limb length discrepancy are all independent risk factors of hip osteoarthritis.

The deviations are mostly idiopathic, but they may indicate numerous pathological processes (e.g. phosphate diabetes, renal osteodystrophy, Marfan syndrome, Ehler-Danlos syndrome etc.).

Deviation of the lower limb biomechanical parameters frequently occurs in clinical practice. Although changes in anatomical and biomechanical parameters during childhood are well known, these conditions may be a reason of concern for parents and relatives, who usually seek medical advice.

I.2. The opportunities to measure lower limb anatomical and biomechanical parameters

To evaluate lower limb anatomical and biomechanical parameters, both physical examination and imaging techniques are used in clinical practice. While physical examination can be appropriate for estimating the limb's parameters limitations in its accuracy should be taken into consideration.

In regards to imaging techniques, conventional X-Rays are the most widely used technique in the clinical practice, but the projective and summative character of a method with a static source and single two-dimensional image does not make it suitable for measurement of 3D parameters. Patient positioning is also crucial in conventional radiography, as inaccurate positioning may lead to measurement differences.

CT and MRI examinations could be used as alternative methods, but they are limited by factors such as a higher radiation dose, non-weight bearing position, the need for anaesthesia (especially in children) and a higher overall cost.

With US examination the radiation can be avoided, but the inaccuracy, soft-tissue- and operator-dependant sensitivity of the method limits its use for hip evaluation in infants and young children.

I.3. The goal of this study

Considering the importance of the lower limb anatomical and biomechanical parameters in clinical practice and basic sciences, and the apparent lack of published data based on 3D measurement in big population, the aim of this study was to

1. perform a reliability study of the EOS 2D/3D method in the 2-24-year-old age group for the measurement of the lower limb anatomical and biomechanical parameters;
2. define the normal values of the lower limb anatomical and biomechanical parameters in a large population in childhood, adolescence and young adulthood;
3. characterize the gender-specific differences of these parameters;
4. define the population-specific reference ranges of the parameters.

II. Examined population and methods

II.1. The EOS 2D/3D technology

The multiwire chamber concept, which earned Georges Charpak the 1992 Nobel Prize in Physics, has led to a revolutionary new imaging technique called the EOS 2D/3D imaging system (EOS Imaging, Paris, France) (Figure 1.).

This device produces weight-bearing, whole-body simultaneous AP and lateral imaging with the help of co-linked pairs of X-ray tubes and detectors moving together vertically (Figure 2.).

Figure 1. The EOS system

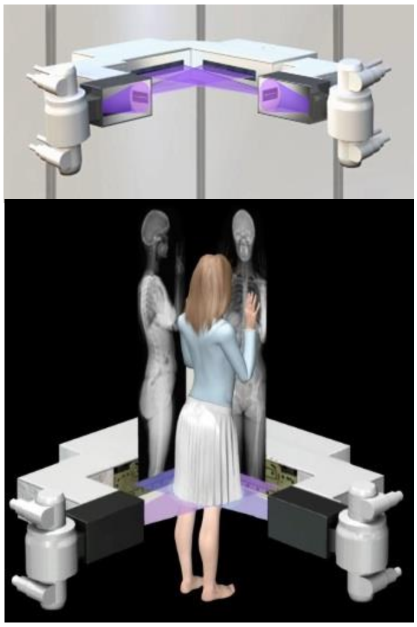

Figure 2. The functioning of the EOS system

The use of ultra-low dose radiation is a prominent advantage of this technique, as a bidirectional, full-body image of an adult requires exposure to <0.30 mGy of radiation. Another significant advantage of this technology is that during examination, the patient is in a standing, weight-bearing position, which enables the examination of mechanical parameters.

The system’s SterEOS 3D software makes possible the preparation of 3D models from the records (by manual fitting a general model, in so-called ‘Full 3D mode’) (Figure 3.). If the image is not suitable for Full 3D reconstruction, the software gives the opportunity to make a simplified model using just a few reference point (called ‘Lower limb alignment’ mode).

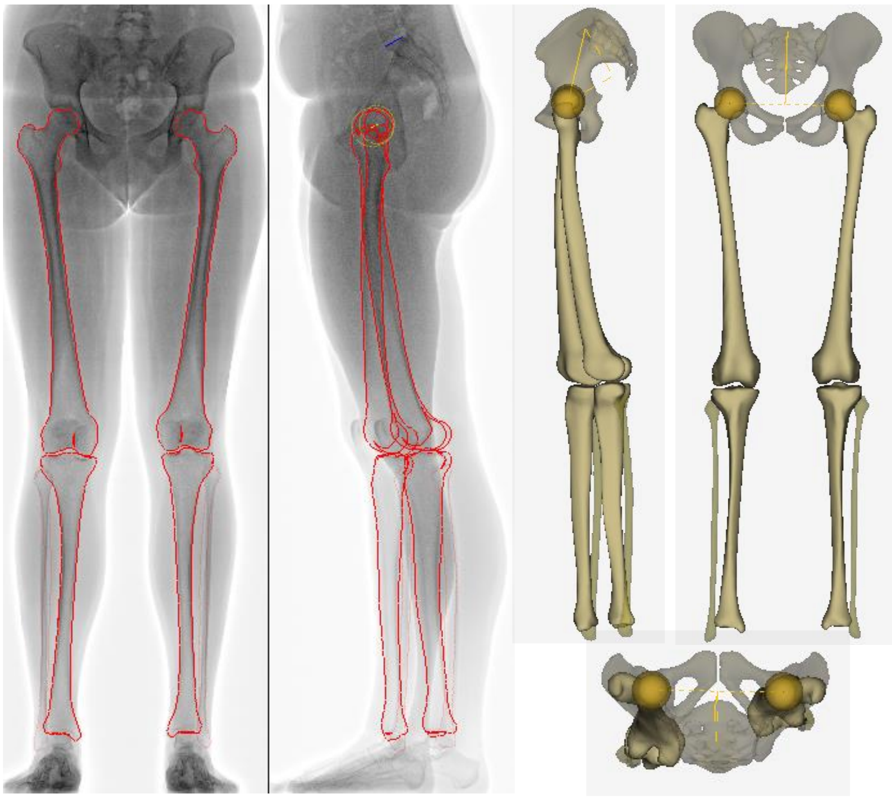

Figure 3. SterEOS Full 3D lower limb reconstruction

The Full 3D Lower limb reconstruction gives 15 geometrical parameters automatically:

- Length of the femoral mechanical axis (femur length);
- Length of the tibial mechanical axis (tibia length);
- The length of the lower limb (limb length);
- Femoral head diameter;
- Neck length (the distance between the centre of the femoral head and the proximal diaphyseal axis, when following the axis of the femoral neck);
- Neck shaft angle, aka the collodiaphyseal angle (CD angle, the angle between the femoral neck axis and the proximal diaphysis axis);
- Femoral offset (the distance between the centre of the femoral head and the closest point of the femoral shaft axis);
- Mechanical tibiofemoral angle (mTFA, the angle between the mechanical axis of the femur (which passes from the femoral head through the centre of the distal femur) and the mechanical axis of the tibia (from the centre of the proximal tibia to the middle of the ankle) in the frontal plane of knee (convention dictates that in the varus position angles are negative, and in valgus positive)
- Sagittal tibifemoral angle (sTFA, the angle between the femural and tibial mechanical axis in the sagittal plane);
- Femoral mechanical axis-femoral shaft angle (FM-FS, the angle between the mechanical and anatomical axis of the femur in the frontal plane of the knee);

- Femur mechanical angle (FMA, the angle between the femoral mechanical axis and the tangent of the femoral condyles medially);
- Tibial mechanical angle (TMA, the angle between tibial mechanical axis and the tangent of the tibia plateau medially);
- Femoral torsion (the angle between the femoral neck axis and the posterior condylar line projected on a plane perpendicular to the mechanical axis of the femur);
- Tibial torsion (the angle between the transmalleolar and transcondylar axis projected on a plane perpendicular to the mechanical axis of the tibia);
- Femorotibial rotation (the angle between the posterior condylar line of the femur and tibia).

The Lower limb alignment mode results the following parameters:

- Femur length;
- Tibia length;
- Limb length;
- Femoral head diameter;
- Mechanical tibiofemoral angle;
- Sagittal tibiofemoral angle;
- Femoral mechanical axis-femoral shaft angle.

II.2. The examined population

In this study, we evaluated the results of EOS 2D/3D radiographs obtained during routine diagnostic practice in the Department of Orthopaedics, University of Pécs, between 2007 and 2012. Of the 7108 records, we selected cases in which there were no previous surgical interventions or deformities influencing the biomechanics of the lower limbs. Cases in which anamnesis revealed any disorders that may influence growth were excluded.

Under the age of 16 years we attempted to assess all suitable cases. Over 4 years of age Full 3D reconstruction of both lower limb was performed. Under the age of 4 years – because of the uncertainty caused by larger growth cartilages – the lower limb alignment mode was used. Finally 622 (258 boys, 364 girls) modelling were successful.

From the 1113 examinations representing the 17-24-year old age group, 25 males and 25 females were randomly selected from each year, resulting in a total of 400 image-pairs.

In total, measurements were successful in 1022 cases (458 males, 564 females).

II.3. Statistical analysis

The statistical analysis was performed using SPSS v22 (IBM Corp., Armonk, NY, USA) and Microsoft Office Professional Plus v14.0.6112.5000 (Microsoft Corp., Redmond, WA, USA).

Normality of data was checked using the Kolmogorov–Smirnov test. Intra- and inter-observer reliability was investigated using the intraclass correlation coefficient (ICC). The investigated parameter and laterality were evaluated by paired samples t-est. Relationship between measured data and age was evaluated using Spearman correlation and one-way ANOVA, while differences between genders were analysed using independent samples t-test.

For randomized selection the RAND.BETWEEN formula of the Microsoft Excel software was used.

P-value <0.05 was accepted as significant.

III. Results

III.1. The reliability study of the EOS 2D/3D system

Intraobserver reliability of the EOS system was >0.9, regarded as ‘excellent’ by Winer’s criteria. The interobserver reliability studies also achieved excellent results, except in the femoral torsion, tibial torsion and femorotibial rotation, which achieved 'good' results.

Only the sagittal tibiofemoral angle was found to be affected by the step-forward examining position (p=0,047), therefore this parameter was excluded from the further examinations. In the other parameters the further calculations were performed using the mean of the both side.

III.2. The correlation between the lower limb parameters and calendar age

All of the examined parameters had a strong correlation with calendar age (based on Spearman correlation).

Using one-way ANOVA, significant differences were observed between the age groups.

III.3. Gender specific differences

Except FM-FS, all of the examined parameters showed gender specific differences.

III.4. The evolution of the lower limb anatomical and biomechanical parameters

III.4.1. Longitudinal parameters

All three of the longitudinal parameters showed a continuous and moderate rate of growth until the 15-year-old group.

Femur length increased from 19,14 cm to 44,13 cm (16-year-old), then its value stagnated between 14-42 cm. Tibial length rose from 16,34 cm, then reached the plateau phase at the age of 15 years at 38,56 cm.

Limb length started at 35,7 cm and by 16 years old, at an average length of 82 cm, it started to fluctuate with a moderate variation.

III.4.2. The anatomical parameters of the proximal femur

The collodiaphyseal angle showed – with mild fluctuation – a continuous, slightly decreasing tendency: from 131,58°to 127,39° (Figure 4.).

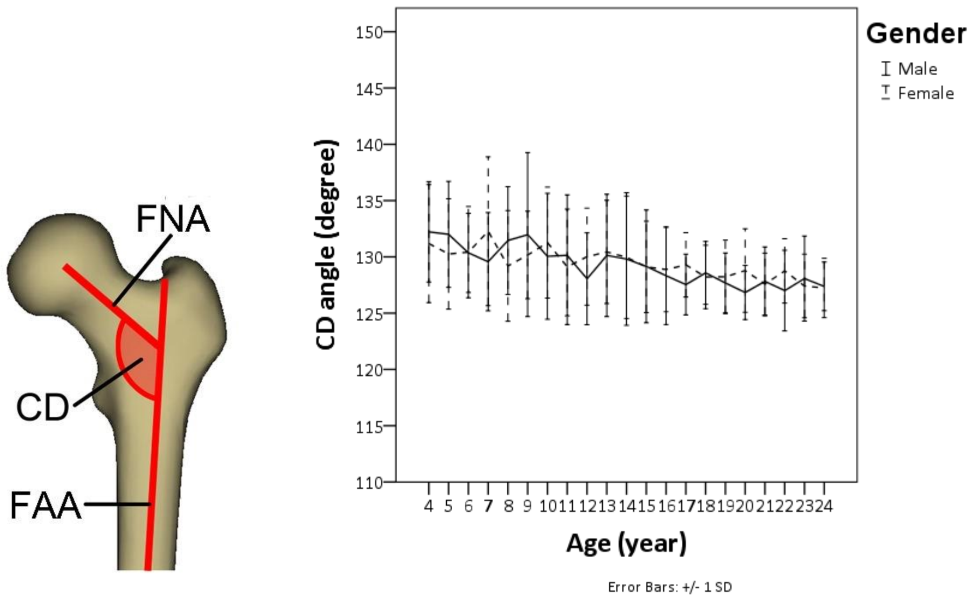

Figure 4. Collodiaphyseal angle

The collodiaphyseal angle (presented on own EOS 3D reconstruction images) (FNA-femur neck axis, CD-collodiaphyseal angle, FAA-femur anatomical axis). The measured values in mean ± S.D. format.

The femoral head diameter increased from 23,38 mm to 43,81 mm (at 15-years old) followed by a plateau phase.

The value of the femoral offset rose from 24,33 mm (4-year-old) to 39,34 mm (16-year-old), then exhibited moderate fluctuation.

The femur neck length climbed from 32,21 mm (4-year-old) to 50,15 mm (16-year-old), and then ceased elongation.

III.4.3. The axis of the lower limb

In the case of the mTFA, valgus position was observed in both genders at the 2 years old. The valgisation tendency continued until the age of 3 years, when the peak valgus was seen at 4,27° in boys and 4,85° in girls. After this, varisation started. In girls the value fell significantly: 1,29° was observed at the age of 4 years. Then a moderate decrease came until the age of 10-11 years, when the mTFA assumed the neutral position. After this age the value did not differ significantly from the zero value. In contrast, in boys the mTFA decreased more moderately until the age of 8 years, when a 0,90° varus position was obtained. This varus peak was followed by slow neutralisation as they approached the 0° value around the age of 10-11 years. In the 14-16-year-old age group another varus deflection was attended (1,75°of varus at the age of 16 years). The axis normalised at the age of 17 years, and afterwards did not vary more then 0,53° (Figure 5).

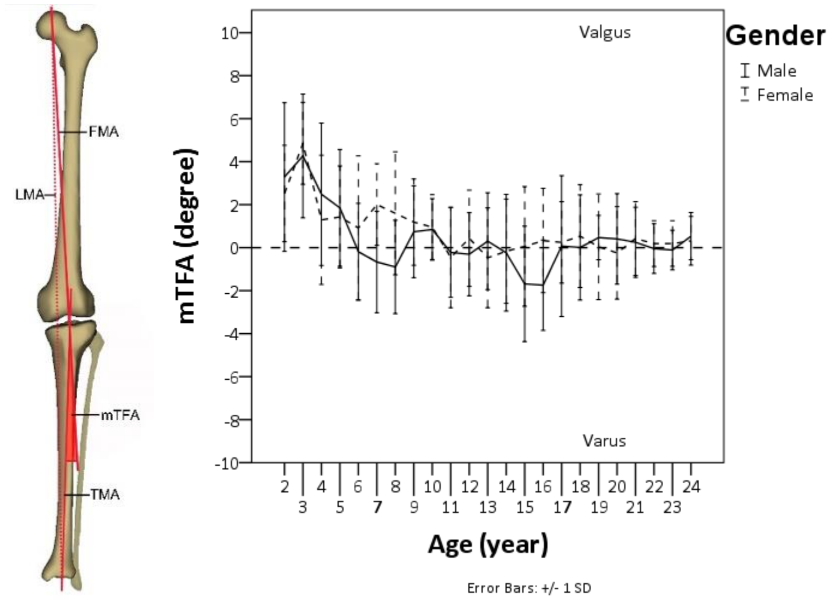

Figure 5. mTFA

The mTFA (presented on own EOS 3D reconstruction images) (FMA-femur mechanical axis, LMA – lower limb's mechanical axis, TMA-tibia mechanical axis). The measured values in mean ± S.D. format.

FM-FS showed similar dynamics to the mTFA: there was a peak at the age of 3 (5,47°), that decreased until 3,74° at the age of 4 years, then – after increasing moderately – did not vary much around 4,50°.

Femoral mechanical angle was found to be 92,50° at the age of 4 years, which underwent a mild increase (until 94,06°, at 13 years old). After a slight fall, a value of 92,25° was observed in the 24-year-old age group.

In the tibial mechanical angle changes similar to those found in the femoral mechanical angle were seen. At the age of 4 years 88,86° was measured. This was followed by a moderate increase, in girls in the 10-year-old group as high as 90,20° was also detected. After a moderate decrease, it showed 88,89° at the age of 24 years. A significant fall must be highlighted that took place in boys in the 14-16 year-old age group (86,45°), this coincided with the varus deflection seen at that time in the mTFA's.

Based on the Spearman correlation there was no significant connection between the FM-FS, femoral mechanical angle and the mTFA, however the correlation was significant between the tibial mechanical angle and the mTFA (p_{FM-FS}=0,356, $p_{fem.\ mech.\ angle}$=0,751, $p_{tib.\ mech.\ angle}$=0,028).

III.4.4. The torsional and rotational parameters of the lower limb

The femoral torsion was measured at 22,41° in boys, and 21,60° in girls at the age of 4 years. After that – during which a large variation in values were found (26,45° in girls at the age of 5 years, 25,75° in boys at the age of 10) – a clear decreasing tendency emerged in both genders. At the age of 24 years values of 16,06° in males, and 16,09° in females were recorded (Figure 6.).

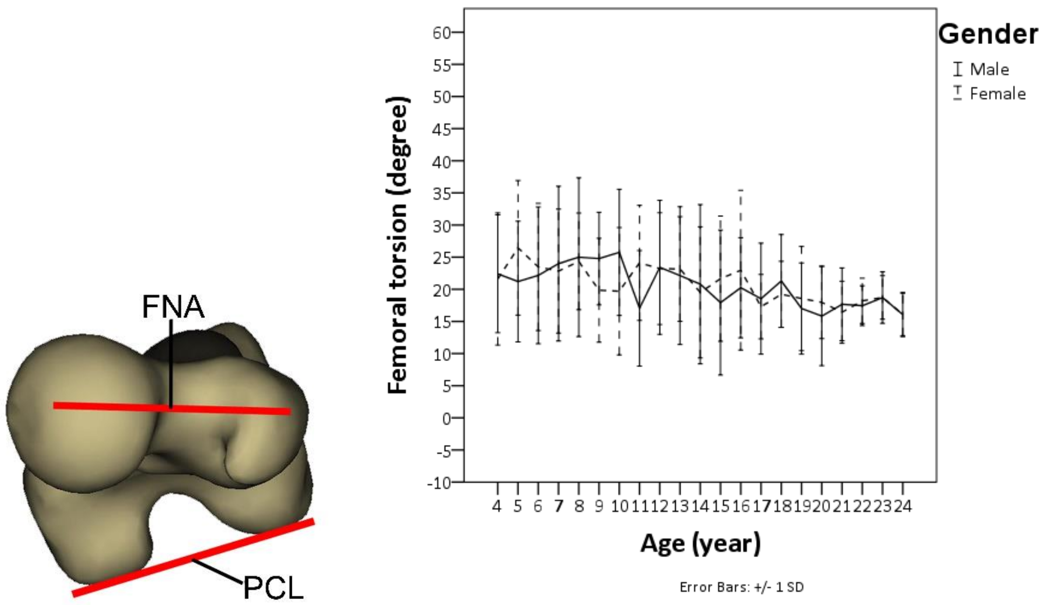

Figure 6. Femoral torsion

The femoral torsion (presented on EOS 3D reconstruction images) (FNA-femur neck axis, PCL – posterior condylar line). The measured values in mean ± S.D. format.

Tibial torsion decreased from 32,15° to 30,31°, until the age of 8 years after which the tendency reversed, and the value increased until 38,96°.

The femorotibial rotation showed external rotation except an isolated internal rotation value at the age of 4 years in boys (1,68°), and at the age of 8 in girls (0,13°). After the age of 9 years increased values (8,05° in girls, 5,41°in boys) were noticed. This increased value persisted until the age of 17 years. At the age of 24 years a value of 4,12° was observed in males and 4,27° in females.

IV. Conclusions

We have shown that the EOS 2D/3D system is a feasible technology for measuring anatomical and biomechanical parameters in 2-24 year olds. Under 4 years old, only measurements using the Lower limb alignment mode were possible to carry out due to the uncertainty caused by the large growth cartilages. The slight asymmetry caused by the 'step-forward' position may influence the value of the sagittal tibiofemoral angle therefore we cannot recommend assessing it using this method.

Using EOS technology we evaluated the normal gender-specific values of 14 anatomical and biomechanical parameters in a large population of 2-24 year olds. We believe some of this data to be a novelty in the literature, as certain parameters have not been previously examined, examined only in small populations, or were determined using a less accurate measuring method.

We found that all the examined parameters were related to age.

Gender differences were found in all parameters except the FM-FS. The reason for this can be the fact that the FM-FS shows only a minimal change in the examined age group, apart from one peak (5,47°in 3 year olds) its value stays in a 1° range (3,74°-4,65°).

The tendency in the examined parameters fits into the available literature data, though the absolute values were substantially different in some parameters. This could possibly be explained due to the high accuracy associated with our measuring method and that in combination with this sizable examined population, we have come closer to the true values.

Due to its clinical significance 3 parameters should be highlighted: the CD angle, who's value decreased from 132,22° to 127,38° from 4 to 24-year-old boys and among girls across the same age range it decreased from 131,18° to 127,27°. The mTFA, that showed valgus position in the 2-year-old group (boys 3,29°, girls 2,52°) then reached its valgisation peak at 3 year olds (boys 4,27°, girls 4,85°) continued with varisation that caused a nearly neutral value in the 6-year-old group. We observed that the changes in mTFA values are correlated to the changes of the tibial anatomy. The Femoral torsion value decreased in boys from 22,41° to 16,06° and in girls from 21,60° to 16,09° in the examined population.

The description of the femorotibial rotation values in this age group and our observiation of the increase in outer rotation in 10-16 year olds - an increase especially significant in girls - are both novelties. As far as we know we are also the first to describe the reference range of femoral head diameter, femoral offset and femur neck length in this age group.

V. Summary

Considering the outstanding clinical importance of this topic, its widespread appearance in the literature is not surprising. Nevertheless, the number of patients or the accuracy of the applied method is usually low in such studies.

The novel EOS 2D/3D imaging system, which can capture low distortion whole-body stereo X-ray scans of standing patients at an ultra-low radiation dose is a useful tool for such studies. Using its stereo images, 3D models of the lower limb can be generated measuring 15 anatomical and biomechanical parameters automatically.

This study aimed to evaluate the reliability of the EOS 2D/3D system and establish normal reference standards for the measurement of gender-specific lower limb parameters in children, adolescents and young adults.

The reliability study of the EOS 2D/3D method was first performed, after which 1022 children, adolescents and young adults were evaluated for 15 different parameters measured on lower-limb reconstructions from radiological examinations carried out with the EOS 2D/3D system in the course of routine orthopedic indicated diagnostic practice. Spearman correlation, ANOVA and t-test were used for statistical analysis.

Summary of novel results and statements

1. The EOS 2D/3D system was used successfully to measure the lower limb anatomical and biomechanical parameters in the 1022 individuals in the 2-24-year-old age group.
2. Under the age of 4 years uncertainty caused by the growth cartilages prevents the use of Full 3D reconstruction mode. In these ages the Lower limb alignment mode gives a good alternative to make a simplified model.
3. The step-forward position used during the imaging can influence the measurement of the sagittal tibiofemoral angle, therefore this parameter should not be evaluated using this technology.
4. The reliability of the SterEOS Full 3D and Lower limb alignment reconstructions proved to be excellent.
5. In a large population, using an accurate 3D-based measurement 15 lower limb parameters' normal values were defined in the 2-24-year-old age group. As far as we know the reference ranges of the femorotibial rotation, femoral head diameter, femoral offset and femur neck length were not published before.
6. The gender specific character of the lower limb parameters were described: except the FM-FS, all of the measured parameters showed gender specific differences.

7. The pattern found in this study confirms the results of previous publications investigating Caucasian populations, however, absolute values differ significantly in several cases. We suppose the differences are due to our greater accuracy as we used a large examined population with a highly accurate method as part of this study.

8. Considering their outstanding clinical importance, the collodiaphyseal angle, mechanical tibiofemoral angle and the femoral torsion must be highlighted:

   a. The collodiaphyseal angle decreased from 132° to 127° in the 4-24-year-old age group. The former publications described higher values in childhood and a more significant decrease with growth. The cause of the difference may be the 3D-characteristics of our measuring method, which excludes the torsional effect of the femoral torsion, a parameter which decreases at this time.

   b. The mechanical tibiofemoral angle showed a valgus position in 2 year olds. It reached its valgisation peak in the 3-year-old group with a value of 4,5°. After that a varisation tendency was observed causing neutralisation until the age of 6 years. A connection between the changes of the mechanical tibiofemoral angle and anatomy of tibia was observed.

   c. The value of the femoral torsion fell from 22° to 16° in the examined population. This change is also more moderate than the previously published data, however the variation between those publications data is also significant. We hypothesize, again, that our large examined population and the accurate measuring method is the cause of the difference.

Publications related to this thesis

Schlégl ÁT, O'Sullivan I, Varga P, Than P, Vermes Cs: Determination and correlation of lower limb anatomical parameters and bone age during skeletal growth (based on 1005 cases). J Orthop Res, 2016 Aug 11. doi: 10.1002/jor.23390. [Epub ahead of print] **IF: 2,88, SJR: 1,464 (Q1)**

Schlégl ÁT, O'Sullivan I, Varga P, Than P, Vermes Cs: A Hassel–Farman módszer alkalmazása a csontkor meghatározására, valamint ennek összefüggése az alsó végtag biomechanikai paramétereivel. Magyar Traumatológia Ortopédia Kézsebészet Plasztikai Sebészet, 2015;58(4):105-121.

Schlégl AT, Szuper K, Somoskeöy S, Than P: Az alsó végtag tengelyállásának vizsgálati lehetőségei - Tapasztalataink az új EOS 2D/3D technológiával. Magyar Traumatológia Ortopédia Kézsebészet Plasztikai Sebészet, 2015;58(2-3):127-139.

Schlégl ÁT, Szuper K, Somoskeöy S, Than P: Three dimensional radiological imaging of normal lower-limb alignment in children. Int Orthop. 2015 Oct;39(10):2073-2080. **IF: 2,39, SJR: 1,508 (Q1)**

Schlégl ÁT: Az alsó végtag anatómiai és biomechanikai paramétereinek 3D rekonstrukció alapú vizsgálata gyermekkorban a csontkor függvényében. Magyar Ortopéd Társaság: Zinner Nándor pályamunka 2015

Szuper K, **Schlégl AT,** Leidecker E, Vermes C, Somoskeöy S, Than P: Three-dimensional quantitative analysis of the proximal femur and the pelvis in children and adolescents using an upright biplanar slot-scanning X-ray system. Pediatr Radiol. 2015 Mar;45(3):411-421. **IF: 1,53, SJR: 0,593 (Q2)**

Schlégl AT, Szuper K, Somoskeöy S, Than P: [Evaluation of the usefulness of the EOS 2D/3D system for the measurement of lower limbs anatomical and biomechanical parameters in children]. Orv Hetil. 2014 Oct 1;155(43):1701-1712. IF: was published first in 2015, **SJR: 0,152 (Q3)**

Schlégl AT, Szuper K, Somoskeöy S, Than P: A csípőízület 3D modellezése gyermekkorban. Magyar Traumatológia Ortopédia Kézsebészet Plasztikai Sebészet, 2014;57(4):81-91.

Schlégl ÁT: EOS 2D/3D módszer alkalmazhatóságának vizsgálata a szabad alsó végtag anatómiai és biomechanikai paramétereinek mérésére gyermekkorban, valamint ezek összefüggésének vizsgálata életkorral, magassággal illetve nemmel. Orvosi Hetilap-Semmelweis Egyetem: Regőly-Mérei pályamunka 2014

Schlégl ÁT: A szabad alsó végtag normál anatómiai és biomechanikai paramétereinek vizsgálata gyermekkorban EOS 3D rekonstrukcióval. Magyar Ortopéd Társaság: Zinner Nándor pályamunka 2014

Presentation on international conference

Schlégl Á, Szuper K, Somoskeöy Sz, Than P: The 3D examination of lower limb alignment in 806 children, adolescents and young adults – 16th EFORT Congress, Prága, 27-29. May 2015. Scientific Programme. pp. 91.

Varga P, O'Sullivan I, **Schlégl ÁT**: Examination of the lower limb's torsional parameters in point of bone age - VII. International and XIII. National Interdisciplinary Grastyán Conference, Pécs, 19-21. March 2015.

Schlégl Á, Somoskeöy Sz, Szuper K, Than P: EOS 2D/3D examination of the proximal femur and pelvis in 508 children and adolescents – 10th CEOC, Split, 8-11. May 2014. Abstract Book. pp. 67.

Schlégl ÁT, Szuper K, Somoskeöy Sz, Tahn P: The examination of the knee joints alignment in children – HMAA Summer Conference Balatonfüred 2014, 22-23. August 2014. Abstract Book. pp. 22.

Schlégl ÁT: The 3D examination of the lower limb's axial parameters in children - HMAA Summer Conference Balatonfüred 2013, Balatonfüred, 16-17. August 2013. Abstract Book. pp. 17.

Schlégl ÁT: The childhood examination of the femoral bone- and hip joint's anatomical parameters with EOS in 2D and 3D - HMAA Summer Conference Balatonfüred 2012, Balatonfüred, 18-19 August 2012. Abstract Book. pp. 20.

Presentation on Hungarian conference

Schlégl ÁT, O´Sullivan I, Varga P, Than P, Vermes Cs: A collodiaphysealis szög és a csontkor kapcsolatának vizsgálata 1005 EOS 3D rekonstrukció alapján – Magyar Ortopéd Társaság 2016. évi Kongresszusa, Pécs, 23-25. June 2016.

Varga P, **Schlégl ÁT,** O´Sullivan I, Maróti P,Than P, Vermes Cs: 3D nyomtatás lehetőségei a primer és revíziós csípő protetikában – Magyar Ortopéd Társaság 2016. évi Kongresszusa, Pécs, 23-25. June 2016.

Somoskeöy Sz, **Schlégl ÁT,** Belák M, Begovits B, Than P: Primer térdizületi endoprotézis-beültetés műtéti tervezéséhez használt 3D tervező szoftver megbízhatósági vizsgálata – Magyar Ortopéd Társaság 2016. évi Kongresszusa, Pécs, 23-25. June 2016.

Schlélg ÁT, Varga P, O'Sullivan I, Vermes Cs: Az alsó végtag biomechanikai paramétereinek vizsgálata a csontkor függvényében – Magyar Ortopéd Társaság és a Magyar Traumatológus Társaság 2015. évi közös Kongresszusa, Szombathely-Sárvár, 11-13. June 2015.

Schlégl ÁT, Szuper K, Somoskeöy Sz, Than P: A csípőízület anatómiai paramétereinek 3D vizsgálata gyermekkorban – Magyar Ortopéd Társaság és a Magyar Traumatológus Társaság 2014. évi közös Kongresszusa, Szeged, 22-24. June 2014. Programgüzet. pp. 63.

Szuper K, **Schlégl ÁT**, Somoskeöy Sz, Dömse E, Wiegand N, Than P: Femur és tibia diaphysis törések műtétet követő vizsgálata EOS 2D/3D röntgen készülékkel – Magyar Ortopéd Társaság és a Magyar Traumatológus Társaság 2014. évi közös Kongresszusa, Szeged, 22-24. June 2014. Programgüzet. pp. 59.

Than P, Somoskeöy Sz, **Schlégl ÁT**: Új preoperatív protézis tervező szoftver alkalmazhatóságának vizsgálata – Magyar Ortopéd Társaság és a Magyar Traumatológus Társaság 2014. évi közös Kongresszusa, Szeged, 22-24. June 2014. Programfüzet. pp. 17.

Schlégl ÁT: Az alsó végtag tengelyállásának 3D vizsgálata gyermekkorban - V. Nemzetközi XI. Országos Interdiszciplináris Grastyán Konferencia, Pécs, 17-19. April 2013.

Schlégl ÁT: A csípőizület és a femur anatómiai paramétereinek vizsgálata LDX (EOS) készülékkel gyerekkorban - IV. Nemzetközi és X. Országos Interdiszciplináris Grastyán Konferencia, Pécs, 12-13. April 2012.

Poster on international conference

Kinga Sz, **Schlégl ÁT**, Somoskeöy Sz, Than P: Geometrical values of the normal and arthritic hip and knee detected with the EOS 3D imaging system – 10th CEOC, Split, 8-11. May 2014. Abstract Book. pp. 86.

Schlégl ÁT, O'Sullivan I, Varga P, Than P, Vermes Cs: Bone Age - A potential indicator of lower limb's anatomical and biomechanical parameters – 17th EFORT Congress, Geneva, 1-3. June 2016.

Schlégl ÁT, Varga P, Maróti P, O'Sullivan I, Vermes Cs, Than P: Patient specific 3D printed hip models for easier teaching and better understanding the total hip arthroplasty in developmental dysplasia of the hip – AMEE 2016, Barcelona, 27-31. August 2016. Abstract Book pp. 587.

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