Biomechanical of knee joint during gait cycle

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Abstract. The purpose of this work is to study the angular displacement and kinematics of the knee joint during walking. and spatio-temporal gait characteristics using motion capture data analysis, based on the observation of a group of healthy young adults. The angles of knee joint were registered for 29 young men at age 18-35. Was used Vicon motion capture system consisting of 10 cameras T40, AMTI platforms and Vicon Polygon and Vicon Nexus software. Results. The amplitude of knee joint flexion was 54.2±0.9°; knee axis rotation - 8.9±0.9°; lateral knee displacement - 11.9±0.9°. A relationship was found between flexion and extension of the knee joint and rotation of the hip joint. The relevant time-spatial gait parameters in the stance and swing phase, movement amplitude of the knee should be taken into account when choosing the best treatment. The data obtained in this study can be used as a normative basis for research in the early diagnosis of pathologies of the musculoskeletal system.

Keywords: gait, kinematic parameters of knee, knee joints, knee, gait cycle, Vicon motion capture system, Vicon.

1. INTRODUCTION

The research of the anatomy and biomechanics of the knee joint during the gait is useful to properly diagnose and treat different of knee joint injuries and pathologies. The gait is a cyclic locomotion involving a wide range of movements. The gait cycle begins with the contact of the leading foot and the support and ends at the moment when this leg begin a next contact with the support. The gait cycle also consists of two support periods - double and single. It can be conditionally divided into a gait cycle of the right leg and a gait cycle of left leg [1].

The knee joint is one of the largest and most complex joint in the human body. It is formed by the tibia and femur, performs musculoskeletal functions and maintains balance during movement. The knee joint is under enormous stress, since almost 98% of the body weight falls on it. That is means that it is loaded as much as possible during the person movement. Therefore, the knee joint is constantly susceptible to various injuries and has a tendency to wear out much faster than other joints.

The three-dimensional video data analysis system allows using modern methods in the study of the function of the knee joints. An individual skeletal model is created [2]. This model allows us to study angular displacements of knee joint in three planes [3]. We received an information how do the knee joint interact with other segments of the human body.

The purpose of this work is to estimate the kinematic and spatio-temporal parameters of the knee joint during walking.

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2. METHODS

We organized a study of 29 young healthy men at the age 18-35 years. The study was made in the Multimedia center of Astrakhan State University. The average age of men was 20.3±0.4 years. The group of studies included persons who had previously been tested by a traumatologist-orthopedist for the presence of chronic diseases and pathologies of the musculoskeletal system and the knee joint.

The length of the body, trunk, limbs, their volume, muscle mass and other anthropometric characteristics affect the spatial, temporal and other biomechanical parameters of human locomotion. Therefore, the study group included persons with the most common body type. All subjects were assigned to the normosthenic somatotype. The normative study group consisted of 250 males aged 18-25 years. All people passed anthropometric studies and research using Vicon's motion capture and analysis system. Somatotyping was performed using the Pignet index, which was calculated using the Pignet formula = height - (weight + chest circumference): the value of the Pignet index of more than 30 corresponded to asthenic constitution, from 10 to 30 - normosthenic, less than 10 - hypersthenic. The group of subjects included males with the following anthropometric parameters: height 177±3.7 cm, weight - 77.2±4.1 kg, chest circumference - 85.7±1.5 cm. The Pigne index was 16.75±0.48, which corresponds to the normosthenic body type.

The study of the gait cycle was carried out using a Vicon motion capture system for analyzing the movement (Vicon, Oxford, Great Britain). The Vicon system consist of ten cameras Vicon T40 (240 Hz), a dynamometric platform AMTI (model (OR6-5-1000, Watertown MA, USA) and software Vicon Nexus and Vicon Polygon. We used a full body model (Plug-in-Gait Full body) with 39 reflected markers.

Infrared cameras record the dynamics of the movement of markers in three planes and transmit the data through the Gyganet control module to the Vicon Nexus software. In the same way is exported the information obtained as a result of video filming and the passage of the subject on the dynamometer platform. Based on the obtained parameters, a dynamic three-dimensional model of the subject is created in Vicon Nexus. The analysis of the data obtained is carried out in the Vicon Polygon reporting system, where human movements are analyzed according to 36 main parameters.

Gait cycle is customary divide it into the cycle of the right leg and the cycle of the left leg, but since in a healthy person these cycles are identical, it is traditionally accepted to take as a basis the study of the cycle of the right leg in comparison with the cycle of left leg [4, 5]. The gait cycle is a complex structure consisting of moments, periods, stages and phases. This classification is based on moments of the cycle. There are eight of them: the initial contact of the leading leg with the support (1), separation of the toes contralateral leg from support (2), heel lift of the leading leg (3), initial contact contralateral leg with support (4), separation of the toes of the leading foot from the support (5), reduction of the legs or the moment of symmetrical position of the knee joints of both legs (6), vertical position the tibia of the leading leg (7), the final contact of the leading leg with the support (8) [6-8].

The time of gait cycle was taken by default at 100% [9]. The timeline has been split every 10%. The kinematic characteristics were also taken into account. All data were statistically processed using the MathCad software package [10]. The degree of accuracy of the study was determined less than or equal to 0.95%; significance level P≤0.05; for features with a normal distribution, Student's t=2 test was used, for features with a distribution other than normal - the Wilcoxon (Mann-Whitney) nonparametric U-test with the same level of significance [10]. The work used the universal mathematical package MathCad. Correlation analysis was carried out to reveal the relationship between the studied values.

3. RESULTS

When studying the gait cycle, the following spatio-temporal parameters were studied: cadence, period of double support, period of single support, half-step length, half-step width, half-step time, step length, step time, step speed, lameness index.

The main parameters of the gait cycle are presented in Table 1. In the study group, the following parameters were obtained: cadence 124±2,7 steps/min; double support 0,21±0,1 s.; lameness index 0,98±0,1; single support 0,43±0,1 s.; half step length 0,63±0,4 m.; half step time 0,55±0,4 s.; step length 1,06±0,1 m.; step time 1,11±0,1 s.; walking speed 0,9±0,1 s.

Table 1. Spatio-temporal characters of gait

Cadence (step / min)	124±2,7*
Double support (s)	0,21±0,1
Leg separation (%)	58,9±3,56
Lameness index	0,98±0,1
Opposite contact (%)	50,1±1,98
Opposite leg separation (%)	10,08±2,6
Single support (s)	0,43±0,1
Half step length (m)	0,63±0,4
Half step time (s)	0,55±0,4
Step base (m)	0,15±0,3
Step length (m)	1,06±0,1
Step time (s)	1,11±0,1
Walking speed (m / s)	0,9±0,1

Since the movement of the lower limb begins with flexion in the hip joint, it is logical to assume that from this joint begins the series of movements in the transverse plane. Our task is to trace the dynamics of rotation in the knee joint and the relationship of rotational movements.

During the gait cycle, the hip joint is in a state of constant external rotation, the values of which change depending on the phases and periods of the cycle. The maximum value of external rotation occurs at the end of the swing phase (96% of the gait cycle). It coincides with the maximum extension of the knee joint (97% of the gait cycle) and decreases in parallel with the decrease in the flexion angle. This process continues in the next cycle and reaches a minimum at the moment of detachment of the toes of the contralateral foot in the stance phase, when the rotation decreases to a phase minimum (10% of the gait cycle) in the form of a pronounced peak.

This peak of the minimum coincides with the maximum value of the knee flexion angle in the stance phase (11% of the gait cycle) and the end of the first double support phase. During the stage of single support, there is a very smooth, unexpressed increase in the indicators of external rotation, which has the character of a plateau and reaches its maximum values in the phase in the middle of the second stage of double support (55% of the gait cycle). This coincides with the maximum peak of hip extension (51% of the gait cycle).

The knee joint is an anatomical formation with two degrees of freedom: the first degree is the flexion and extension. In the gait cycle, this is the state of knee extension of leading leg in the initial, middle and final periods of the stance phase; knee flexion in the period of preparation for the transfer of the leg and the period of the beginning of the transfer and extension on average the period and the period of the end of the transfer of the leg [11, 12]. The second degree of freedom is tibia rotation around the vertical axis passing through its intercondylar elevation, which is possible only when the knee joint is bent (flexion of the knee joint during the preparation for the leg transfer and the period of the beginning of the transfer in the gait cycle.

According to the accepted provision of the gait cycle, the stance phase accounts for 60% of the entire gait cycle time, and the remaining 40% falls on the transfer phase [13]. We found that the greatest amplitude of knee flexion in the study group was 54.2±0.9°. Two maximum peaks of flexion were revealed, in which the lower values are at the beginning of the support phase (10% of the beginning of the GC) 21.9 ± 0.5 ° and a larger one in the swing phase 63,8±1.3° (70% of the beginning of the GC) (Fig. 1).

In the period from 20% to 40% of the beginning of the gait cycle, the flexion angle decreases, which is due to the extension of the limb in the knee joint, which acts as a support. At the beginning of the transfer phase, the maximum extension of the supporting leg was revealed, the amplitude of which was 11.1±0.4°. In Figure 1, we see that at the end of the stance phase, the initial moment of knee flexion occurs. The maximum flexion amplitude occurs 70% of the time from the start of the gait cycle and is 63.9±0.1°.

Gradually, towards the end of the gait cycle, a gradual decrease in the flexion angle is noted. By the end of the gait cycle of the supporting leg, the flexion angle is 13.6±0.7°, and its amplitude decreases by 49.8±0.8° from the moment of maximum flexion. In general, we can say that the knee joint has one degree of freedom, which allows it to rotate around a horizontal axis.

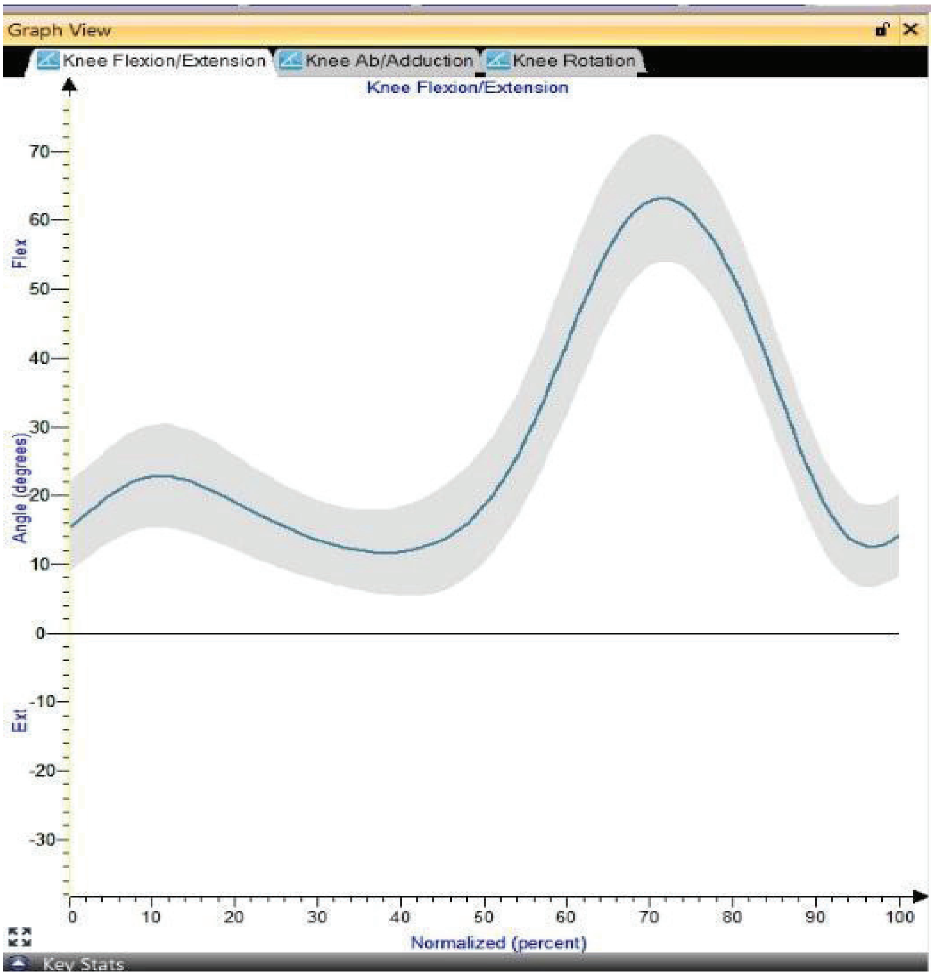

Figure 1. Knee joint flexion/extension during gait cycle.

However, when the knee is flexed, it has an additional degree of freedom, which manifests itself as rotation of the lower leg around the vertical axis. In this case, the intercondylar eminence of the tibia acts as an axis of rotation. The amplitude of this movement is 8.9±0.9°. Moreover, as shown in Figure 2, in the support phase of the gait cycle, this indicator varies from -16.4±0.5° to -20.9±0.6°.

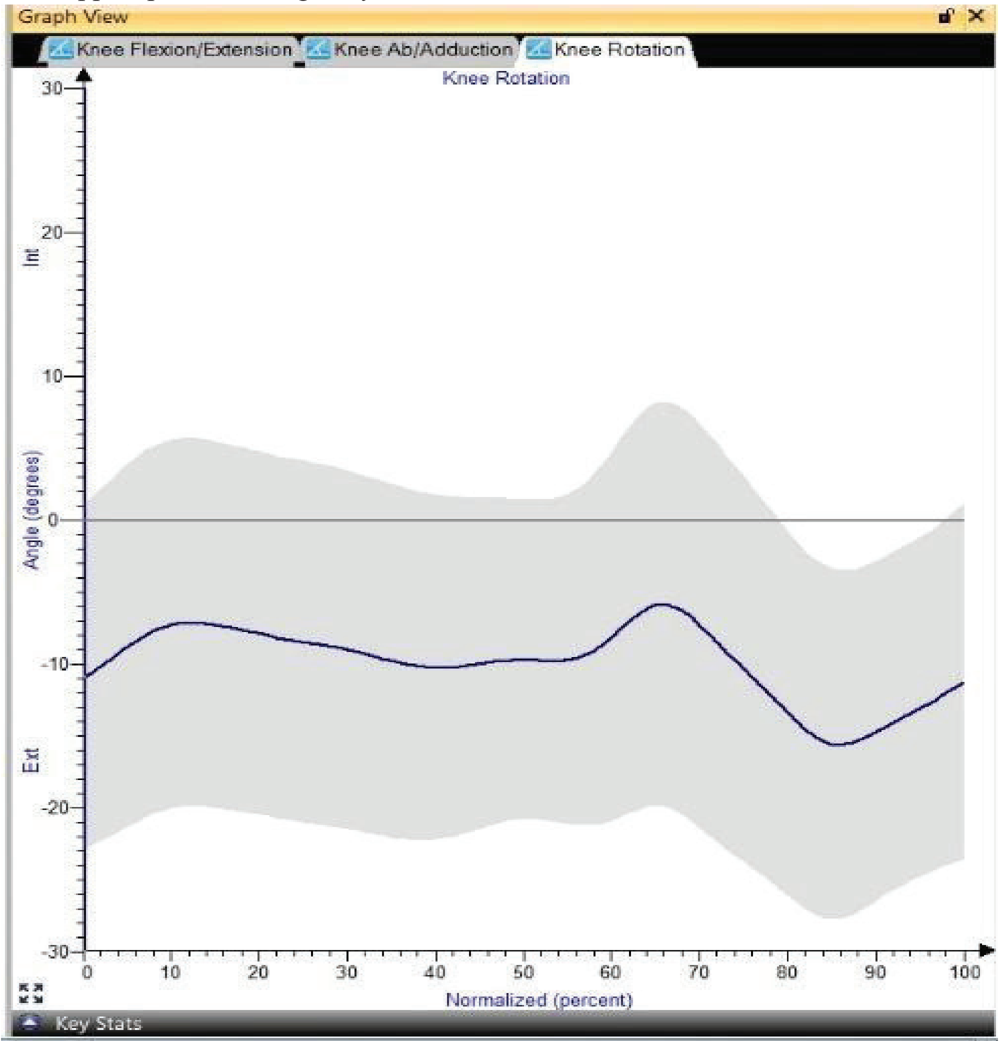

Figure 2. Knee joint rotation during gait cycle.

At the beginning of the swing phase (70% of the beginning of the GC), the mean values of the tibia rotation angle reach 14.9±0.6°, which indicates the maximum internal rotation of the lower leg at the moment of the greatest flexion of the limb in the knee joint.

At the end of the gait cycle, when the knee joint is in the extension position, external rotation of the lower leg takes place, which is characteristic of the swing phase. At each moment, period and phase of the gait cycle, the position of the knee joint was determined, as well as the angular displacement. Were obtained negative values of the angles between the longitudinal axes of the leg and femur. This proves that the knee is in a valgus position during the entire gait cycle, and these values are 11.9±0.9°. An increase in the angle between the longitudinal axes of the leg and thigh was recorded, which was -0.42±0.08°. This gave us the opportunity to say that the knee in the stance phase will mix outward. After the end of the support phase in the gait cycle, the knee joint begins to move in the opposite direction (point 70% from the beginning of the GC 13.9±0.4°).

During the remainder of the swing phase, the knee returns to its original position. The relationship between knee flexion and the position of the knee in space was determined. This determines the lateral displacement of the knee during extension of the lower limb in the support phase and its medial position during flexion in the knee joint. In addition, simultaneously with the change in the knee setting, axial rotation of the lower leg occurs, as evidenced by the correlation coefficient r = 0.4 (moderate relationship). The relationship between the kinematic indicators at maximum flexion in the knee joint (point 70% from the beginning of the gait cycle) characterizes the coefficient of association of average strength (r=0.6).

When analyzing the results of studying the deviation of the knee joint in three planes in the gait cycle using optoelectronic systems, it should be borne in mind that the graphs of flexion and extension of the joint does not cause difficulties in interpretation, the true rotation of the knee joint is demonstrated during the preparation of the leg for the transfer and at the beginning of the transfer of the leg (at moments 4, 5, 6 of the step cycle), and the true valgus of the knee joint can be judged by the state of the graph in average and final periods of the stance phase (at moments 2, 3, 4) [14, 15].

At the same time, the value of the axial rotation of the lower leg -22.2±0.6°) indicates that during extension in the support phase, the lower leg and the amplitude of its motion is nearly 8.9±0.9° (Fig. 3).

4. DISCUSSION AND CONCLUSION

In general, the obtained spatio-temporal characteristics of gait and kinematic of knee joint can be considered as reference, therefore, they can be used not only for performing subsequent work on this project, but also for carrying out a number of other studies in the field of biomechanics of human gait.

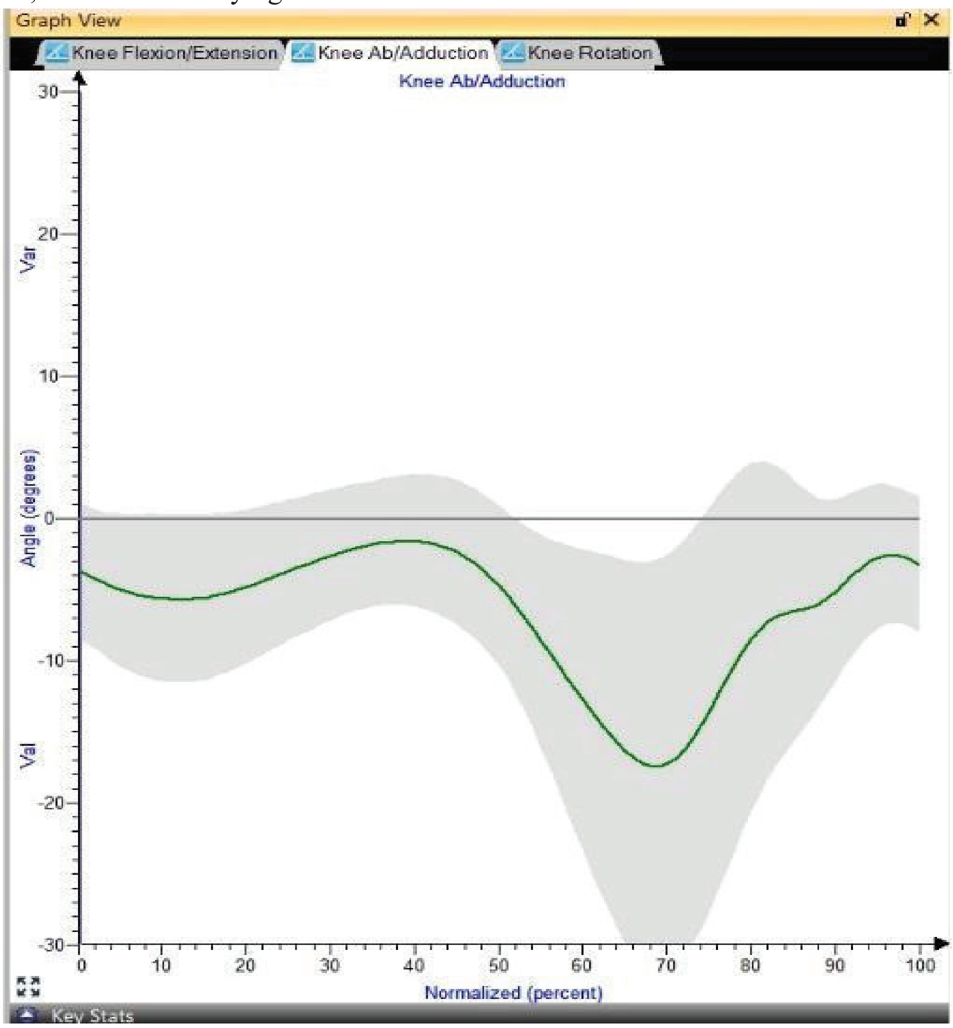

Figure 3. Knee joint abduction/adduction during gait cycle.

Was determined the range of motion in the knee joint in men during gait cycle using the Vicon 3D video data analysis system. They are respectively: flexion / extension 54.2±0.9°, rotation 8.9±0.9°, lateral displacement of the knee joint - 11.9±0.9°. The obtained parameters can become prognostic criteria in the diagnosis of various changes occurring in the knee joints, in the detection of pathologies and the early stage of lesions of the musculoskeletal system. Such normative indicators can become important diagnostic criteria when conducting professional examinations, including for vehicle drivers, calculating the level of loads and risks associated with injuries to the musculoskeletal system.

AUTHORS’ CONTRIBUTIONS

T. Galushko and L. Udochkina developed the idea and the theory of the article. O. Vorontcova carried out the experiment and performed the computations. All authors discussed the results and created the final manuscript.

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