

Gait analysis of healthy, young subjects and in the pre- and post-operative periods of meniscectomy

Theses of PhD dissertation

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Budapest
2014

1. Introduction

Meniscus injury (lesio menisci), more precisely, bucket handle tear in the posterior medial part of the meniscus, is one of the most common sports injuries in youth. The reason to this is partly the increasing popularity of extreme sports, partly the lack of sufficient preparation before starting to do training. The treatment of medial meniscus injury is called meniscus resection (meniscectomy). Diagnosing medial meniscus injuries, exposing various techniques of surgery and rehabilitation protocols and the impact assessment of these are all crucial questions of ortopedic researches. From the results of radiological exams done in the course of long-term follow up of patients who suffered meniscus injury and resection, some researchers deduct that meniscus resection might be the basic indicator of arthritis in the knee joint.

The number of patients with medial meniscus injuries is increasing in my own practice as well. Patient follow-up shows that even one year after surgery, the movement of patients could differ from that of the healthy ones. The question occurred to me how the medial meniscus injury and partial meniscectomy can change the various parameters of gait. I spent part of my specialist years at the MÁV Hospital in Szolnok. With the help of gait analysis in the Biomechanical Laboratory of the hospital I had the opportunity to study the effects of medial meniscus injury and partial meniscectomy on the kinematic and muscle activity parameters of gait on a treadmill.

2. Aims of research

The general aim of the research is to numerically represent with the help of gait analysis the pattern and variability of gait in the one-year lasting follow-up period for mediscus injuries diagnosed with radiology scans and after medial and partial meniscectomies. From the factors affecting pattern and variability of gait, impact assessment of gait speed and the subject's gender are also part of the research in healthy subjects. On the basis of the literature review, the scopes of our research are as follows:

1. In the case of healthy, young subjects, how the gait speed and the subject's gender affect the kinematic parameters and the parameters of variability of gait describing pattern and variability of gait, respectively.
2. Gait analysis comparing spatial-temporal and angular variables as well as muscle activity parameters in the one-year-lasting follow-up period after a medial meniscus injury as well

as after medial, partial meniscectomy, and these in comparison with the gait parameters characteristic of the control group of the same age.

3. Analysis of variability of gait in the one-year-lasting follow-up period of a medial meniscus injury, and that of a medial, partial meniscectomy through the analysis and comparison of the parameters of variability of gait, that is, the coefficient of variance of spatial-temporal and angular variables, and their comparison with the parameters of variability of gait in the control group of the same age.
4. In the one-year-lasting follow up period of a medial meniscus injury and a medial, partial meniscectomy the effect of gait speed and the subject's gender on the kinematic parameters as well as on the parameters of variability of gait.

3. Methods

3.1. The subjects

In the control group of impact assessment of a medial meniscus injury (laesio menisci medialis) and following medial, partial meniscus resection (medial, partial meniscectomy) there were 31 males and 20 females, whereas the patient group consisted of 18 males and 21 females. Before the surgery, 34 males and 29 females were examined. After surgery 8 males and 4 females had to be excluded from the study, as in these cases surgery had revealed partial rupture in the cruciate ligament, which is an exclusion criterium. 8 males and 4 females failed to appear at the check-up following the 3rd and 12th months of surgery. These patients had to be excluded as well.

Prior to the gait analysis, all participating subjects were informed both orally and in writing about the course of research and about their right to stop participating at any time. They all signed a consent to participate according to the relevant paragraph of the Declaration of Helsinki. The Institutional Research Ethics Committee of the Szolnok MÁV Hospital have approved the research.

3.2. Surgical procedure and rehabilitation protocol

Surgical technique, rehabilitation protocol and documentation were uniformly carried out according to the Hungarian and international standards. In all cases a two-channel (antero-lateral and antero-medial), arthroscopic procedure was applied. The exercises of the eight-week-long rehabilitation protocol included both closed and open kinetic chain exercises. The aim of such exercises is to increase the range of motion in the knee joints as well as to strengthen the muscles around the knee.

3.3. The method of ultrasound-based gait analysis

The aim of ultrasound-based gait analysis in addition to determining the spatial position of the anatomical points necessary for the calculation of kinematic parameters is to record the activity of the designated muscles with the help of surface electromyography (EMG). The research was carried out in the Biomechanical Laboratory of the Szolnok MÁV Hospital with zebris CMS-HS (zebris Medizintechnik GmbH, Germany) an ultrasound-based, motion analyzing system.

During the ultrasound-based gait analysis the measuring head is placed behind the subject examined (*Figure 1*). For fixing the spatial position of the lower limb segments five measurement triplets are to be used on the sacrum, on the left and right thighs and on the left and right calves (*Figure 1*). The ultrasound-based gait analysis with one measuring head attached to the back uses the 19- points biomechanical model. When analysing the parameters of variability of gait the spatial position of the anatomical points required for the calculation of gait features has to be recorded during at least 400 gait cycles, thus the research is ideally conducted on a treadmill.

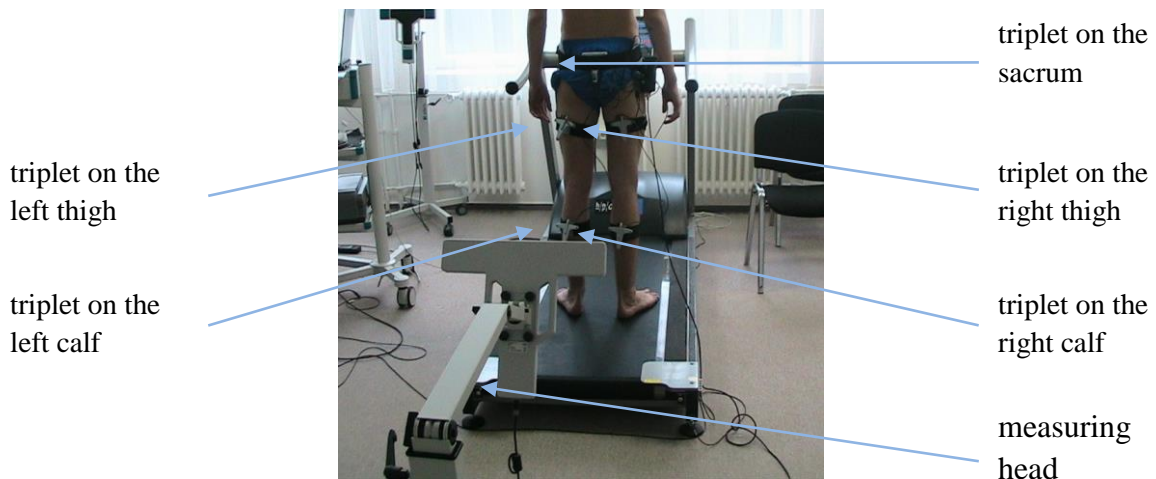


Figure 1: Assessment of the ultrasound-based gait analysis

Recording the activity of 8-8 lower-limb muscles was a crucial part of the research. The zebris CMS-HS motion analysing system and the ArmModel measuring software are capable of fixing the designated spatial anatomical points and at the same time measuring with surface electromyography the change in electric potential resulting from muscle activity. From these measurements we can establish the intermuscular coordination of certain muscles during gait. For detecting the changes in the electric potential of the muscles Ag-AgCl, round, 18-mm-diameter, monopolar electrodes (blue sensor P-00-S, Germany) were used. Considering SENIAM (Surface Electromyography for the Non-

Invasive Assessment of Muscles) recommendations, we placed the electrodes in the vicinity of the muscle belly, parallel to the muscle fibers. The muscle groups involved in the research are shown in *Figure 2*.

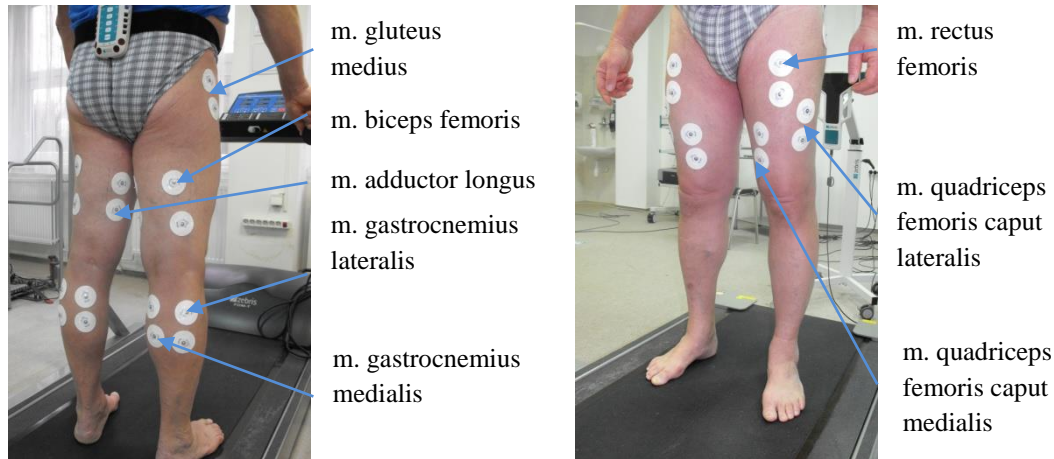


Figure 2: Position of EMG sensors on the lower limb

Based on these data, two different controlled walking speeds were used for gait analysis. Based on previous researches, we conducted our research at 1.0 m/s and 1.2 m/s speeds while walking on a treadmill. *With the exception of processing and assessing the results of the muscular activity measurement which was only conducted at 1.2 m/s walking speed.*

From the spatial position of the designated anatomical points spatial, temporal and angular parameters were calculated. The spatial and temporal parameters mean one single piece of data per gait cycle, which means that at each speed for all the gait cycles (more than 400) of each and every subject the average, standard deviation (SD) and coefficient of variance (CV) reflecting on the subject's gait cycle can be calculated from defined variables. The average will characterize the gait pattern of the subject, while the variability of the gait is shown by the standard deviation and coefficient of variance of the spatial-temporal parameters. The angular parameters are continuously changing during the gait cycle. To calculate the variability of the joint range of motion in case of the knee angle, hip angle and bending, tilting, and rotating of the pelvis for all gait cycles of the subject, the angular variables shall be calculated at every integer percentage of the gait cycle upon having normed to 0-100% cycles For each subject, angular parameters and their average, standard deviation and coefficient of variance were calculated at each integer percent of the gait cycle. The variability of motion is represented by MeanCV can be determined as the average CV over all integer percents.

The aim of our research with the control group and the patient group is to determine intermuscular coordination (on-off pattern) considering the muscles examined in the

lower limb. Applying international practice, a given muscle is considered active if its normalized value is higher than 0.2.

For making a comparison between the two groups regarding the self-selected walking speed the t-test was used. The statistical analysis of parameters of gait and gait regularity was carried out with the help of the multivariate, repeated measures ANOVA model with a post hoc examination added. The variables within the healthy group: speed of gait (1.0 m/s and 1.2 m/s) and the side (dominant and non-dominant). The variables within the patient group: speed (1.0 m/s and 1.2 m/s), the side (affected and non-affected), date of examination (before surgery, 3 and 12 months after the surgery). Assessment of the results of muscular activity was only conducted for the 1.2 m/s walking speed, thus the results at the comparison between the control group and the patient group are based on the two-sample t-test, whereas in case of the patient group, the one-sample t-test was used. The statistical analysis was carried out with the Statistica (ver. 12.0 SAS Institute Inc, Cary NY, USA) software; the difference is significant, if $p \leq 0.05$.

4. Results

4.1. Effect of the self-selected walking speed

The self-selected walking speed for each and every subject was determined on a 10-m long walkway prior to the gait analysis. In case of the patient group before the surgery ($p=0.02$) six weeks after the surgery ($p=0.02$), 3 months after the surgery ($p=0.04$) self-selected walking speed on a walkway, which 1.0 m/s is significantly lower than the self-selected walking speed of the control group (1.2 m/s). 12 months after the surgery, the self-selected walking speed of the patient group (1.2 m/s) did not significantly differ from that of the control group.

4.2. Analysing the influence factors of the patterns and variability of gait in healthy, young subjects

The analysis of the kinematic variables describing gait patterns shows that with some exceptions excluded, increased walking speed leads to increased parameter values (*Figures 3-6*).

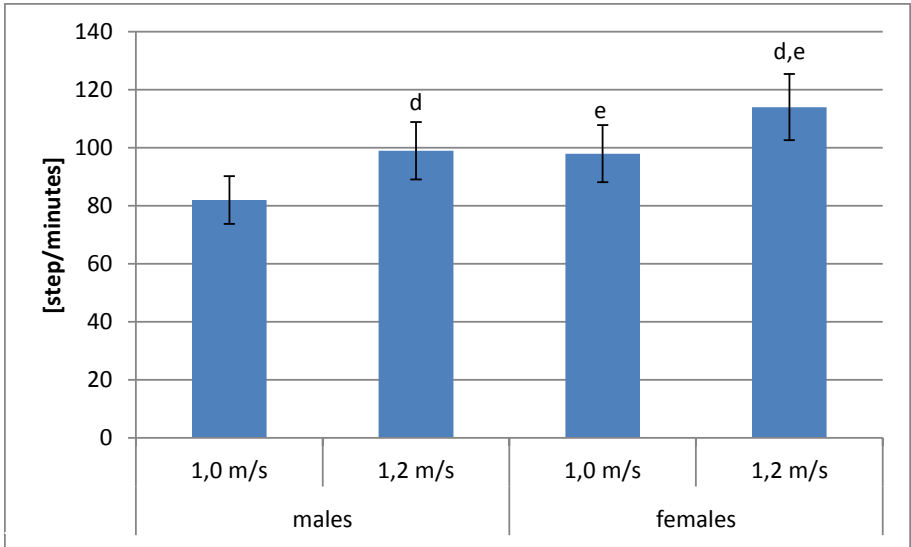


Figure 3:
Cadence in healthy males and females at 1.0 és 1.2 m/s walking speeds

^d: significant difference between the gait patterns at 1.0 m/s és 1.2 m/s tape speeds;
^e: significant difference between the results of males and females.

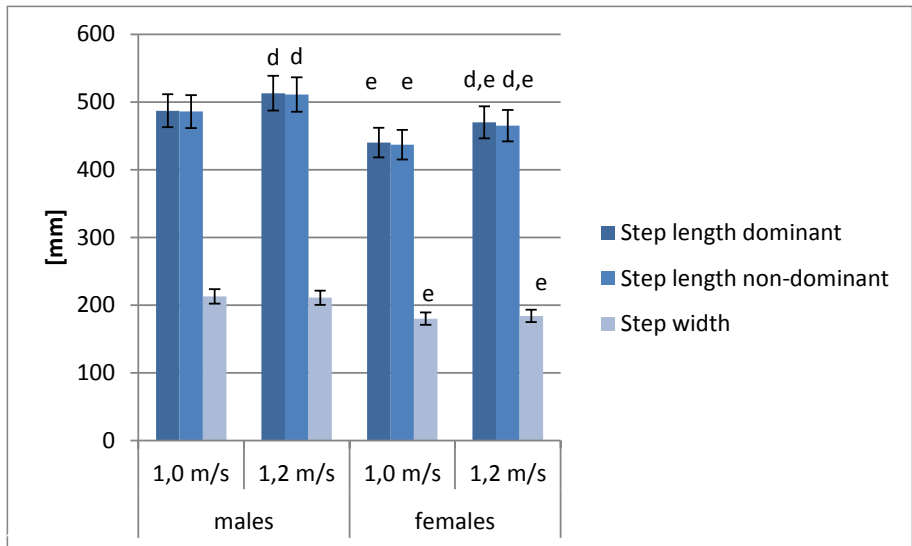


Figure 4:
Step length and step width in healthy males and females at 1.0 és 1.2 m/s walking speeds

^d: significant difference between the gait patterns at 1.0 m/s és 1.2 m/s tape speeds;
^e: significant difference between the results of males and females.

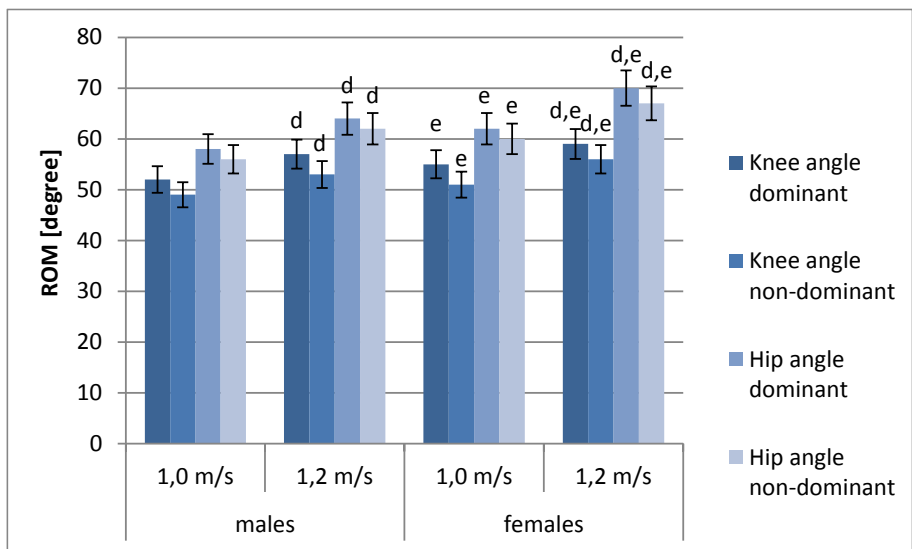


Figure 5:
Range of motion in the knee and hip angles in healthy males and females at 1.0 és 1.2 m/s walking speeds

^d: significant difference between the gait patterns at 1.0 m/s és 1.2 m/s tape speeds;
^e: significant difference between the results of males and females.

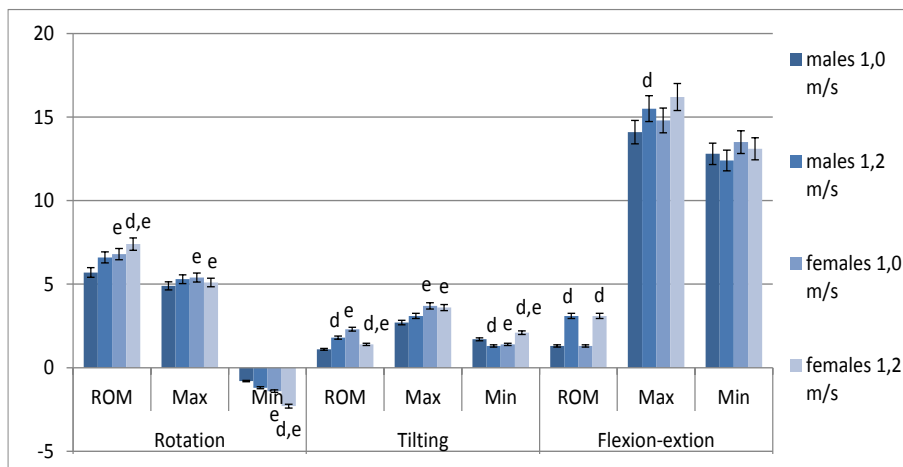


Figure 6: Pelvis movement in healthy males and females at 1.0 and 1.2 m/s walking speeds
 d: significant difference between the gait patterns at 1.0 m/s és 1.2 m/s tape speeds;
 e: significant difference between the results of males and females

The analysis of the parameters of variability of gait, in the case of healthy, young subjects (control group) self-selected walking speed (1.2 m/s) shows that the CV of spatial-temporal parameters (Figure 7) is the lowest, while the average CV of the angular parameters is the highest (Figure 8). No significant difference is observed in case of any of the parameters regarding variability of gait.

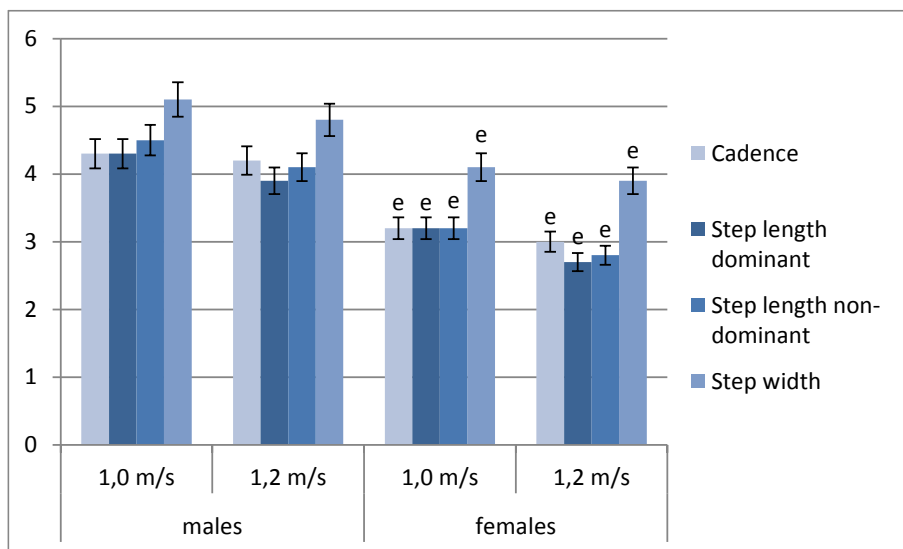


Figure 7: CV of spatial-temporal parameters in healthy males and females at 1.0 and 1.2 walking speeds
 e: significant difference between the results of males and females

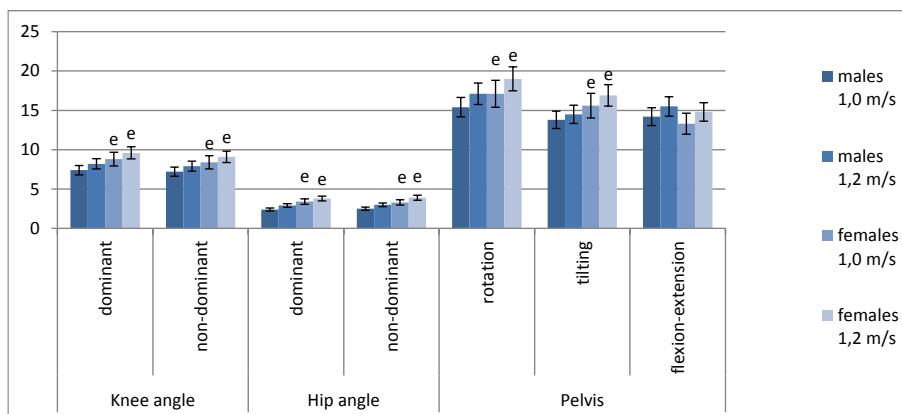


Figure 8:
MeanCV of joint motion in healthy males and females at 1.0 and 1.2 m/s walking speeds
 e: significant difference between the results of males and females

The analysis of the kinematic variables describing gait pattern shows that the gender of the subject significantly affects most of the kinematic parameters (*Figures 3-6*). The evaluation of the parameters also shows that cadence is significantly lower, (*Figure 3*) while step length and step width are significantly bigger (*Figure 4*) in males than in females. In order to increasing the walking speed, males tend to increase step length (*Figure 4*) by significantly changing the movement of the knee and hip joints (*Figure 5*). The flexion in the knee and hip joints significantly increases which leads to a significant increase in the range of motion (*Figure 5*). The gender of the subject significantly affects pelvis rotation and pelvis tilt, but the difference in case of pelvis flexion-extension is not significant (*Figure 6*).

With the analysis of the parameters of gait variability, we can establish that the CV of spatial-temporal parameters in females (*Figure 7*) is lower compared to that in men. The variability of joint motion shows reverse trend, because the MeanCV of angular parameters in females (*Figure 8*) is higher than in men. The difference is by far the most outstanding in case of parameters of variability of gait, with the exception of the CV of the stance phase and the double-support stance period and the MeanCV of the pelvis flexion-extension.

4.3. The effect of medial meniscus injury and medial, partial meniscectomy on the gait pattern

As far as the spatial-temporal parameters describing gait pattern are concerned, prior to the medial partial meniscectomy, 6 weeks and 3 months following the surgery the cadence significantly increases (*Figure 9*), while the step length of both sides significantly decreases (*Figure 10*). For more stable walking prior to the surgery the step width is significantly greater than the values in the control group (*Figure 10*). 12 months after the medial, partial meniscectomy the spatial-temporal parameters reach to those of the control group.

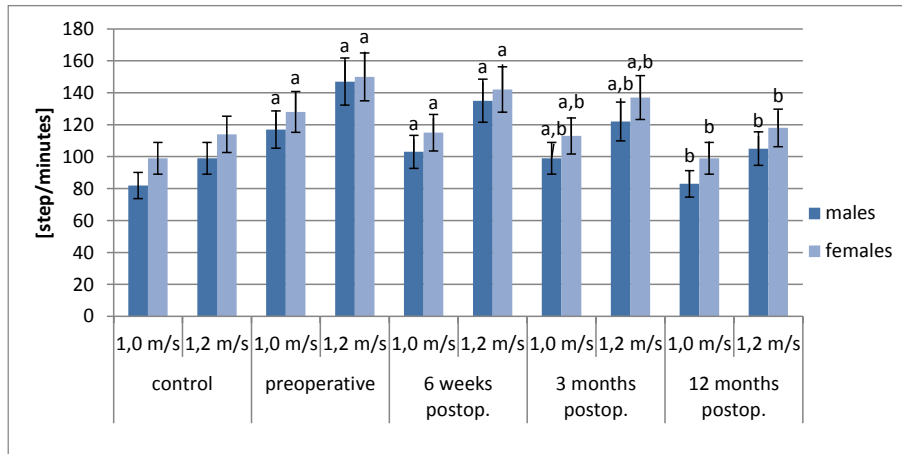


Figure 9:
Cadence in the control group and in the patient group
 a: significant difference compared with the values of the control group;
 b: significant difference compared to the values measured before the surgery

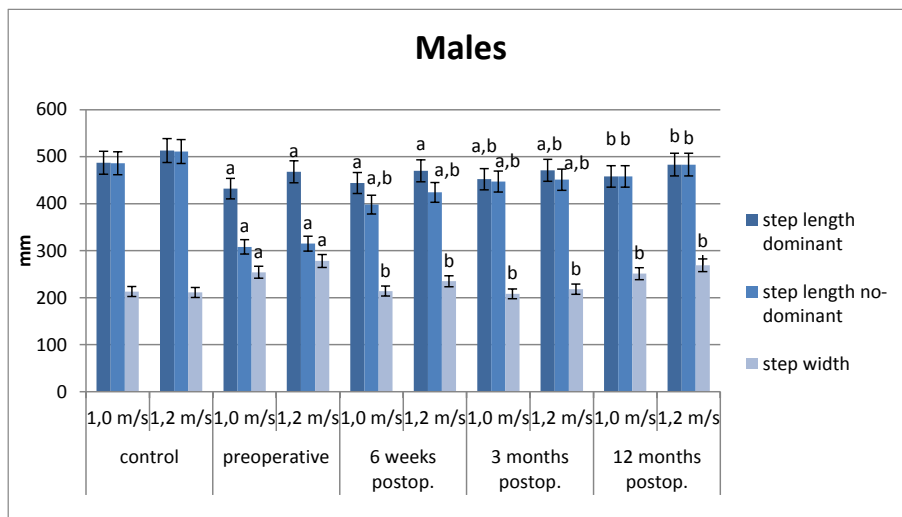
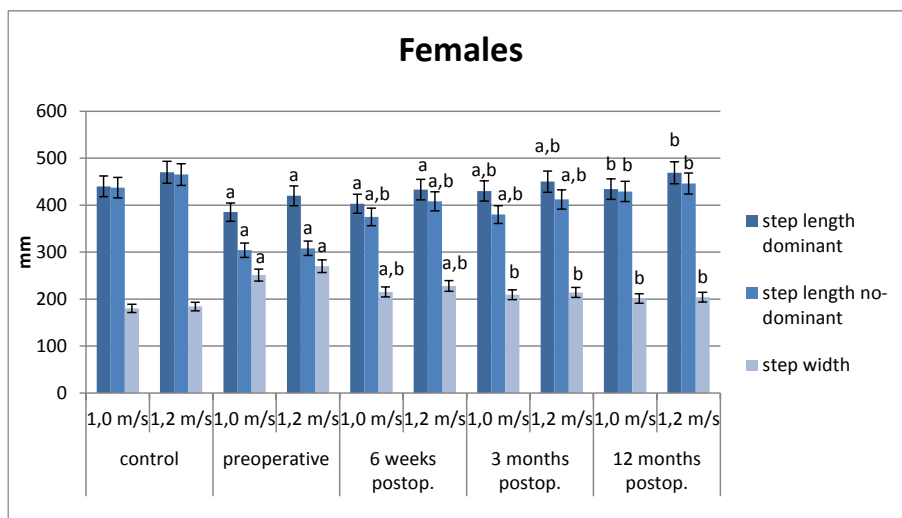


Figure 10:
Step length and step width in the control group and in the patient group



a: significant difference compared with the values of the control group;
 b: significant difference compared to the values measured before the surgery

The analysis of the angular parameters show a much more nuanced picture (*Figures 11 and 12*). The range of motion of the knee and hip joints on the affected side significantly narrows as a result of the medial meniscus injury (*Figure 11*). In the post-operative period the range of motion in the knee and hip joints on the affected side is continuously increasing, but does not reach the the values in the control group even 12 months after surgery (*Figure 11*). In the knee joint on the non-affected side significant decrease is seen only prior to - and 3 weeks and 6 months following the surgery. In the post-operative period the range of motion in the knee joint on the non-affected side is also increasing continuously and reaches the values in the control group 12 months following surgery (*Figure 11*).

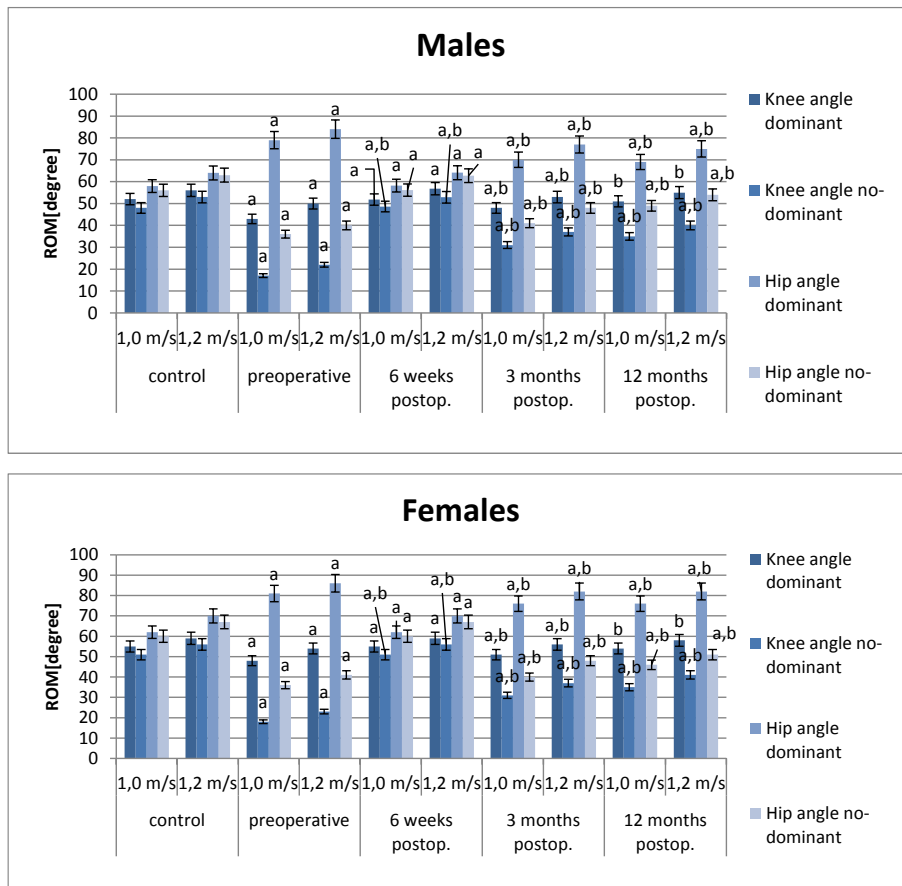


Figure 11:

Range of motion in the knee angle and in the hip angle in the control group and in the patient group

a: significant difference compared with the values of the control group;
b: significant difference compared to the values measured before the surgery

The range of motion in the hip joint on the non-affected side is significantly higher both prior to surgery and in the post-operative period than the values in the control group (*Figure 11*). In order to protect the joints on the affected side the pelvis rotation compared to the values in the control group is not only significantly reduced upon the medial

meniscus injury but even 12 months following the medial, partial meniscectomy (Figure 12). This significant reduction is clear even though both the narrowed range of motion in the joints on the affected side and the pelvis movements in the post-operative period significantly increase (Figure 12).

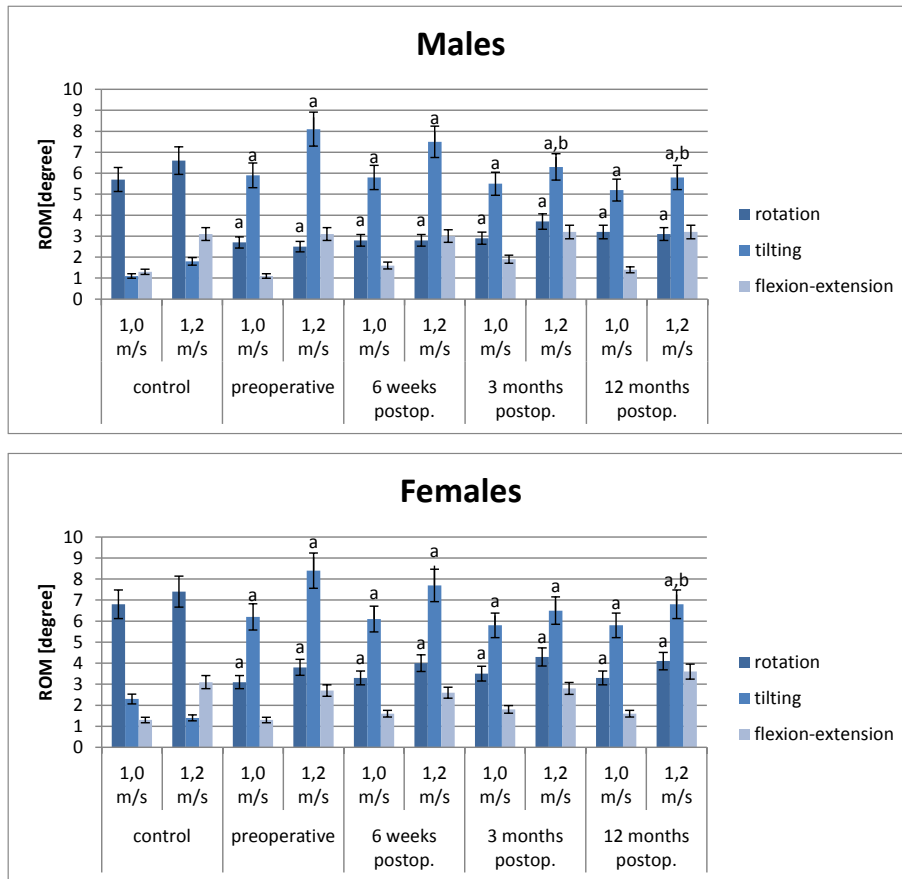


Figure 12:
Range of motion of pelvis rotation, - tilt and -flexion-extension in the control group and in the patient group

^a: significant difference compared with the values of the control group;
^b: significant difference compared to the values measured before the surgery

The intermuscular coordination of the designated muscles in the lower limb shows a significant difference prior to the medial, partial meniscectomy and even after 12 months following surgery both on the affected and non-affected sides.

In the patient group the way of increasing gait speed changed as the increased step length only appears in the late post-operative period. Pelvis flexion-extension and rotation do not play a role in increasing speed at all. The effect of the subject's gender on the gait pattern is observed in the late post-operative period.

4.4. The effect of medial meniscus injury and medial, partial meniscectomy on variability of gait

Based on the changed CV of spatial-temporal parameters the variability of gait was significantly affected by the medial meniscus injury and the medial, partial meniscectomy (Figures 13 and 14). In the patient group the CV of spatial-temporal parameters is significantly higher prior to surgery and 6 weeks and 3 months following surgery compared to the control group (Figures 13 and 14). 12 months following the medial, partial meniscectomy the CV of spatial-temporal parameters equals to those of the control group (Figure 13 and 14).

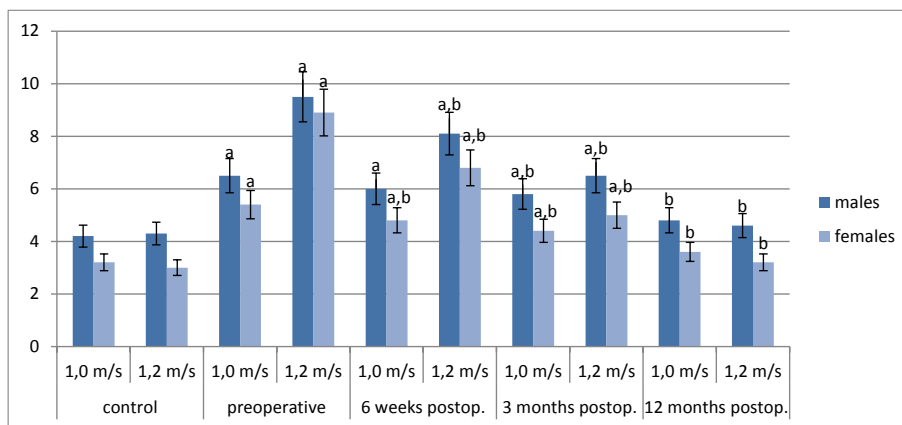


Figure 13:
CV of the cadence in the control group and in the patient group.
a: significant difference compared with the values of the control group;
b: significant difference compared to the values measured before the surgery

The MeanCV of the hip- and knee angles on the affected side compared to the control group decreases significantly both in the preoperative and post-operative periods (Figure 15). Although following surgery the MeanCV of the hip- and knee angles on the affected side increases significantly compared to the preoperative values, it falls behind the values in the control group (Figure 15).

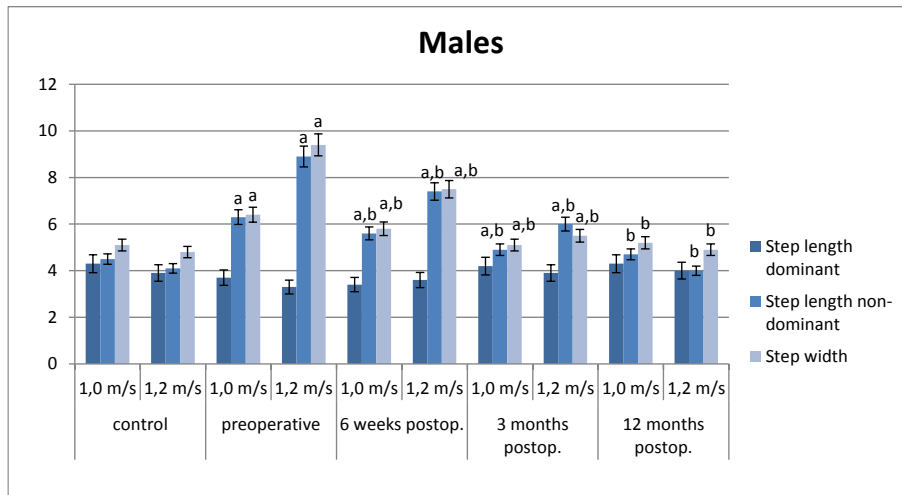
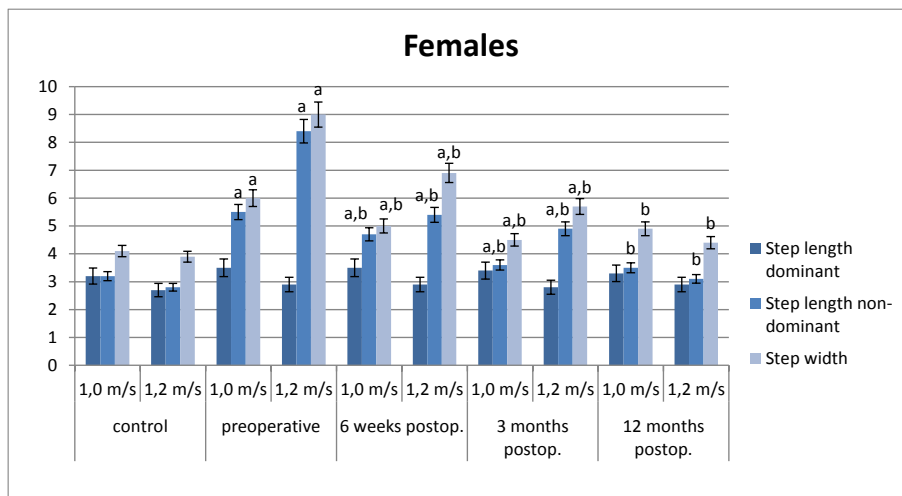


Figure 14:

CV of step length and step width in the control group and in the patient group



^a: significant difference compared with the values of the control group;
^b: significant difference compared to the values measured before the surgery

The results of the present study show that in the preoperative and full post-operative periods of medial, partial meniscectomy the meanCV of the hip- and knee angle on the non-affected side as well as the pelvis tilt is significantly higher (Figures 15 and 16) compared to the control group.

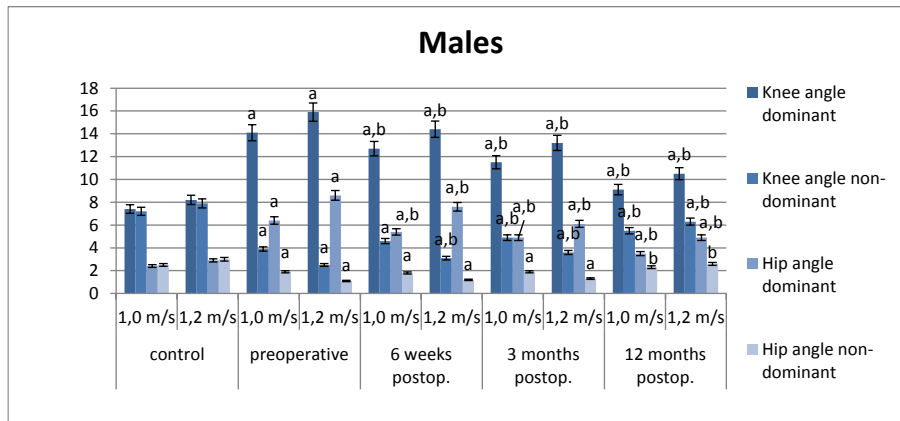
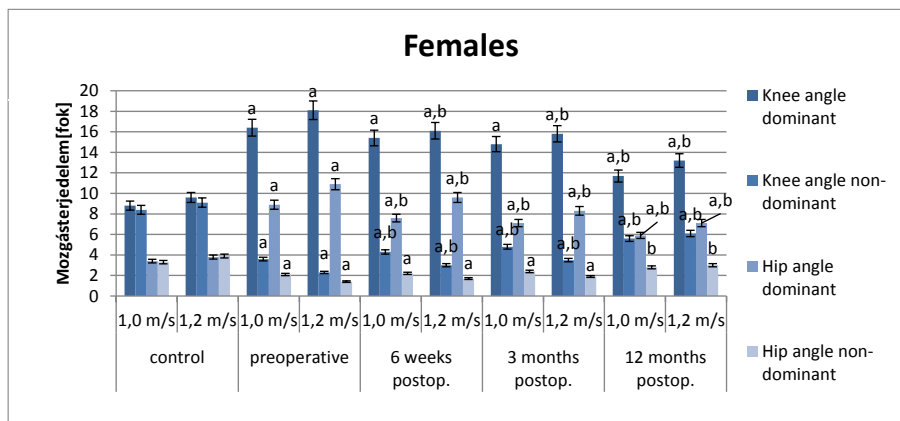


Figure 15:

MeanCV of movement in the knee joints and in the hip joints in the control group and in the patient group



a: significant difference compared with the values of the control group;
 b: significant difference compared to the values measured before the surgery

With the change in the speed of gait the parameters of the variability of gait significantly change in the patient group as well. Prior to and following the medial, partial meniscectomy the CV of the spatial-temporal parameters on the affected side increased significantly, whereas the MeanCV of the angular parameters of the joints on the affected side and the MeanCV of the pelvis rotation were significantly reduced, when the walking speed differed from the self-selected walking speed.

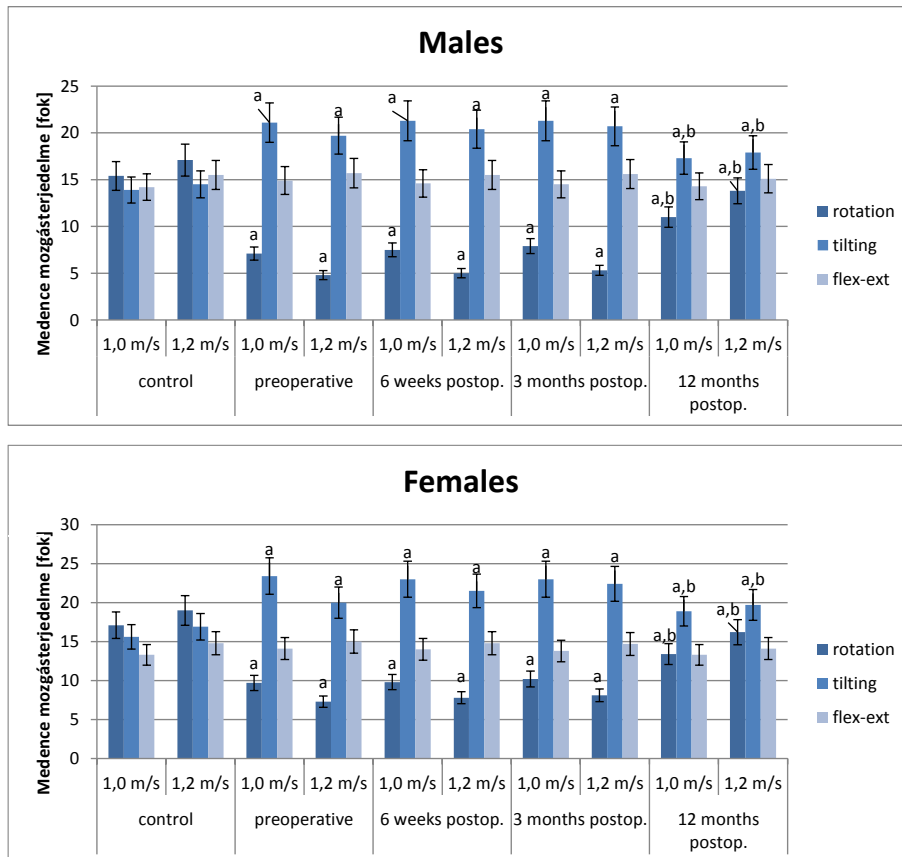


Figure 16:

Mean CV of pelvis motions in the control group and in the patient group

Analyzing the effect of the subject's gender it is a difference compared to the control group that in the preoperative period the subject's gender does not significantly affect neither the CV of the spatial - temporal parameters nor the MeanCV of the joint motion on the affected side. However, in the post-operative period comparing males and females the difference among the parameters of variability of gait is significant. The variability of joint movements on the affected side does not differ significantly. Similarly to the control group, in females, the MeanCV of the angular parameters of the non-affected joints and pelvis tilt and-rotation is higher than in males.

5. Conclusions

The aim of the research based on biomechanical methods and summarized above was to determine how gait speed, the subject's gender and medial meniscus injury and medial, partial meniscectomy affect gait pattern and variability of gait. Based on the statistical

evaluation of the results of the gait analysis, the following new scientific conclusions are drawn:

1. In healthy, young subjects when examining gait on a treadmill it could be established that the kinematic parameters are significantly affected by gait speed and the subject's gender (*Figures 3-6*). The parameters of variability of gait are significantly affected only by the subject's gender.

a. Increased gait speed the kinematic parameters of gait are increased: increase in speed is secured by increasing cadence, step length and with the significantly increased range of motion in the knee and hip joints (*Figures 3-5*). The role of pelvis movement in increasing speed differs in young males and young females. In males, the increased speed is partly a result of the significantly increased range of motion of pelvis tilt caused by a raise of the minimum value and of the significantly increased range of motion of the pelvis flexion-extension caused by a raise of the maximum value (*Figure 6*). In females, in addition to the significantly increased two ranges of pelvis motion the significant increase in the pelvis rotation caused by a raise of the minimum value also plays an important role in the increased gait speed (*Figure 6*).

In males, cadence is significantly lower, step length step, step width and the range of motion in knee and hip joints are significantly higher (*Figure 3-5*) compared to females's values. In case of the extension of knee joint did not differ significantly. The most probable explanation accounting for this difference might be that we conducted our research on a treadmill, not on walkway. The subject's gender significantly affected the movement of pelvis tilt and pelvis rotation, but we found no significant difference when examining pelvis flexion-extension (*Figure 6*).

b. When the gait speed differs from the value of the self-selected walking speed, the CV of the spatial-temporal parameters increased (*Figure 6*), but the meanCV of the angular parameters decreased (*Figure 8*), meaning that the tendency of change is reverse. These together would result in an overall decline in consistency and complexity of gait, but the difference was not significant.

In males, CV of spatial-temporal parameters is significantly higher (*Figure 7*) but the meanCV of their angular parameters are significantly lower (*Figure 8*) compared to females's values. Similarly to the effect of the change in gait speed, the tendency of change is reverse. In females, the complexity of gait is better than that of men.

Related publication: Magyar et al., 2012a

2. Medial meniscus injury and medial partial meniscectomy change the kinematic and muscular activity parameters of gait (*Figures 9-12*).

The significant change in gait pattern present preceding the partial meniscectomy and in the early post-operative period disappears in the late post-operative period (*Figures 9 and 10*), but the significant narrowing in the range of knee joint-, hip joint- and pelvis rotation motions caused by the reduced use of the affected joint is still present even 12 months

following surgery (*Figures 11 and 12*). The hip joint and pelvis tilt of the opposite side counterbalance the narrowed range of motion (*Figures 11 and 12*). This is supported by the change in the intermuscular coordination characterizing muscular activity as well.

Related publication: Magyar et al., 2008a; 2008b

3. Medial meniscus injury and medial, partial meniscectomy change variability of gait (*Figures 13-16*).

In the preoperative and post-operative periods of medial, partial meniscectomy the CV of spatial-temporal parameters significantly increases compared to controls (*Figures 13, 14*), it means the step by step repetition of accurate and consistency gait pattern declines. The MeanCV of affected joint's angular motion significantly decreases (*Figure 15*), the flexibility of the joints on the affected side and their role in continuous revision and correction is also reduced. At the end of the post-operative period the CV of spatial-temporal parameters does not differ significantly to controls (*Figures 13 and 14*), it means the consistency of motion returns. However, MeanCV of affected joint's angular motion significantly decreases compared to controls (*Figure 15*), the flexibility of the affected joints declines, which means that their role in the revision and correction of movements is reduced. This might mean that even at the end of the post-operative period the subject's ability to adapt to change in environment is worse compared to the control group.

The increased MeanCV of the joints on the non-affected side and the pelvis (*Figures 15 and 16*) show that they play an important role in counterbalance and in developing stable gait, which strengthen the establishment on basis result of gait pattern.

Related publication: Magyar et al., 2012a

4. Medial meniscus injury and medial, partial meniscectomy change the way of increasing speed. Before and one year after meniscectomy, the variability of gait deteriorate, when the gait speed differs from the value of self-selected walking speed. The subject's gender influenced the pattern and variability of gait in the late post-operative period. The conservation of the affected side is clearly shown by the fact that the effect of the subject's gender and walking speed do not differ the pattern and variability the non-affected side's joint in the preoperative and post-operative period.

a. In case of the patient group we can state that the way of increasing gait speed changed, as the increase in the step length on the affected side only occurs in the late post-operative period. Pelvis tilt and rotation do not play a role in increasing speed at all.

When the gait speed differs from the self-selected walking speed, the parameters of gait variability change significantly, meaning that the consistency of gait declines. The reverse tendency in the change of CV of spatial-temporal parameters and the MeanCV of the angular parameters occurred in the patient group as well.

- b. The subject's gender in the pre- and early post-operative periods- with the exception of the hip joint movement of the non-affected side- has no significant effect on the parameters of gait.

The influence of the subject's gender on the gait pattern -- with the exception of the joints of affected side- becomes relevant only in the late post-operative period. In the preoperative period, the subject's gender has no significant effect on either the CV of the spatial-temporal parameters or on the mean CV of joint movements on the affected side. The reduced motion of the affected side is clearly shown by the fact that the effect of the subject's gender is only relevant in case of the joints of the non-affected side.

When comparing males and females in the post-operative period the difference is already significant among the variability parameters of gait pattern. The variability in the range of motion of the joints on the affected side does not show a significant difference, while the variability of the non-affected joints and the pelvis tilt and -rotation is better in females compared to those in men.

The results of our research shown that the medial meniscus injury and medial, partial meniscectomy significantly influence the pattern and the variability of gait at the end of the one-year-long post-operative period. It could be recommended the extension of research until 3-5 years after medial, partial meniscectomy for establishment the effect of medial, partial meniscectomy on the degenerative changes of the knee joint.

Deterioration of gait variability means that the subject's ability to adapt to change in environment is worse compared to the control group, however it could suggest the deterioration of proprioception too. It could be important question, the examination of balancing ability, specially balancing ability after sudden perturbation.

List of own publication

Publications directly related to the dissertation topic:

Magyar OM, Illyés Á, Knoll Zs, Kiss RM (2008a). Effect of medial meniscectomy on gait parameters. *Knee Surg Sports Traumatol Arthrosc*, 16: 427-433.

Magyar O M, Illyés Á, Knoll Zs, Kiss RM (2008b). A járás kinematikai és izomaktivitási paramétereinek változása medialis meniscus partialis reszekciója után. *Magy Traumatol Ortop Kézseb Plaszt Seb*, 51(3): 215-222.

Magyar OM, Knoll Zs, Kiss RM (2012a). The influence of medial meniscus injury and meniscectomy on the variability of gait parameters. *Knee Surg Sports Traumatol Arthrosc*, 20: 290-297.

Other publications related to motion analysis:

Knoll Zs, Kiss RM, Kocsis L, Jurák M, Magyar M. (2003). A járás vizsgálat pontosságának ellenőrzése. *Magyar Traumatológia, Ortopédia, Kézsebészet és Plasztikai Sebészet*, 46: 237-243.

Illyés Á, Magyar OM, Kiss RM (2004). Szabadidő sportolók és gerelyhajítók vállízületének összehasonlító elektromiográfiai vizsgálata elemi karmozgások és dobás közben. *Sportorvosi Szemle*, 45(4): 271-284.

Magyar OM, Knoll Zs, Kiss RM (2012b). Effect of medial meniscus tear and partial meniscectomy on balancing capacity in response to sudden unidirectional perturbation. *J Electromyogr Kinesiol*, 22: 440-445.