The Modified Thomas Test Realized by Optoelectronic Kinematic Measurement

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Abstract

Objective: To test the method of 3D kinematic measurement of the Modified Thomas Test (MTT) and to compare it with standard 2D goniometric method. According to the authors' knowledge, a research including 3D kinematic measurement and analysis of the MTT has not yet been attempted.

Methods: Research has been conducted in the Biomechanics Laboratory, Faculty of Kinesiology, during May 2016. The sample comprised of 54 male participants (108 lower limbs) age ranging between 19 and 27 years (mean age 21.8). A high degree of physical activity of participants was confirmed based on IPAQ. Kinematic features of MTT were evaluated using two objective methods: 2D goniometry (goniometer KaWe) and 3D kinematics (automatized optoelectronic kinematic measurement system ELITE, BTS Bioengineering Corp. with 8 cameras, frequency 100 Hz and 9 passive markers). Goniometric evaluation was performed by the examiner having 11 years of clinical experience. Sample of variables were four angles: knee flexion, hip extension, hip abduction and hip rotation. All measurements were conducted using two instruments simultaneously, bilaterally, taken initially after performing MTT. The tested limb was chosen by coin method, while non-tested extremity and lumbo-pelvic complex were stabilised with a strap. The procedure was repeated for the other limb. In total, 864 angles were measured, out of which 30 fell out from the experiment. Spearman's correlation coefficient was used in data processing.

Results: Optoelectronic kinematic evaluation resulted with following mean values: knee flexion 52.72°±11.49° (goniometry = 56.72° ± 11.18°); hip extension 24.27°±8.55° (goniometry=10.07°±10.08°); hip abduction 8.2° ± 6.44° (goniometry = 7.84° ± 4.45°); external hip rotation 0.58°±4.38° (goniometry=0.98°±5.76°). Results assessed by two instruments were correlated and coefficient of $r = 0.91$ was determined. Unexplained variance was comprised of systematic (differences in precision and marker positioning protocol of two methods, i.e. Trochanter vs. ASIS) and non-systematic sources of variability.

Conclusion: Normative values for 4 angles at MTT were established. This study has shown high correlation between two types of measurement. Optoelectronic kinematic evaluation has shown superior with regard to goniometry due to the possibility of simultaneous measurement of angles and automated processing with expeditious reporting, making it a relevant modality for precise and comprehensive measurement of ROM.

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Introduction

The Modified Thomas Test (MTT) is a special frequently used observational clinical test for posture, postural adaptation, and lower extremity kinematics. Indirectly, it supplies information on flexibility of hip and knee musculature, primarily *m. iliopsoas*, *m. rectus femoris*, *m. tensor fasciae latae* and *m. sartorius*. The test is often used for clinical evaluation of passive range of motion (ROM) while extending the hip and flexing the knee. Most often it is of subjective nature, however, since it is based on observation, it is evaluated as positive or negative, with respect to commonly accepted norma.[1-3] Assessment of length of lower extremity muscles is provided indirectly, by measuring hip and knee ROM-and results are compared bilaterally, and with normative values. Normative values for length of lower extremity muscles, i.e. hip and knee ROM, are important for injury prevention through detection of impaired flexibility.[4]

The mentioned element of subjectivity in application of MTT makes it less applicable in realms of a paradigm of evidence based medicine. In clinical conditions it does not suffice to make such a dichotomous evaluation, but ROM should be quantified due to objective evaluation of the state of a patient, existence of dysfunction or injury and improvement through rehabilitation. Test is considered positive if the tested leg does not reach a neutral horizontal line or lower.[1,2,4,8] Most often objectification of the test includes goniometric[4-9] and trigonometric[7,10] methods as well as applying digital photography.[11-13] Goniometry is considered a gold standard, and is performed using a goniometer or inclinometer. According to Kendall et al,[1] inability of passive hip extension until neutral position (and further) indicates strain in one-joint hip flexors (*m. iliopsoas*), while inability of knee to be passively flexed over 80° indicates shortening of two-joint hip flexors (*m. rectus femoris*, *m. tensor fasciae latae*, *m. sartorius*). Additional existence of hip abduction and internal rotation indicates shortening of *m. tensor fasciae latae*, while external hip rotation indicates shortening of *m. sartorius*. Evaluation using MTT in clinical practice includes observational analysis of ROM in three planes of movement, as described in the literature.[1, 3] However, in published research[4-14] authors were focused exclusively to measuring movement in the sagittal plane. According to the knowledge of authors of this paper, there are no published scientific reports showing 3D kinematic analysis of MTT.

The goal of this research is to quantify results of observational clinical test-MTT, and to investigate the method of 3D automatized optoelectronic kinematic analysis and to compare it to the goniometric 2D method. Hypothesis of this research is the existence of high correlation between the two methods. Furthermore, the advantages offered by automatized optoelectronic kinematic evaluation support its use for scientific purposes, but also surpass particular factors that limit its implementation in clinical practice.

Methods

Participants

Research was conducted in the Biomechanics Laboratory of the Institute of Kinesiology at the Faculty of Kinesiology, University of Zagreb, during May 2016. The sample was randomised. It was comprised of 54 male participants, age ranging from 19 to 27 years (mean value 21.9) that were measured bilaterally. Based on International Physical Activity Questionnaire (IPAQ) (Croatian version of the IPAQ Questionnaire[15]) a high level of physical activity of participants was determined. Research was approved by the Faculty's Ethical Committee. MTT was applied for this research.

Examiners

Application of questionnaires and anthropometric measurements were provided by two kinesiologists with three and four years of clinical experience. Positioning of the subject and application of MTT was performed by a master physiotherapist with 11 years of clinical experience. The same practitioner placed markers on subjects and performed goniometric measurements. Optoelectronic measuring was controlled by a master of mechanical engineering.

Procedure

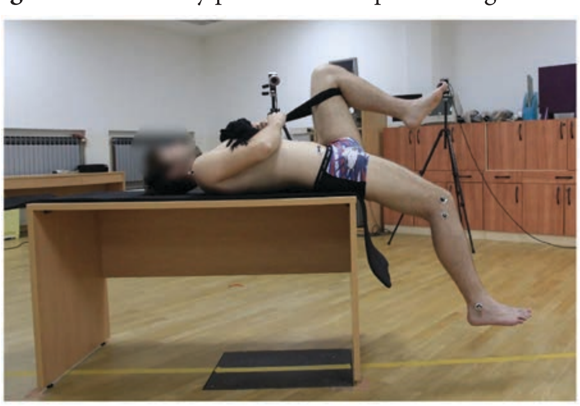
All measurements were made approximately at the same time of day (AM) and subjects did not have intense physical activity during the day. The requirements on subjects included being well rested minimally 12 hours without physical activity before the test. Prior to measurement subjects were acquainted with methods, goals and expected clinical contribution of the research. They were also informed on measurement protocol and possible inconvenience that might happen during its performance. They signed informed consent.

The participants had no injuries nor surgery during the three-year period prior to measurement, and this was confirmed by a specially constructed anamnestic questionnaire. Participants have also filled the short version of IPAQ, encompassing professional activities, leisure activities and transport. Anthropometric measurements were taken followed by positioning of markers. A coin method was used in selecting the extremity first to be measured. Markers were positioned on following anatomical prominences: acromion L+R, ASIS L/R, medial femoral epicondyle L/R, lateral femoral epicondyle L/R, medial tibial epicondyle L/R, fibular head L/R, medial malleolus L/R, lateral malleolus L/R (Figure 1).

After marker placement, participants were positioned for MTT and given instructions for performing the test according to protocol, based on[1-3,6]: participant is laying supine on the table, with pelvis near the edge of the table and is holding both knees on chest. It provides a neutral position of lumbar spine, holding pelvis in the posterior tilt position. Non-tested leg is being passively stabilised with a strap, forming the angle of 120° (in flexions over

Figure 1. Positioning of markers: acromion L, acromion R, ASIS R, medial femoral epicondyle R, lateral femoral epicondyle R, medial tibial epicondyle R, fibular head R, medial malleolus R, lateral malleolus R

Figure 2. Final body position while performing MTT



120° the position results in lumbar kyphosis). Then, subject is instructed to take a deep breath and, while exhaling, to gradually lower his leg, in a controlled manner, due to gravity, thus allowing hip extension with knee flexion. The sole force leading to mentioned movements is the weight of the tested extremity. The same procedure is repeated for the other extremity (Figure 2).

Kinematic features of MTT are evaluated using two objective methods: 2D goniometry (goniometer KaWe)[16] and 3D method using automatized optoelectronic system ELITE 2002 (Bioengineering and Technology Systems (BTS), Milano). The later includes eight cameras, with 100 Hz sampling rate, and uses nine passive retroreflective markers.[17] Measurement and data acquisition were performed using the GaitEliClinic software package, a part of the BTS ELITE 2002 system. Furthermore, data processing was performed using the SmartAnalyser software package. The features of the BTS system enable measurement, with high spatial (lines per mm) and temporal resolution, and automatic detection and acquisition of a 3D trajectory coordinates of a number of markers. The system functions based on automatic detection of coordinates of reflective passive markers by the method of cross-correlation, and by employing close-range photogrammetry algorithms for calculation of 3D marker coordinates. When marker trajectories are acquired, a number of kinematic parameters of a particular recorded movement can be calculated. The system is described in detail in.[18] In the present application, following angles were calculated: knee flexion, hip extension, hip abduction and hip rotation.

After subject performed the test, initial measurements were obtained using the two methods. Acquisition lasted for 2 seconds, while goniometry on average required 25 seconds. Second measurements were obtained in the same way, with the equal position of participant. Those measurements were used as an indication of flexibility. This procedure was then repeated for the other extremity.

Flexibility of *m. iliopsoas* was estimated in sagittal plane by measuring hip-extension ROM. In the same plane, flexibility of *m. rectus femoris* was estimated by measuring knee-flexion ROM. Flexibility of *m. tensor fasciae latae* was estimated by measuring hip-abduction ROM, in the frontal plane, and by measuring hip internal rotation ROM, in transverse plane.

In total, 864 angles were calculated, while 30 fell out the experiment, due to sweating, 3D method artefacts and trick movements.

Statistical analysis

Kolmogorov-Smirnov test was used for determining normality in data distribution, with $P = .05$. Correlation analysis was used to determine mutual connection of measured parameters. Since distribution showed deviation from normality, Spearman's coefficient of correlation was used for data processing. Statistics were calculated using Statistica 12 package.

Results

Optoelectronic kinematic evaluation (K) and goniometry (G) resulted in following mean values and standard deviations: knee flexion–K = 52.72° ± 11.49°, G = 56.72° ± 11.18°; hip extension K = 24.27° ± 8.55°, G = 10.07° ± 10.08°; hip abduction–K = 8.2° ± 6.44°, G = 7.84° ± 4.45°; external hip rotation K = 0.58° ± 4.38°, G = 0.98° ± 5.76° (Figure 3).

Correlation between results obtained by the two methods was determined by calculating the Spearman's coefficient: r = 0.91 (Figure 4).

Discussion

The objective of this research was to compare 3D and 2D methods of kinematic evaluation for special clinical test–MTT, and to quantify the results of the test that combines evaluation of passive hip-extension and knee-flexion ROM, along with possible abduction and hip rotations.

Compared to Thomas test (TT) which is performed in full supine on the testing table,[2,3,10] MTT is performed in supine on the table, with pelvis and hips near the edge, in order to allow movement of the examined upper leg below the horizontal line. Consequently, MTT provides an opportunity to evaluate not only one-joint, but also two-joint hip flexors. Today, in research and in clinical practice, MTT is applied more often than TT.

Inability of upper leg to extend to the neutral position or below the horizontal line is considered positive MTT.[1,2,4,8] However, in clinical practice, and especially in this research, dichotomous assessment is not sufficient. A number of special clinical tests lack quantitative dimension, making it difficult to implement them in scientific research, therefore, they remain robust tools of everyday practice.

Special clinical tests can help in determining if particular type of dysfunction or injury is present or has a potential to occur.[2] In their research paper, Corkery et al[4] identified the flexibility of *m. rectus femoris*, evaluated using MTT, as the predictor of injuries of hamstrings in amateur athletes. Individuals with ≤51° of knee flexion were identified as those more prone to injury of hamstrings. The authors recognize length evaluation of *m. rectus femoris* to be important for assessment of athletes' condition and injury prevention, due to its biarticular functions. The imbalance between the extensions of right and left hip, at the level of posture, function and structure of muscles, is associated with a predisposition to injury of the lower extremities. Wang et al[9] used MTT to assess the length of *m. iliopsoas*, while their research found no difference between the muscle length in athletes and non-athletes. The authors explained this with a theory that both groups spent a lot of time sitting, which could had led to muscle shortening.

Several authors attempted to objectify TT and MTT. Ferber et al[5] conducted a study on flexibility of *m. iliopsoas* using MTT on a sample of 300 recreational athletes (600 entities surveyed). Authors presented the results (10.60° ± 9.61°) as normative values for hip-extension ROM, i.e. they set the criteria for flexibility of *m. iliopsoas*. Harvey[6] estimated the flexibility of *m. iliopsoas* using goniometric method of MTT, assessing hip ROM on 117 top athletes. The resulting hip extension angle was an average of 11.91° ± 5.57°. In their research, Corkery et al[4] positioned subjects (N = 72) in full supine position on the table and, by using TT, measured hip ROM. The study included an initial warming up by using cycle ergometer with the default intensity for 3 minutes, in order to standardize the level of physical activity prior to measurement for all participants. Results showed hip-extension ROM -2.3° ± 1.9° (the negative indicates a flexed position of 2.3° above the horizontal line). Wang et al[9] used a similar approach in their research, where 40 participants warmed up prior to the test, and performed stretching of *m. iliopsoas* and *m. rectus femoris* for 30 seconds. In this study, participants were not subjected to warming up; moreover, any intense physical activity was strongly prohibited during 12 hours prior to the test, in order not to influence the results. In literature, only Peeler and Anderson[10,14] indicate such elimination criterion (they set the limit of 4 hours prior to the test) thus excluding warming up before the test. These authors measured 54 participants using TT for measuring hip ROM and MTT for measuring knee ROM. Results of their evaluation showed mean values of 7° ± 2° of hip extension and 50° ± 12° of knee flexion. In relevance to the length of

Figure 3. Results of measuring 4 ROM parameters obtained by using 2 methods: K and G. 1K - knee flexion K, 1G - knee flexion G, 2K - hip extension K, 2G - hip extension G, 3K - hip abduction K, 3G - hip abduction G, 4K - external hip rotation K, 4G - external hip rotation G

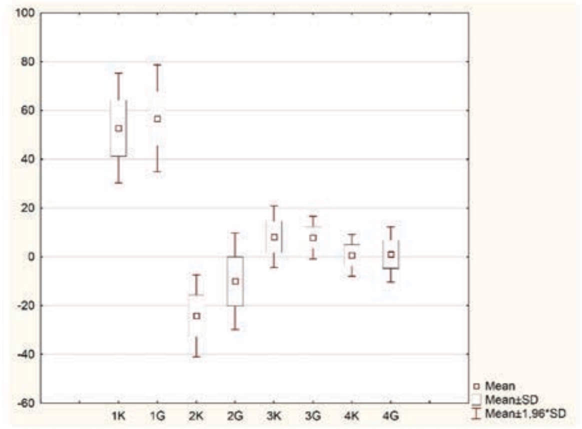
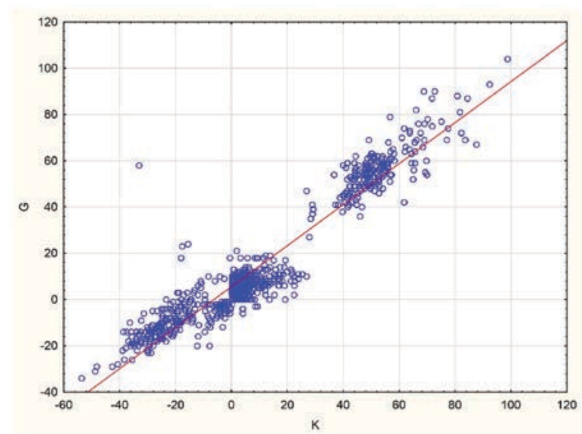


Figure 4. Spearman's correlation between results obtained by the two methods



m. rectus femoris, Corkery et al[4] established the mean value of knee angle, which was 53.5 ± 11°. Those results are similar to the ones obtained by Harvey,[6] who evaluated the length of *m. rectus femoris* in top athletes using MTT and recorded a mean value of 52.5 ± 7.56°. The results of goniometric evaluation of knee ROM in this research paper (56.72° ± 11.18°) are comparable with the results obtained by Harvey,[6] Corkery et al,[4] and Peeler and Anderson.[10] All values mentioned above are minor to those described in the literature that is most commonly used as reference source in clinical practice, such as Magee,[2] who specified 90° as a normal ROM for this particular test, or Kendall et al[1] who suggest the angle at 80°.

The results of goniometric evaluation of hip ROM in this study (10.07° ± 10.08°) are consistent with the results of Harvey[6]: 11.91° ± 5.57° and Ferber et al[5]: 10.60° ± 9.61°. However, in relation to Corkery et al,[4] and Peeler and Anderson[14] they differ. The reason for this difference arises from the application of different tests (Corkery et al,[4] and Peeler and Anderson[14] carried out TT, while the researchers of this study along with Harvey[6] and Ferber et al[5] carried out MTT). In addition to this, Corkery et al[4] did not randomize the order in which they tested particular extremity first; instead, they always started with testing the right leg, followed by left. This non randomized order can affect the results.

Ferber et al[5] and Harvey[6] used similar positioning of a subject as the one conducted in this study, making the results comparable. However, those authors used a different stabilization, where the subject passively holds the upper leg in the maximum flexed position (Corkery et al[4] and Peeler and Anderson[14] used the same stabilization). In this study, a norm of the initial flexed position of the upper leg in the hip was set at 120°, which ensured straight back without formation of lordosis or kyphosis that occurs at angles over 120° of hip flexion. This position was ensured by using a strap. Kim and Ha[12] emphasize the importance of stabilization for norming, as one of the requirements for precise measurement, which reduces measurement errors that can lead to inadequate evaluation by using MTT. Wakefield et al[7] used external stabilization, a bench, which ensured the position of non-tested leg at the angle of 90° of hip flexion. Compared to other studies of MTT,[6,8,10,11,14] in the one mentioned above the controlled conditions of trunk and pelvis stabilization were secured, but that position was insufficient for ensuring the neutral position of lumbar spine. The result of the aforementioned was a larger hip ROM (mean value of 15.4°) than the hip ROM showed in this paper, and the ones of Harvey [6] and Ferber et al.[5] Another lack of Wakefield et al[7] research is that the tests were performed only on right lower extremities, on a small sample (N = 22). Based on indicators from the literature, anatomical and biomechanical determinants and clinical experience, the authors of this paper suggest the fixation of non-tested leg at 120° of hip flexion.

Aggravating factors in goniometric measuring showed the inability of precise placement of fixed and movable arms towards prominent points and difficulties with placing the centre of instrument on the local rotation axis of a joint.

Optoelectronic method of evaluation, used to quantify the results of MTT, according to the knowledge of authors of this paper, has not yet been researched and discussed in scientific literature.

The advantages of this research are precise 3D measuring instrument,[19] large sample, stabilization norming and assessment of abduction and rotations in all three planes (sagittal, frontal and transverse) simultaneously, while the studies described in the so far available literature mention measurements performed only in sagittal plane. The reason for the latter could be that the measuring instruments such as goniometer, inclinometer and digital photography are limited to only one plane (2D methods), while optoelectronic kinematic 3D evaluation uses comprehensive approach, thus providing more opportunities.

There are some disadvantages to the research: differences in determining the anatomical prominences for measuring hip ROM have been found, e.g. a line connecting trochanter to acromion in 2D method was replaced with a line connecting ASIS to acromion in 3D method, resulting in difference in ROM between the two methods: 24.27° ± 8.55° (3D) and 10.07° ± 10.08 (2D).

The overall correlation coefficient r = 0.91 is very high. Unexplained variance includes systematic (difference in accuracy and positioning protocol of the markers in two methods, a sample composed of men of high levels of physical activity and without injury) and non-systematic sources of variability.

Goniometric evaluation is a routine procedure used by clinicians to assess ROM. Due to its wide application in practice, reliability of goniometry is well researched.[10] It is performed by visual orientation of the instrument's arms and centre of the instrument according to prominent anatomical structures. Therefore, partial implementation is quicker, but also prone to error. The entire assessment of angles through MTT requires four partial implementations of goniometry (one assessment for each variable), data recording and entering it into a computer, data analyses and feedback. Automated optoelectronic 3D analysis requires more time to prepare for measurement (calibration of the system, placement of the markers); however, it allows the possibility of simultaneous measurement of all angles and automatic data processing with fast feedback, which makes it a relevant modality for accurate and comprehensive measurement of ROM.

In future research, there is a possibility of applying optoelectronic kinematic evaluations for objectification and quantification of other frequently used orthopaedic special clinical tests, in order to establish normative values and the formation of a reliable assessment method.

Conclusion

Normative values for four angles of ROM have been established for MTT. This research showed a high correlation between the two methods of measurements. The high correlation suggests that both, 3D and 2D method, can be used for evaluating passive ROM in MTT. Optoelectronic kinematic 3D evaluation proved to be superior to 2D goniometry due to the possibility of simultaneous measurement of all angles and automatic data processing with fast feedback, which makes it a relevant modality for accurate and comprehensive measurement of ROM.

The results demonstrate the validity of using optoelectronic kinematic evaluation, not only for research purposes, but also for use in clinical practice. This example of MTT opened up opportunities for application of optoelectronic kinematic evaluation for objectification and quantification of other frequently used orthopaedic special clinical tests, which is the subject of future research. The authors of this paper believe that the inclusion of optoelectronic kinematic evaluation in corpus of such clinical tests can provide a significant contribution to rehabilitation, and injury prevention.

Author Disclosure Statement

The authors declare that they have no conflict of interest.

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