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Leg Length Measurement: Review

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Background. Measurement of the length of the lower extremities is an important part of the assessment of the musculoskeletal system. If there is a discrepancy in the length of the legs, the accuracy of the measurement technique will determine the choice of further tactics for treating the patient. However, to date, there is no consensus among experts regarding the optimal and accurate method for assessing this clinical condition.
The aim is to analyze foreign and domestic researches about measurement of LLD and to determine the optimal method for measuring the lengths of the lower extremities.
Methods. More than 70 scientific articles were selected from 1983 to 2021 in the PubMed/MEDLINE and eLIBRARY databases in Russian and English languages.
Results. An analysis of the literature data did not reveal the optimal method for measuring the length of the lower extremities. Clinical evaluation procedures have demonstrated poor reproducibility and high measurement errors. Radiation imaging techniques also have measurement errors, additionally exerting radiation exposure on the patient. Imaging techniques such as ultrasound and MRI are described in several studies, which does not allow to fully determine all the advantages and disadvantages of these methods when measuring the lengths of the lower extremities.
Conclusion. The study and development of new methods for diagnostics different lengths of the lower extremities, as well as the improvement of existing methods, will improve the quality of diagnosis of this pathological condition, and therefore affect the quality of the treatment for its correction.

Keywords: LLD, measurement limb length discrepancy, limb length inequality.

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Измерение длины нижних конечностей: обзор литературы

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Введение. Измерение длины нижних конечностей является важным элементом оценки состояния опорно-двигательного аппарата. При выявлении несоответствия в длине ног точность методики измерения будет обуславливать выбор дальнейшей тактики лечения пациента. Однако на сегодняшний день не существует единого мнения специалистов относительно оптимальной и точной методики измерения длины нижних конечностей.
Цель обзора — на основании анализа зарубежной и отечественной литературы определить оптимальную методику измерения длины нижних конечностей.
Материал и методы. Было отобрано более 70 научных статей с 1983 по 2021 г. в базах данных PubMed (MEDLINE) и eLIBRARY на русском и английском языках.
Результаты. Анализ литературных данных не выявил оптимальной методики измерения длины нижних конечностей. Клинические методики оценки продемонстрировали плохую воспроизводимость и высокие погрешности измерений. Лучевые методики визуализации также не лишены погрешностей измерений, дополнительно оказывают на пациента лучевую нагрузку. Методики визуализации, такие как УЗИ и МРТ, описаны лишь в нескольких исследованиях, что не позволяет полноценно определить все их достоинства и недостатки при измерении длины нижних конечностей.
Заключение. Изучение и разработка новых методик определения разной длины нижних конечностей, а также усовершенствование уже существующих методик позволят улучшить качество диагностики данного патологического состояния, а следовательно, повлиять на качество проводимого лечения.

Ключевые слова: разновеликость нижних конечностей, измерение длины нижних конечностей, разная длина нижних конечностей.

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BACKGROUND

Determining the lower extremity (LEL) is an important point in assessing the pathology of the lower extremities. According to the literature, almost 90% of the population suffer from LEL discrepancy up to 1 cm [1, 2]. Anatomical and functional differences are distinguished [3]. Anatomical length discrepancy occurs when the total length of bones and the thickness of cartilage differ significantly between the limbs. The main causes of anatomical length discrepancy are congenital and acquired [4]. The most common congenital causes are hip dislocations, hemihypertrophy with injury to the skeleton of the lower extremities, unilateral clubfoot. Acquired causes may develop due to infections, paralysis, tumors, surgery such as total hip or knee arthroplasty [4]. Functional length discrepancy can be caused by contracture of soft tissues, contractures of the hip or knee joints, pelvic tilt or deformities of the foot [1, 3]. For example, flexion contractures of the knee and hip joints can cause an obvious shortening of the leg, while the hip abduction contracture and equine foot position can functionally lengthen the affected limb.

The assessment of different sizes is a difficult task for researchers and clinicians, since there are still disagreements about the optimal method of measuring the LEL, and data on their reliability and diagnostic accuracy differ. The accuracy of the method is defined as the spread of measurement using the imaging method compared to the actual measurement, whereas the reliability of the method lies in the difference between the measurement results of different researchers and the same researcher when measuring different patients [5]. The choice of the correct surgical method for correcting the LEL discrepancy requires improving the quality of diagnostic techniques for this pathological condition [6, 7, 8, 9, 10].

The aim of the study was to determine the optimal method of measuring the LEL based on the analysis of foreign and domestic literature.

METHODS

The search for scientific articles was carried out from 1983 to 20 in the PubMed (MEDLINE) and eLIBRARY databases. Keywords used for searching: *leg length discretion, limb length discretion, leg length inequality, leg length, limb length, measurement LLD*. The second stage was to look through the literature lists of the found articles for additional selection of publications of a suitable subject.

RESULTS

Two main categories of methods are used to evaluate the LEL: clinical methods and imaging methods [1, 5, 11].

Clinical methods for evaluating the LEL

Measuring with a centimeter tape

The technique is used to measure the length of each lower limb by measuring the distance between the bone landmarks and is called a direct clinical method for measuring the difference in size. In 21 studies, a centimeter tape was used to measure the length of segments [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32]. In most studies, the values obtained using a centimeter tape were compared with the results of X-ray images as reference [13, 14, 15, 16, 21, 22, 23, 25, 29, 31]. However, only some authors used full-fledged radiographs of the lower extremities, while some researchers estimated the difference in the LEL from targeted radiographs of specific areas, such as hip, knee and ankle joints [12, 16]. In two studies, the reference values were ultrasound diagnostic data [18, 20]. Several authors used CT scans as reference values [23, 26, 27]. One study assessed the distance of the medial and lateral ankles from the floor [29]. Some authors evaluated the inter-expert and intra-expert consistency of the results of the measurements obtained [11, 12, 17]. Another study compared the results obtained using a centimeter tape with the results obtained using a Metrecom device [16]. According to I.T. Batrshin and T.N. Sadovaya, when measuring the LEL and segments using a centimeter tape, 1000 children in 19% of cases had a change in the length of the segments depending on the position in which the measurement was made – standing, sitting and lying [32]. Only a few publications have reported that the measuring method with a centimeter tape is reliable and/or valid [22, 23, 26, 27]. Most of the authors [11, 13, 15, 18, 19, 20, 24, 26, 28, 30] it was concluded that the tape measurement technique is inaccurate: a wide range of results was revealed, weak correlation with other methods and a length discrepancy

with radiography, which may lead to an incorrect calculation of a small difference in the LEL. In addition, there are certain causes of different sizes, such as fibular hemimelia and posttraumatic bone loss involving the foot, where a significant part of the shortening of the limb is more distal in relation to the medial ankle, respectively, is not evaluated when using this assessment technique.

The blocks technique

The alignment of the patient's pelvis position relative to the horizontal plane in a standing position with the placement of blocks of known height under a short limb is called an "indirect" clinical method of measuring the difference in size. This method was used in 11 studies [12, 14, 18, 19, 20, 21, 23, 24, 29, 33, 34]. When evaluating the results, the data obtained during CT [23] and ultrasound [17] were considered the reference value. In all other studies, the reference value was considered to be the results of an X-ray examination. The blocks technique is defined as reliable, accurate and relevant or superior to the measurement technique with a centimeter tape in five studies [12, 21, 23, 24, 29]. However, several studies have revealed low validity and reliability compared to X-ray studies [14, 19, 34]. In addition, J. Edeen et al. identified the blocks technique as less accurate in comparison with ultrasonic measurement [20].

E. Hanada compared the blocks technique with palpation of the iliac crests to determine the magnitude of the difference. The values obtained using this technique were compared with the X-ray data as a reference value. The researchers concluded that the results obtained indicate high reliability and sufficient validity of the proposed methodology, but there are no other references to the use of this technique in the literature [35].

Osteopathic techniques

To determine functional shortening, osteopaths use unique techniques, such as the Derifield-Thompson test, which allows to accurately determine the difference in length of less than 3 mm when assessing interexpert consistency [36, 37, 38]. However, these studies were conducted on small groups of patients, and none of them used a different method for evaluating the the difference in the LEL.

This research design flaw was leveled in a study by D.W. Rhodes et al., in which the osteopathic measurement technique was compared with measurements obtained when assessing the difference in size on radiographs of the lower extremities in the standing position [39]. Despite the positive correlation, the values of the difference in the length of the limbs differed greatly depending on the measurement method, which prompted the researchers to conduct another study aimed at determining the difference in the LEL depending on the patient's position – lying on his stomach and lying on his back [40]. The results obtained were compared with radiographs of the lower extremities in the standing position, which revealed the low validity of the test and less than expected reliability of the study.

The study by H.T. Nguyen et al. is devoted to the assessment of interexpert consistency in measuring the LEL in patients in the supine position, which demonstrated good reproducibility when using the activator method [41].

In another study, the minimum size of the difference was calculated, which can be accurately determined using the osteopathic assessment technique – 3.74 mm. Such accurate data were obtained due to the known size of the pads simulating the different size of the lower extremities in the experiment [42].

Later, the data of the mistake-free determination of the difference in the LEL were increased to 4-6 mm due to the use of modified surgical boots [43].

A number of researchers believe that the inter-expert consistency in assessing the diversity depends on the experience of researchers and decreases when trying to increase the accuracy of measurements. [44, 45, 46, 47]. A modern study by R. Cooperstein and M. Lucente, devoted to assessing the difference in the patient's lying on his back and lying on his stomach, demonstrated low consistency between the measurements obtained [48]. Another study, also conducted by R. Cooperstein et al., was devoted to the evaluation of the compression technique for detecting different sizes and determining the differences between anatomical and functional shortening. The results demonstrated high reliability of intra-expert and inter-expert consistency, however, the authors indicate that radiological measurement methods are more accurate and reliable [49].

Another study by R. Cooperstein et al., devoted to the mathematical modeling of the Allis test, refutes the value of osteopathic assessment methods due to the significant length discrepancy in the results obtained during the measurement process, arising due to the peculiarities of positioning of patients at the time of the procedure [50]. A study by M. Farella et al. aimed at identifying the length discrepancy caused by disorders in the temporomandibular joint did not reveal a correlation between the pathology of the temporomandibular joint and the different LEL [51].

Visualization methods

Currently available imaging methods include conventional radiography, computer radiography, microdose digital radiography, ultrasound, CT and MRI. The spread of digital radiography served as an incentive for conducting a study on comparing measurements obtained during the evaluation of film and digital images [52].

Comparison of the results obtained by measuring film and digital images

S. Khakharia et al. conducted a study of comparability, accuracy and reproducibility of measurements of the difference between digital images in the PACS system and standard printed radiographs [52]. The measurements were carried out independently by two researchers. For both methods, comparable reliability and excellent consistency of the results obtained were claimed. Therefore, the transition from printed film to digital images was recommended.

Radiography of the pelvis to determine the magnitude of the length discrepancy

In 4 studies, the comparability of the measurement results of the LEL discrepancy obtained by measuring pelvic radiographs in a direct projection was evaluated [53, 54, 55, 56]. The reference studies were panoramic radiographs of the lower extremities in an AP projection in a standing position or CT results. The authors of all studies concluded that caution should be exercised when determining the magnitude of the length discrepancy in pelvic radiographs due to the limitation of their comparability with reference methods.

Panoramic radiography of the lower extremities in the standing position

Panoramic radiography of the lower extremities in the standing position is recognized as the gold standard for assessing the LEL discrepancy[4]. A number of studies have determined the high or almost perfect reliability of the panoramic radiography method [57, 58, 59, 60]. The CT method was the reference method in some of these studies, and in one of them panoramic radiography in an anterior-posterior projection in a standing position surpassed the CT scan in accuracy of the measurements obtained [60]. In addition, the specialists who conducted these studies recommend using the technique not only to determine the LEL discrepancy, but also to assess the axial deformities of the lower extremities. However, the results of a study by M.D. Ahrend et al. have also been published, demonstrating mistakes of up to 6 cm when measuring panoramic radiographs in an AP projection in the same patients during the treatment period. The authors of the article claim that when comparing the measurement results of an intact limb, the values differ by more than 2 cm in 76% of the studied [61].

EOS Biplane Imaging System

The EOS system is an X-ray machine that allows filming in two mutually perpendicular projections [62, 63]. A number of studies have been conducted to assess the accuracy of measurements of the LEL discrepancy [64, 65, 66]. Due to the high accuracy of the results obtained, the reference evaluation method was not used. When comparing the X-ray load A. Clavé et al. concluded that the obtained images of phantoms are comparable to diagnostic ones and can be used for subsequent examination of living patients in order to reduce radiation exposure [64]. In two other studies, 2D and 3D measurements using the EOS system were considered accurate and highly reliable. However, both studies revealed methodological problems [65, 66].

Computed tomography

In their study, V.Poutawera and N.S. Stott evaluated the reliability of measurements of different LEL obtained using CT [67]. The reference standard was not used. Although the intra-expert con-

sistency of repeated measurements was almost perfect, CT scans should be performed more than once and rechecked by the attending physician.

Ultrasound examination

Several studies have been devoted to assessing the reliability of measurement with the LEL discrepancy by ultrasound diagnostics [18, 20, 68, 69]. The reference standard was radiographic measurement. The authors of all the studies came to the conclusion that ultrasound for the assessment of length discrepancy is a simple technique in performance and much more accurate in comparison with clinical methods, regardless of what type of device is used.

Magnetic resonance imaging

Although MRI is traditionally used for soft tissue imaging, this diagnostic method is becoming increasingly popular for assessing bone abnormalities. In a study by J. Riad et al., the magnitude of the difference in limb length was assessed using MRI [70]. On sagittal T1-weighted tomograms of the lower extremities, the length of the pelvis, femur, lower leg and calcaneal bone was measured in the patient's position on the back with fully straightened legs. The measurements were carried out by two experienced experts and repeated two weeks later. The results obtained indicate the high reliability of the technique for estimating the size of the segments of the lower extremities.

DISCUSSION

Clinical methods are characterized by ease of application in routine practice and poor reproducibility with high inaccuracy rate of the obtained measurement results. Radiological techniques are also not devoid of mistakes, in addition, they have an X-ray load on the patient. That is why, in our opinion, it is impractical to use CT in the daily diagnosis of the LEL discrepancy. The studies devoted to ultrasound diagnostics and magnetic resonance imaging to assess the LEL discrepancy are one single nature and do not allow us to fully assess the advantages and disadvantages of these methods for assessing different limb lengths.

In addition, the difficulty of diagnosing the length discrepancy in the LEL lies in the fact that the results are compared with methods that also have inaccuracy. When directly measuring the bones of people of the Holocene epoch (modern people), the difference in the length of the thigh and lower leg is no more than 1% of the segment length [71], whereas according to studies describing the methods of clinical and visualizing methods for assessing the difference in size, different limb lengths in the population occur up to 90% of the population [1, 2], which indicates rather the high inaccuracy rate of the measurement methods used than the "epidemic" of dicrepancy.

CONCLUSION

As the analysis of literature sources has shown, there is no universal method for diagnosing dicrepancy today. The development of new diagnostic techniques of different LEL, as well as the improvement of existing ones, will improve the quality of diagnosis of this pathological condition, and therefore the quality of treatment for its correction.

DISCLAIMERS

Author contribution

Daria A. Petrova — the collection and processing of material, writing the draft.

Vladimir M. Kenis — research conception, text editing.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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