THE STATE OF THE ART IN ORTHOPEDIC MEASUREMENTS

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Abstract: This paper presents the current state of the measuring systems in orthopedics, analyzing each method with their advantages and disadvantages, range of applicability and measurement principle. Along with the existing methods, that are used by doctors, a length measurement system in orthopedics, which belongs to authors is described. The system is going be built and then tested, both as a clinical method for assessment of lower limb discrepancies, as well as intraoperative method, eliminating the risk of exposure to radiation of both patient and doctor.

Keywords: orthopedics, limp length, measurement system.

1. Introduction

Leg length inequality affects different functional activities and increases the risk of a series of pathological conditions. This problem is relatively common, 65% -70% of the population suffering from this disease [14]. According to Guichets study, a discrepancy greater than 20 mm affects at least one in 1,000 people [10]. Since these problems are common, and an optimal method for measuring the length of bone segments on a patient has not yet been finalized, it is proposed to build a device to measure these lengths with high accuracy and ease of use, allowing the measurement both at bedside, and on the operating table. To assure an increased accuracy, there have been conducted researches on measurement methods, which are currently divided into three main categories, each with the related subcategories, as follows:

a. Clinical methods:
   - Measurement method using a tape
   - Measurement method using wooden blocks
   - Measuring pelvic crest height difference
b. Imaging methods:
   - Radiography
     - Orthoroentgenography
     - Scanography
     - Teleoroentgenography
     - Computed radiography
     - Microdose digital radiography
     - Computed tomography
   - Ultrasonography
   - Magnetic resonance imaging
c. Intraoperative methods:
   - Measurement between fixed landmarks around the hip joint
   - Measurement of the resected femoral bone.

This article aims to summarize each method, to propose an innovative measurement method (d. Length measurement system in orthopedics), and to present the final conclusions on the methods the authors studied.

2. Clinical methods

Measuring the lower limb using a tape is an easy to use, accessible and noninvasive method, but with low precision [4]. When using this measurement method several sources of errors can occur, such as the difference in growth and circumference of both legs, difficulty in determining projections bone, pelvic asymmetry [8], contraction or muscle atrophy, obesity [5], surgical intervention or previous fractures, which may have altered normal structures [26]. It is recommended not to depend entirely on this method for clinical decisions regarding an appropriate treatment [4].

Another leg length discrepancy measuring method refers to placing wooden blocks of different sizes under the short leg, when the patient is standing [26, 30]. An alternative method is presented in Hanada’s study from 2001 [11]. This involves correcting the length discrepancy with a book. Compared to the wooden blocks method, it offers greater accuracy and differences of 1 mm to 5 mm can be also measured. The conclusion of the study shows that this technique is very reliable, when there is a history of pelvic deformity and the iliac crest can be easily palpated.

The measurement with PALM (PALpation Meter) device is suitable for determining the pelvic crest height difference, but not enough accuracy for measuring the inequality of lower extremities as
Petrone and colleagues have demonstrated in their study [27]. This device, shown in Figure 1 [6], determines the relationship between a given line, such as shoulders or hips line, and the horizontal line; the method of use may be observed in Figure 2 [6].

The caliper heads allow direct palpation of bone markers [18]. The indicator shows the distance between the two points and the deviation angle of the line between them. Using these two values and the ruler, the doctor will be able to calculate exactly the difference of height between the two points.

3. Imaging methods

The imaging methods are divided into three categories: radiography, ultrasonography and magnetic resonance imaging. The radiographic measurements of leg length is a well known method to determine the presence and inequality degree of the lower limbs. The six methods described in literature are orthoroentgenography, scanography, teleoroentgenography, computed radiography, microdose digital radiography and computed tomography [30, 13]. The orthoroentgenography was originally described by Green [9] and was designed to reduce measurement errors resulting from enlargement, using three exposures centered on the hip, knee and ankle, processed on a single film, as it can be seen in figure 3.

It was designed a tunnel with a long cassette, were two sliding plates with shield role for ionizing radiation were built. Thereby, this device allows the exposure of any third of the radiographic film, while the other two are protected by the plates.

Since only perpendicular rays are positioned to the ends of long bones, the length of the bones is preserved and undistorted view of the epiphyses line is possible.

The term "scanogram" was first mentioned in slit scanography technique, described in 1937 [24], where the X-ray beam is collimated to a thin transversal slit, that exposes the film while X-ray tube is moved from one end of the limb to the other. Others use the term "scanogram" [29, 31] to describe a change of orthoroentgenogram, which involves using a standard sized cassette (35x43cm) versus a long-sided one (35x110 cm). The scanography can improve the measurement accuracy by reducing parallax errors.

But accuracy is obtained despite of vital information. Because three separate anteroposterior images centered on the hip, knees and ankles joints are obtained, as it can be seen in Figure 4, the angular deformities of the legs can’t be observed. In patients with large discrepancies, the ankles and knees may differ substantially from one foot to the other, and the exposure does not include foot, so in a case of bone loss, the magnitude gap could be misinterpreted.
Several authors [9, 12, 25] have mentioned the occurrence of a magnification error towards the evaluation of leg length, when they used a teleoroentgenogram. The magnitude of magnification error depends on various factors, including length and circumference of limbs, distance from the X-ray source to the cassette, and divergence of X-ray beam. This technique has several disadvantages, such as: high exposure to ionizing radiation, subjective errors in terms of reading the teleoroentgenography [9], the need of special equipment, such as grids and filters [29].

Computed radiography is an advanced technology that is gaining more popularity [28, 29]. A latent image is produced, which is stored on a photostimulatable phosphor receptor found in a standard radiographic cassette. Images are recorded on a computerized radiography image system. The operator can improve the final image using the computer to adjust the image parameters. As a result, high quality radiographs can be obtained with a significant reduction of radiation dose, compared to standard video systems, a feature that is very useful for patients that require repeated radiographic examinations because of their leg inequality [17].

Microdose digital radiography is another form of computer-assisted imaging techniques, which substantially reduces radiation exposure of a patient compared with conventional radiographic techniques [2]. The patient sits in front of a X-ray assembly with a vertical arm, and remains still during the scanning process that lasts 20 seconds [1]. A continuous beam of photons is collimated so that it works as an X-ray point sources, and is designed to be projected through patient tissues and later to meet a computerized detector in perpendicular incidence. The assembly source-detector moves along, scanning the field "line by line" so that the beam always remains horizontal to the patient. Because the detector is very effective in detecting and processing the point source of X-ray photons, a patient is exposed to radiation of only 1 to 2 mrad during scanning. This exposure to radiation is almost negligible to the patient, and that makes this technique particularly attractive for patients with problems that require repeated radiographic evaluation, such as progressive inequality of leg length.

Digital images obtained with computed tomography (CT) were also used for measuring discrepancies of lower extremities, with a sensitivity of less than 1 mm [1, 33]. This technique is usually chosen, because the patient is exposed to low-dose radiation, radiation being estimated at a level of 50 to 100 times lower than with conventional scanography. The computer tomography facilitates the production of a series of comparable images with high accuracy that can be used to assess even growing limb [34]. Images are less prone to errors, which can result from positioning and muscle contraction, and lateral measurements can also be performed.

Computed tomography can be used to measure distances between points on the radiographic film, reducing errors from angular deformities [22]. Another big advantage is that patients are exposed to low doses of radiation, making it an appropriate method for assessing leg length of children.

3D ultrasound evaluation technique of legs inequality proved to be an accurate method to determine discrepancies, without using ionizing radiation [15], with a standard deviation towards reproducibility of leg length measurement of 1.6 mm.

Also, in other studies [7, 19], a high reliability has been reported when using ultrasound to measure discrepancies, compared to other clinical and imaging methods.

This technique involves using an ultrasound transducer to identify bone landmarks from the hip, knee and ankle joints. Although the use of ultrasound is less reliable than using fixed radiography, given the lack of radiation, the authors recommend ultrasound evaluation as a initial tool to estimate the patient's lower extremities inequalities.

Although magnetic resonance imaging (MRI) is traditionally used for imaging soft tissue, has become a more popular method for assessing bone abnormalities. MRI images were obtained using T1-weighted spin echo sequence [21]. Although an MRI does not expose patients to ionizing radiation, measurements obtained with this technique are less precise than those obtained with a scanogram or CT [16]. Moreover, MRI has not been so well studied in clinical investigations, as an evaluation tool for the leg discrepancy, is more expensive, may require sedation for young children and can be contraindicated in patients with certain implanted devices. Thus, at this time a scanography made with MRI remains an experimental tool, which requires clinical validation before it can be recommended for general use.

4. Intraoperative methods

Leg length inequality may also occur after an operation, so it is also required an intraoperative measurement. The methods described below are available to doctors when surgery is done. Measurement between fixed landmarks around the hip joint was used during total hip arthroplasty, often with good results [3, 20]. In all cases, an initial assessment is made before the femoral head dislocation, having the hip joint in neutral position. Fixed anatomical landmarks are chosen on both sides of hip, bolts, or screws are placed on these landmarks and metric systems are adjusted over them.

Takigami and colleagues [32] have presented an
The state of the art in orthopedic measurements

A intraoperative measurement method that uses a caliper retractor with two pins, as it can be seen in Figures 6 and 7, which can not be displaced from ilion.

According to preoperative radiographs, the average level of leg length inequality is between 14.2 ± 9.3 mm, shortening ranging from 31 mm respectively lengthening from 10 mm after surgery. The inequality of lower limbs showed significant improvement, with a postoperative average of 4.2 ± 3.2 mm.

This method is applicable in almost all cases of total hip arthroplasty and this technique helps minimizing the leg length discrepancy after the surgery, and the correct positioning of the femoral component.

The measurement of the resected femoral bone is performed after dislocation of femoral head and before osteotomy. The caliper is used to measure the distance between the highest point of the femoral head and the chosen osteotomy level. This position can be determined before surgery, using radiographic templates. These templates are magnified by about 20% to match the enlarged image on radiographs [26].

The acetabular template is placed at the appropriate depth, immediately below the subchondral bone, in an 40° abduction and 20° anteversion, and femoral template is placed in a total relationship with the medullary canal. The hypothesis is based on the fact that, if the same amount of head and femoral neck, intra-articular space and subchondral bone of the acetabulum is removed and replaced with prosthetic implants of the same height, leg length should remain equal.

Ideal equation is: "the femoral head and part of removed neck (X) + intra-articular space (~ 2mm) + removed acetabular subchondral bone (~ 1 mm) = thickness of the prosthetic acetabular implant (A) + femoral head and neck prosthetic implant (B)". When A and B are known, we can easily calculate X.

4. Length measurement system in orthopedics

A length measurement system is described in [23]. The system is noninvasive, has high measurement precision and is easy to use. Figure 8 is a schematic diagram of the measurement system. The system, consists of three articulated rods 3, 4, 5 that allow the movement of the probe 6 in a workspace, the stylus position being measured continuously using angular incremental transducers T1 ÷ T5 mounted on the rods and joints. The measuring system is placed on a stand 1 with wheels 12 where the command computer 9 and the display 10 are also placed. The whole assembly can be moved and fastened to the patient's bedside or operating table by means of a clamp 13, to allow precise measurement of lengths in orthopedics. When the operator moves the probe and touches with its spherical head 6 a point of interest on the patient body, the transducers T1 ÷ T5 measure the angles of rotation of the system elements and the software determines the spatial coordinates of the sphere in relation to a fixed reference system connected to the operating table. When the probe is moved to the second measuring point, its spatial coordinates are determined, and the distance between the two points is calculated, this representing the length of the measured bone segment.

One of the advantages of the system is that it can measure more accurately the lengths in orthopedics, both at the bedside and on the operating table, the results being stored in the computer memory. It is also possible to precisely position the bone implants holes, facilitating the operation of fixing them without needing to use portable X-ray devices. The system is noninvasive and has also a sterilizable probe. It can be used both as a method of evaluating the discrepancies, and intra- and postoperative.
5. Conclusions

Leg length inequality affects 65-70% of the population. To be able to recommend the most appropriate treatment for each patient, doctors need accurate techniques for quantifying the discrepancies.

In this paper there were analyzed different methods for assessing lower limb inequality, highlighting the advantages and disadvantages of each method. Further a length measurement system in orthopedics was described, which in the authors' opinion is the best option to achieve these measurements.

6. Bibliography


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