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Original research article

Mathematical models in the evaluation of weight distribution asymmetry in lower limbs: Implication for practice

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ABSTRACT

Introduction: Mathematical models quantify asymmetry in weight distribution on bilateral lower limbs using indexes or ratios.
Aim: This study investigates the efficacy of mathematical models to evaluate weight distribution asymmetry in healthy and different clinical populations.
Material and methods: This cross-sectional study recruited 188 participants (149 healthy, 27 stroke and 12 unilateral total knee replacement) through convenience sampling for this study. Two digital weighing scales were used to capture the loading on bilateral lower limbs. The data is further computed with different mathematical models.
Results and discussion: The symmetry index model has problems of inflation with increasing asymmetry values. Symmetry ratio model exhibits low sensitivity to differences in weight distribution, and did not provide the magnitude and direction of absolute weight distribution asymmetry. The direction of the asymmetry is not meaningful from the symmetry angle model, and it fails to predict factual asymmetry values.
Conclusions: Modified symmetry index has better sensitivity to differences in bilateral lower limb weight distribution and is able to quantify the extent of asymmetries and identifies the side of asymmetry. Based on the study results, we suggest the application of the mathematical models to quantify limb loading in the following order: modified symmetry index, symmetry index, symmetry angle, and symmetry ratio for clinical or research practice.

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1. Introduction

In quiet standing, when the body weight is distributed equally on bilateral lower limbs, the weight bearing is said to be symmetrical.[1] In clinical practice, achieving symmetrical weight bearing on the bilateral lower limb is a primary goal in neurological and orthopedic conditions such as stroke, joint replacement and amputees.[1–4] In the aforementioned conditions, the amount of weight distribution (WD) on the lower extremity is crucial in the process of recovery.[5] Asymmetrical weight bearing or non-weight bearing on the lower extremities on different stages of injury and postoperative rehabilitation could lead to a poor functional outcome.[1,3] Hence, evaluation of weight bearing on lower extremities is essential in clinical practice. Evaluation of symmetry of weight bearing between two lower extremities is carried through subjective clinical examination, as well as objectively through measurement devices.[5] Force platform, MatScan, Nintendo Wii balance board, and digital weighing scales are devices that provide more reliable and accurate weight bearing measurements.[6] The measurement data obtained from the devices are further computed using mathematical models to interpret the pattern (magnitude and direction) of asymmetry in WD on bilateral lower limbs.[7]

Mathematical models are methods used to quantify asymmetry using indexes and ratios. Symmetry index (SI), symmetry ratio (SR) and symmetry angle (SA) are the most commonly used models to quantify asymmetry.[7] In addition to the current models, recent literature has proposed a new model, 'modified symmetry index' (MSI).[7]

The mathematical models are given as follows:

$$\mathrm{SI}^{8}\ (\text{in }\%) = \frac{\mathrm{XR}-\mathrm{XL}}{0.5(\mathrm{XR}+\mathrm{XL})}\times 100, \tag{1}$$

$$\mathrm{SR}^{9}\ (\text{in ratio}) = \frac{\mathrm{XR}}{\mathrm{XL}}, \tag{2}$$

$$\mathrm{SA}^{10}\ (\text{in }\%) = \frac{45^\circ-\arctan(\mathrm{XL}/\mathrm{XR})}{90^\circ}\times 100, \tag{3}$$

$$\mathrm{MSI}^{7}\ (\text{in }\%) = \frac{\mathrm{XR}-\mathrm{XL}}{\text{Body weight}}\times 100, \tag{4}$$

where XR and XL represent WD (loading) on right and left sides respectively.

The SI is the widely used mathematical model, which quantifies WD in percentage of unit value such as kilograms or Newtons.[8] A value of SI = 0 indicates perfect symmetry in WD and any other values indicates asymmetrical WD on bilateral lower limbs.

The SR is the mathematical model, which compares the right limb loading values against the left limb. It gives the numerical relation of limb loading with respect to the right limb over the left. A value of SR = 1 designates symmetry and any other value indicates asymmetry.

The SA is a composite mathematical model, which uses trigonometry to quantify symmetry or asymmetry on bilateral lower limbs. A value of SA = 0 indicates symmetry and other values specify asymmetry.

The MSI model is adapted from the symmetry index. The output of the model is given in units of percentage. A score of MSI = 0 denotes symmetrical WD on lower extremities. The magnitude of asymmetry is interpreted from the value of the MSI score and the direction of asymmetry from its positive or negative sign value. A positive value indicates that the affected extremity is weight bearing more than the unaffected/healthy extremity, and the negative value implies *vice versa*. Testing the mathematical models using hypothetical data proved the MSI model as a notable model.[7] However, the competence and application of the MSI model in human data are not known. Additionally, no studies have compared the efficiency of these mathematical models in different populations reflecting varied magnitudes of limb load asymmetries.

2. Aim

The aim of this study is to investigate the efficacy of the mathematical model SI, MSI, SR and SA in healthy population and different clinical population (stroke and total knee replacement).

3. Material and methods

3.1. *Participants*

A total sample of 188 participants was recruited through convenience sampling for this study. The samples consist of 149 healthy participants, 27 participants with stroke and 12 participants with unilateral total knee replacement (TKR). This cross-sectional study was conducted at the musculoskeletal research laboratory in a public university teaching hospital. The inclusion criteria were set based on participants who could stand independently and could understand simple verbal comments. Healthy participants had no clinical signs and symptoms of orthopedic and neurological disease or disorder. Sample participants were excluded if they have any signs of cognitive, visual, or hearing impairment, inability to stand without walking aids and any other impairment, which prevents them from standing independently. The study protocol is approved by the public university research ethics committee. Informed consent was obtained from participants prior to their participation in this study.

3.2. *Procedure*

The limb loading data is measured from healthy population and clinical populations, in order to test data, which could comprise of small to large patterns of asymmetries. Secondly, testing on different clinical and non-clinical populations could reveal the strength and weakness of the model. The WD on lower limbs is quantified with two digital weighing scales (DWSs), A and B. Previous studies show the method of using two DWSs to measure WD on bilateral lower extremities as reliable (ICC 0.95–0.98).[11] The protocol for the measurement is adapted from Kumar et al.[11] The two DWSs of the same brand (BEU-GS27–007, Beurer, Germany) and specification are chosen. Prior to data collection, the two DWSs are tested with