Clinical meaning of the torque between stance leg and ground for the analysis of gait mechanism*

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Summary. Transversal torque between the stance leg and the ground was measured in 169 test persons with normal gait (91 women, 78 men; ages 15–79 years) using three-dimensional force plates. Taking the average of six to ten single steps produces reproducible person- and group-specific data. This permits the isolation and study of individual solutions to specific problems of locomotion, so-called gait mechanisms. The relatively great torque during the double-stance phase is caused mainly by the medially directed, short-term impact peak at heel strike, with the stride length as lever arm. Double-stance torque is therefore determined by motion dynamics and does not help in understanding individual gait mechanisms. Torque measured during the single-stance phase is, in comparison, rather small and is interindividually relatively variable. Experimentally measured torque is considered in terms of various hypotheses concerning the creation of torque in the human gait. Men obviously tend, for reasons of equilibrium and stability, to compensate the various torques. Better than the more known vertical, sagittal, and frontal force components, the remaining torque represents the individual problem solution and therefore permits the study of specific gait mechanisms, both physiological and pathological. Using the characteristic gait of patients with hemiplegia as an example, it is shown that pathological torque observed systematically on the nonaffected side in such patients is a quantitative measure of the trunk rotation necessary to move the plegic side forward. Measurement of this torque therefore permits precise determination of the degree of damage, as well as quantitative control and objective documentation of the rehabilitation progress.

Key words: Gait mechanism – Torque in human gait – Ground reaction forces – Gait analysis

Normal human gait is the individual synthesis of physiological solutions to biomechanical problems of locomotion, including equilibrium control. This synthesis appears to the observing eye, as well as in instrumental gait analysis, as rhythmic and harmonic motion. Pathological gait patterns appear enharmonic; missing or wrong components do not permit such “floating” synthesis.

Normal or pathological solutions of specific motor problems of locomotion are referred to here as gait mechanisms. Since several equivalent solutions to a partial problem are often possible, apparently identical gaits may result from different gait mechanisms. This also applies to typical gait disorders which may only appear similar.

Instrumental gait analysis enables the objective and quantitative measuring, recording, and documenting of forces (kinetics) or joint motion (kinematics) during different phases of gait. The successful isolation of specific gait mechanism requires: (a) the simultaneous registration of force, motion, and muscular activity parameters and (b) the differentiation of parameters that are direct consequences of the underlying physical laws of motion from those that are under voluntary control and inter- and intraindividually variable. Knowledge of such different gait mechanisms is the scientific basis for estimating the strain on certain structures of the locomotive system during walking, as well as for every type of rational and effective gait therapy, in which pathological mechanisms must be avoided and physiological ones encouraged.

In addition to the indispensable clinical assessment of gait, the most practicable instrumental gait analysis is the measurement of the forces and torques that become effective through adhesive friction between the sole of the stance foot and the floor. These so-called ground reaction forces can be easily measured using three-dimensional force plates. The resulting force components plotted into a rectangular Cartesian coordinate system have been described several times in the literature and have also been partly analyzed [1, 3, 5]. Their
time patterns for normal gait may vary from step to step as an expression of the freedom to generate these elements of motion. The measured intraindividual variability can be minimized by averaging six to ten steps; the result is a reproducible person-specific gait chart. After such averaging certain parameters, such as the force components of frontal (Fx), sagittal (Fy), and vertical (Fz) planes, show a surprising interindividual constancy. This allows the definition of group-specific norms of human gait. The personal individuality of gait is therefore represented to only a small extent in the force components Fx, Fy, and Fz; these are therefore not the subject of this article.

The rotational forces effective within the stance leg – or, to be more precise, the transversal torque between the sole of the stance foot and the ground – is the component of gait kinetics with the maximum freedom for individual gait mechanisms. The actual torque is the result of a multitude of involved torques, some elastically stored and some compensated by being directed in opposite directions. Only the resulting difference in torque is experimentally measurable. The importance of this measurable “free torque” (Mz; see below) for understanding gait mechanisms has apparently been underestimated until today. No measurements or interpretations of Mz have as yet been published.

Methodology

To measure the ground reaction forces of Fx, Fy, and Fz components, two piezoelectric Kistler force plates (type 9281B11) were used. These plates have four three-dimensional force sensors at the corners of the plate. They measure forces of up to 100000 N with a resolution of less than 1 N as well as the coordinates of the actual point of force application with a spatial resolution of less than 1 mm. The actual point of force application is the contact point for the resulting total force, defined as the vector sum of all partial forces acting between the contact area of the sole of the foot and the floor.

Three-dimensional force plates permit the calculation of Mz in the transversal plane, which correlates closely with the rotational strain on the ankle joint. This may be considered as rotational force, producing a transversal rotation of the stance foot which is inhibited only by the friction between foot and ground. Mz acts around the actual point of force application. It is independent of the relative position of the point of force application on the force plate, i.e., the position where the foot hits the plate. Mz is calculated directly from the ground reaction forces Fx, Fy, and Fz, measured with force plates in double-stride analysis [3].

With our own three-dimensional double-stride analysis the course of torque was measured and evaluated in 169 healthy test persons (91 women, 78 men). These were grouped into the following three age cohorts: group A, 20 ± 7 years (40 women, 25 men) group B, 35 ± 9 years (29 women, 29 men) group C, 65 ± 7 years (22 women, 24 men). Pathological gait mechanisms were analyzed in 42 hemiplegic patients, all with medium or good capability of free walking (20 left, 22 right brain damaged; both male and female). Torque was measured for both the affected and nonaffected sides. This contribution refers only to Mz; further results will be published elsewhere.

All reported values are the result of averaging six to ten individual steps. In contrast to individual steps, these averaged values have proven reliable in terms of specificity and reproducibility. To facilitate comparability, forces and torques here are given not in absolute but in relative units (percentage of body weight). The measured values are therefore independent of body weight and can be compared directly across different individuals.

Results

Torque during the single-stance phase of different test persons shows only very little systematic: Interindividual variability (Fig. 1) is greater than

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Mz \quad (%BW*cm)
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![Fig. 1. Time course of free torque (Mz; right stance phase) in six different healthy men. Torque and time are given in relative units (see text). Pronounced interindividual variability indicates strong dependence of the measured torque on individual gait mechanisms.](image-url)