Foot Biomechanics in the Normal Horse: A study of the Hoof Force Distribution in the Forelimb with a New Measuring Method

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INTRODUCTION

The foot of the horse is a complex organ which is frequently responsible for lameness. As Leach and Crawford (1983) stated earlier, more knowledge is necessary to consider applications in orthopedics, therapeutics, farriery, racetrack design, the choice of the racetrack surface and the selection of athlete horses. The purpose of this study was to determine the normal distribution of the vertical hoof forces on the forelimb at the walk and trot.

The ground reaction force was studied especially using force plates [Leach and Dagg (1983), Dalin and Jeffcott (1985)]. For the foot biomechanics analysis, it has been preferred to develop a new measuring instrument: a force measuring hipposandal derived from the device used by Marey (1894), Björck (1958), Frederick (1967) and Frederick and Henderson (1970). This paper presents the first application of this Horse Force Measuring System (HFMS).

MATERIAL AND METHODS

The experiments were carried out using twenty sound riding horses of different sexes, ages, breeds and uses.

The HFMS comprises two main parts: a force measuring hipposandal which could be easily attached to the hoof and a data acquisition system [Barrey (1987a,b)]. The force measuring hipposandal provides continuous measurements of the vertical forces in four points of the hoof (Fig. 1). A portable microcomputer placed on the saddle records the data.

The hoof forces are measured on a hard track surface: a fifty metre run at the walk and fifty metres back at the trot.

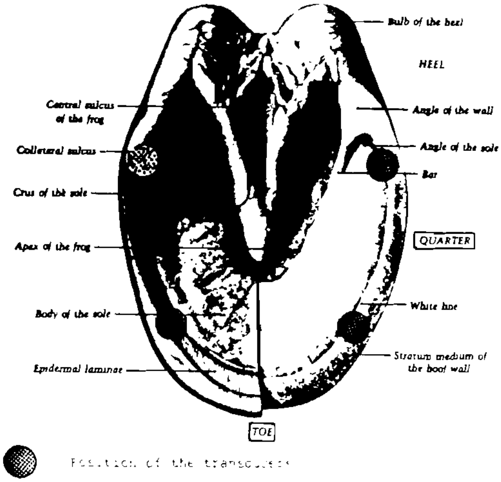

Fig. 1. The hoof terminology and the positions of the force transducers just under the foot.

For each horse, a computer program analyzes about twenty five walking strides and fifteen trotting strides and calculates gait parametres, then hoof force parametres. The parametres which describe the hoof force distribution are:

for each transducer of the force measuring hipposandal:

— the impulse: integration of the vertical force between the beginning and the end of the stance phase, normalized by the body mass of the horse (expressed in daN.s/kg).

— the slopes: mean differentiation of the force with respect to the time between specific points of the curves (expressed in daN/s). This parametre is homogeneous to the jerk. The most important slope considered here takes place between the beginning of the stance phase and the first force peak.

— specific points of the hoof force curves: maxima and minima (forces and dates normalized to the body weight and the stance phase duration).

for the whole hoof surface:

— the summations and percentages of each parametre above.

— the trajectory of the point of zero moment of the four instantaneous vertical forces.

— the mean position of the point of zero moment.

RESULTS

On the one hand, whatever the gait considered, the parametre results display a symmetrical biomechanic function of the foot with respect to the sagittal plane. On the other hand, they reveal different biomechanic functions from the posterior to the anterior region of the foot (Table 1). The vertical hoof forces are more intense and appear earlier on the quarter transducers than on those of the toe (Fig. 2).

TABLE 1

Results of the force parametres for the foot (left=walk, right=trot).

Variable	Mean	S.D.
Impulse (deN.s)	108.7 64.8	43.6 15.9
Impulse / weight (daN.s/kg.)	19.9 11.9	7.6 2.8
Impulse / seconde (daN.s/s)	85.9 89.4	41.6 24.1
Impulse / meter (daN.s/,)	54.3 22.4	—
Average force (daN/kg)	27.9 28.9	8.3 4.6
Force ratio on quarters (%)	63.5 69.9	12.4 10.2

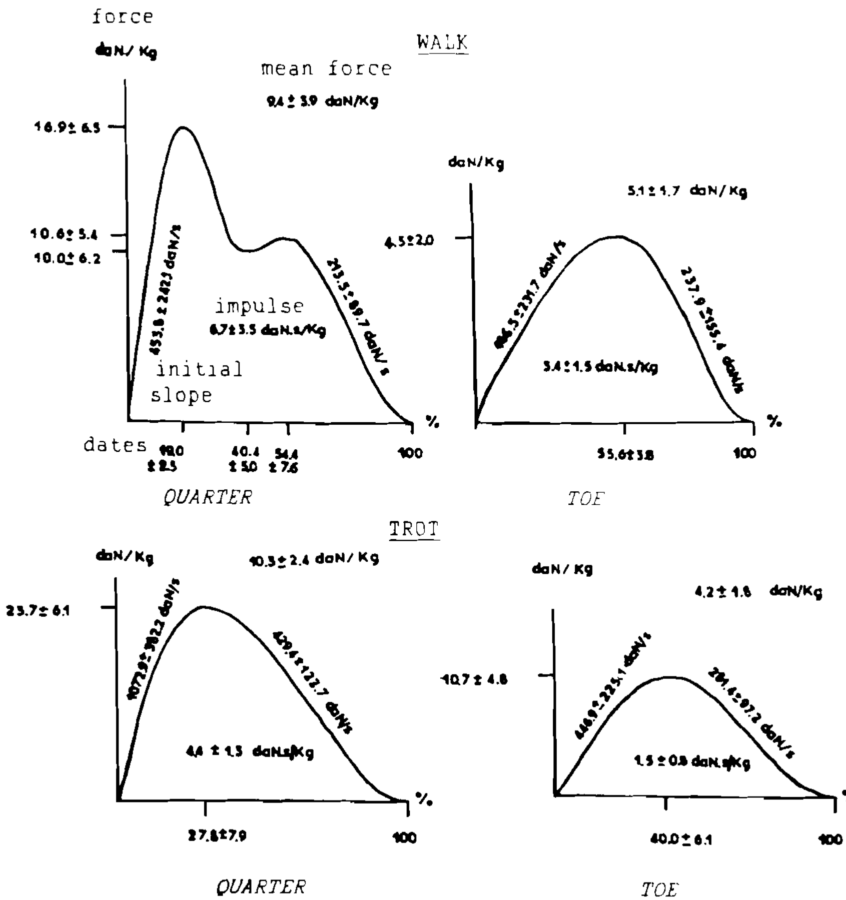

Fig. 2. The results for each type of transducer (quarter and toe) for the walk and for the trot.

The quarter transducers bear the greatest impulse which is graphically expressed by the largest area under the curve (Fig. 2 and 3). The force peak on the quarters takes place immediately after the impact, so the initial slope has an important value (Fig. 2).

The point of zero moment moves from the posterior to the anterior area of the hoofduring the stance phase. Its mean position is located roughly on the vertical projection of the rotating axis of the coffin joint. In all horses, the evolution of the trajectory following axis OX is a constant phenomenon contrary to the evolution following axis OY which is specific in each horse (Fig. 4).

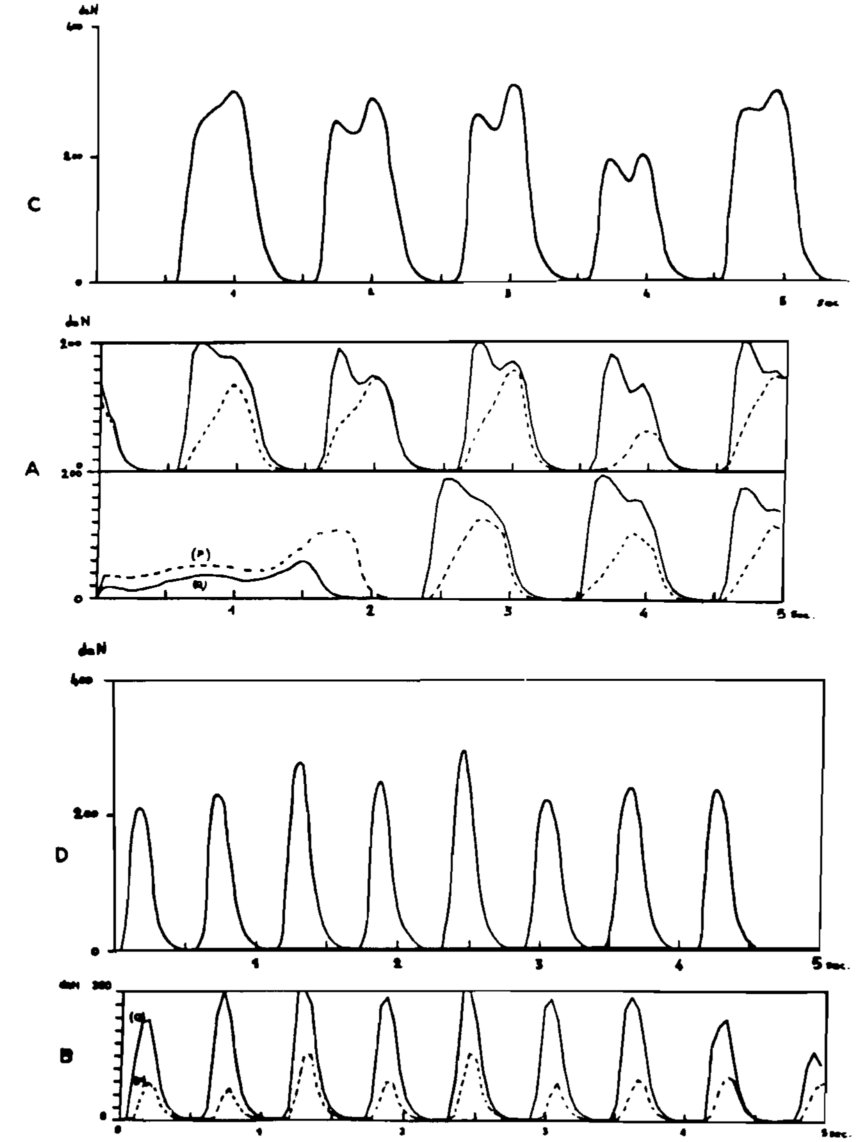

Fig. 3. Toe and quarter curves recorded simultaneously at the walk (A) and trot (B). The curves C and D are obtained by adding up the toe and quarter curves. (doted line=toe; continuous line=quarter).

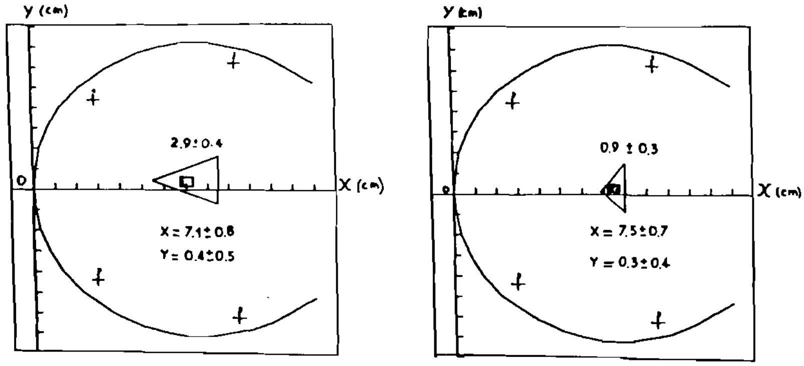

Fig. 4. The results of the point of zero moment for the walk (A) and trot (B). The mean position (.56) and the evolution (◁) of the trajectory following the axis OX are indicated in each case.

Three variation factors of the vertical hoof force distribution were found:

— As the foot and pastern axis angle increases (more than 55°) the anterior region of the foot supports more forces (about 57% of the total impulse). With a low angle (less than 55°) the distribution on the posterior region increases (about 75% of the total impulse).

— The vertical hoof force distribution on the quarters is greater in heavy horses.

— The vertical hoof force distribution on the quarters increases with the stride frequency.

DISCUSSION

Few authors have described the hoof force distribution and the results do not always tally [Auer and all. (1985), Rooney (1981), Schryver and all. (1978), Kingsbury and all. (1978), Rooney and all. (1978)].

According to the results obtained, the vertical hoof forces are not uniformally distributed over the whole hoof surface. The distribution changes continuously during the stance phase. Thus, the mechanical sollicitations are greater in the posterior region than in the anterior region especially after the foot impact on the ground.

After considering the anatomic, histologic and rheologic data as well as the data presented here it is suggested to adopt the following functional pattern: during the stance phase three biomechanic functions are successively assumed by the posterior region, then the central region and finally the anterior region of the foot:
— the damping function
— the supporting function
— the propulsion function.

Each anatomical region is adapted to its biomechanical function [Emery and all. (1977), Rooney (1977) (1981), Knezevic (1962), Blin (1982)]. The anatomical elements of the posterior region have some damping properties due to their developing visco-elastic strain capacity (Frog, heels, digital cushion, veinous plexuses). The central region is structurally adapted to support heavy loads. The sole and the distal phalanx from together an arch-like architecture. The anterior region provides a large contact surface with the ground during the propulsion stage (Toe, sole, distal phalanx).

The evolution of the vertical hoof force distribution from the posterior to the anterior region occurs because of a gradual reverse of the moments exerted on the distal phalanx by the tendons (Common digital extensor, deep digital flexor) and the suspensory ligament. This assumption is also confirmed by the study of the evolution of the hoof moment in vitro Kingsbury and all. (1978), Rooney and all. (1978).

The mechanical sollicitations of the posterior region of the foot require more investigations to understand the relationships between the damping function and the frequent pathology of this anatomical region.

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