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Gait asymmetries in patients with idiopathic scoliosis using vertical forces measurement only

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Abstract This study aimed at identifying measurable asymmetries during gait and relating them to the spinal deformity in subjects with idiopathic scoliosis. We investigated 21 patients aged between 10 and 26 years for gait asymmetries using force plates. All subjects completed five walking cycles over two force plates measuring vertical ground reaction forces. Among the parameters measured were contact time and magnitude of the two peaks of the vertical forces as well as the rate of application of those forces. Published gait data on normal subjects were used as a control group. In 20 subjects an asymmetry of at least one

gait parameter was noted. Multiple regression analysis showed, however, that there was no relation between the noted gait asymmetry and the curve direction, curve magnitude or vertebral rotation. This suggests that although functional asymmetries of the central nervous system have been described in patients with idiopathic scoliosis, they do not appear to have a reproducible effect on gait.

Key words Scoliosis · Gait · Nervous system

Introduction

The aetiology of idiopathic scoliosis (IS) has been the subject of extensive research. Among the most popular hypotheses has been one proposing a neuromuscular origin although genetics and growth may also play an important role. Muscle abnormalities have been described by some researchers [12] although they may well be secondary to the spinal deformity.

A neurological origin has been postulated in particular since research showed that vestibular [10] or posterior column dysfunctions [1] are present in subjects with IS. A developmental abnormality in the central nervous system creating rib-vertebra angle asymmetry has also been postulated as a possible cause of IS [2]. We hypothesised that if a central nervous system abnormality was at the origin of IS, either this neurological dysfunction or the effects of the spinal deformity itself should be expressed in the patient's gait. This study aimed at iden-

tifying asymmetries in some gait parameters of patients with IS.

It has been shown that in normal subjects, asymmetries in the vertical component of the ground reaction forces (GRF) as well as stance time, deviate by less than 4% [6]. Previous research on gait in subjects with scoliosis has either looked into the electromyographic (EMG) activity of the erector muscles [5], or into stride parameters using foot switches [1]. Although an asymmetry of the EMG was found in such patients, no difference was demonstrated in stride parameters. The only study, to our knowledge, that looked into GRF showed some asymmetries in the horizontal components [3].

Patients and methods

Twenty-one patients (20 females and 1 male) attending our outpatient clinic with IS were included in this study. Their average age was 16.1 years (range 9.6–26.1 years). Of those patients eight were awaiting surgery, five patients were skeletally mature and did not

require further treatment, while the remainder were treated conservatively.

Subjects with lower limb abnormalities (including leg length discrepancy), previous spinal surgery, low back pain or unbalanced curves as well as patients with neurological abnormalities on clinical examination were excluded from this study. From the patient's standing full-spine anteroposterior radiograph, the Cobb angle and the vertebral rotation at the apex using the Pedriolle technique [8] were determined for both the primary and secondary curves.

The curve pattern was a right thoracic primary curve in 13 patients, a left thoracolumbar curve in 7 patients and a right thoracolumbar curve in 1 patient. The average Cobb angle of the primary curve was 42° (range 18° – 90°) and the average rotation at the apex of the primary curve was 14° (range 0° – 30°). In the lumbar spine alone the average Cobb angle was 35° (range 15° – 65°) while the average rotation at the apex measured 15° (range 0° – 40°). In the thoracic spine the average Cobb angle was 34° (range 0° – 90°), the average apical rotation measuring 8° (range 0° – 25°).

A Kistler (Winterthur, Switzerland) gait symmetry unit was used to carry out the GRF measurements. The system, developed in conjunction with the Laboratory of Biomechanics, ETH, Zurich [11], consisted of two piezoelectric force plates built in a 8-m-long wooden corridor. This allowed measuring left and right vertical GRF during the same walking cycle (sampling rate of 200 Hz). The plates were connected to a personal computer and a printer. The software allowed for five consecutive double steps and also calculated average values for all five trials. During stance the typical pattern of the vertical component of the GRF is that of a curve with two peaks approximating 110% of body weight, separated by a trough (Fig. 1) [9]. The first peak corresponds to the loading of the leg during touchdown, the trough to the swing phase of the opposite leg, while the second peak occurs during the push-off at late stance. The parameters measured in this study were: contact time, value of the first and second force peaks and loading and unloading rates (Fig. 1). The time of occurrence of the mid-stance trough was also determined and averaged for all five trials. The patients were instructed to walk barefoot at their own pace. Several trials were performed per patient until five "clean" footstrikes were obtained. The "unclean" footstrikes were discarded and not drawn into the calculation.

Previously published data were used as a control group. It has been shown, using similar methods to those used in the present

study, that asymmetries in the vertical component of the GRF as well as stance time deviate by less than 4% in healthy individuals [6].

Left and right parameters for each individual patient were analysed using a non-parametric test (Wilcoxon matched-pairs). Regression analysis was performed between all six averaged gait parameters and Cobb angle as well as rotation of all curves.

Results

Mean stance time for all 21 patients was 0.65 s (SD 0.05). The average loading rate was 4.42 kN/s (SD 0.85) while the average unloading rate was 4.43 kN/s (SD 0.79). The mid-stance trough occurred at an average of 0.31 s after heel strike (SD 0.03). All measured gait parameters reflected a normal pattern. When the mean values for the five trials were considered, asymmetries between left and right of at least one gait parameter equal to or greater than 4% were found in 20 of the 21 patients. The distribution of the gait asymmetries can be seen in Tables 1 and 2.

When the left and right side gait parameters (excluding the mid-stance trough occurrence time) were compared for each of the five trials for each patient using the Wilcoxon matched-pairs test, significant differences ($P < 0.05$) were noted in at least one parameter in 17 of the 21 one patients.

Regression analysis showed, however, that neither the extent nor the direction of the asymmetry for any of the six gait parameters measured was related to the side of the primary curvature, to the Cobb angle of that curve or to the magnitude of the rotation of the apical vertebra. Nor could a relation be found between asymmetry of one of the above gait parameters and direction, magnitude or apical rotation of the curve at the lumbar level, whether the deformity was primary or not.

Fig. 1 Typical appearance of a force versus time plot for the vertical component of the ground reaction forces (F_z). (F_z1 first peak, F_z2 second peak, MS mid-stance trough, BW body weight, LR and UR the slope of the two lines represents respectively loading and unloading rates)

Table 1 Distribution of gait asymmetries (*Fz1* first peak, *Fz2* second peak)

Gait parameter asymmetry $\geq 4\%$	No. of subjects	Range of asymmetry (%)	Mean (%)	Median (%)	Standard deviation
Loading rate	14	4–30	10	6	8
Unloading rate	12	4–14	9.9	10.5	3.4
<i>Fz</i> 1	9	4–12	6.7	5	2.7
Mid-stance trough occurrence	7	4–18	7	5.2	4.9
<i>Fz</i> 2	4	4–9	6	5.5	2.4
Stance time	2	4	4	4	0

Table 2 Number of asymmetrical parameters per patient

No. of patients	No. of asymmetrical gait parameters
5	1
6	2
6	3
2	4
1	5
1	0

Discussion

From the descriptive statistics it appeared that the standard deviations were small, indicating that the variability of the gait parameters was relatively low. The parameters showing the highest asymmetry were the loading and unloading rates. The equipment used allowed investigation of the vertical component of the GRF only. A study on repeatability of gait variables found that mediolateral forces are more subject to variation than the vertical and fore-aft shear forces [7]. A study of symmetry in normal subjects found that symmetry was greatest in the vertical forces and was observed to a lesser extent in the fore-aft forces and even less in the mediolateral forces [6].

It was expected that if a neurological abnormality was at the origin of IS, then this should be expressed in a reproducible manner in gait. In this study, although differences equal to or exceeding 4% were found in the majority of patients, this was not related to the side or the extent of the deformity.

Some neurological abnormalities described, mainly those related to proprioception and the function of the posterior columns, may be only secondary to the spinal deformity itself. Others, such as vestibular dysfunction, are seated well above the deformed spine and therefore could be regarded as primary. If the gait asymmetry was due solely to the deformity of the spine and more specifically to the deformity at the lumbar level, then one would expect the asymmetries to be consistent and related, if not

to the magnitude, at least to the side of the spinal deformity. This, however, was not observed. An explanation might be that the neurological dysfunction that initiates the deformity is always the same, leading sometimes to right and sometimes to left curves. The more probable explanation, however, is that since the origin of scoliosis is multifactorial, the neurological abnormality itself is subtle enough not to produce a gross gait asymmetry. The asymmetries observed are an expression of the patients' neurological function at the origin of the curves as well as of secondary neurological changes.

The whole gait itself may also be influenced by mechanical factors such as the presence of an asymmetrical ability of the lumbar spine and trunk to rotate during ambulation. It has been suggested that the spine itself may be the engine of locomotion by transmitting energy to the pelvis while the lower limbs merely follow this pelvic movement [4]. If this were the case, one would expect that a deformity of the lumbar spine would have a constant effect on locomotion. This was, however, not expressed in the symmetry of the GRF measured in this study. Gait in patients with IS differs from that of normal subjects, although this can only be assessed with sensitive methods rather than by physical examination alone.

Conclusion

When vertical forces are studied during gait of scoliotic patients there are asymmetries observed between right and left side in the loading and unloading rates as well as, to a lesser extent, in the magnitude of the two peaks. Those differences are not related to the side or the magnitude of the spinal deformity.

The above observations do not constitute further evidence that there may be a neurological dysfunction at the origin of idiopathic scoliosis; if there is such a dysfunction, it does not appear to have a consistent expression in gait. Further analysis is required with more patients as well as more in-depth investigation of gait using video cameras.

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