Gait analysis in children affected by myelomeningocele: comparison of the various levels of lesion

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Summary

The aim of this study was to utilise the gait analysis (GA) methodology to characterise the walking act in children with different levels of myelomeningocele. To this end, we analysed 30 children (mean age 11±3 years, still able to walk without orthoses) grouped according to the site of their neurological lesion (localised from L4 down to S5); ten healthy children (mean age 9±2 years) were also analysed for comparison. Of the many kinematic and kinetic parameters provided by GA, we focused on those providing a good correlation with the level of lesion. In particular, the following parameters are presented and discussed: angle of flexion at the knee joint at the moment of contact of the foot with the ground, knee joint flexion-extension range of motion, flexion of the hip at the beginning of the stride, anterior pelvic tilt, range of rotation of the pelvis in the horizontal plane and ankle joint power. The higher the level of the neurological lesion, the more these parameters of gait were found to deviate from those measured in the control group. This study emphasises the relationship that exists between the site (level) of the neurological lesion and the individual aspects of the functional limitation associated with it.

KEY WORDS: Gait analysis, kinematics, kinetics, myelomeningocele.

Introduction

Myelomeningocele is a defect of the neural channel consisting of the failed conjunction of the boneshell of the dorsal medullar canal. This causes the protrusion of a cutaneous sac containing bone and meninx marrow, which damages the nerve roots from the site of the malformation down. Myelomeningocele attacks the foetus in the first three weeks of pregnancy; its aetiology is practically unknown and the only ascertained cause is a lack of folic acid, a vitamin of the B group, in the mother’s diet. The functional damage induced depends on where the cutaneous sac is formed. The higher the lesion is, the greater the number of nerves that will be damaged and consequently the greater the number of muscles paralysed. Paralysis of the lower limb muscles makes the use of orthoses necessary for almost all these patients. Moreover, in the case of higher-level lumbar lesions, affected children have to use cages to maintain their erect position. From a clinical point of view, myelomeningocele is a very complex pathology to approach; in fact, in addition to the problems strictly linked to the site of the malformation, other malformations of the nervous system, such as hydrocephalus, are often present. Furthermore, additional complications may occur at psychological level, too, because these children, quite normal from an intellectual and cognitive point of view, are perfectly conscious of their disability. It should be underlined that until recent years children who were born affected by this pathology died very soon after parturition, precisely because of the complications mentioned above. These complications have only recently become treatable and therefore the question of how to deal with these subjects is still open. At motor level, the primary goal is to preserve the patient’s ability to walk by means of a suitable treatment. The choice of this treatment (surgical, physical, orthopaedic) very much depends on the motor features of the individual child, which means that quantitative evaluation of functional limitation during walking is essential. Various authors (1-5) have documented clearly the characteristic aspects of walking in subjects affected by myelomeningocele and demonstrated how the objective analysis of gait plays a fundamental role in the assessment of both the functional limitation and the outcome of the treatment. The main purpose of this study was to analyse the relationship existing between the site (level) of the neurological lesion and the individual aspects of the functional limitation associated with it. In particular, we set out:

• to identify the kinematic and kinetic parameters of gait best able to characterise subjects affected by myelomeningocele from L3 down to S5, which is the most common spinal site of lesion (6);
• to use these gait parameters to ascertain the level of lesion, within the above mentioned spinal site.

Materials and methods

We analysed 30 myelomeningocele patients with different levels of lesion (mean age 11±3 years), who formed...
the pathological group (PG,) and, for comparison, 10 healthy subjects (mean age 9±2 years), who formed the control group (CG). The patients were split into four groups, according to the site of their neurological lesion (ascertained by X-ray or MRI). These groups were labelled: PG-L4, PG-L5, PG-L5/S1, and PG-S1/S5. The four groups contained patients whose lesions were located, respectively, at the fourth lumbar vertebra, the fifth lumbar vertebra, between the fifth lumbar and the first sacral vertebra, and between the first sacral and the last sacral vertebra.

Figure 1 summarises the cases considered. Informed consent for participation in this study was obtained from the parents of each child. The following criteria were adopted when selecting the patients:

• ability to walk independently without the use of orthoses or aids;
• no previous orthopaedic surgical intervention;
• well-defined neurological picture (level of lesion evaluated on the basis of spinal X-ray and MR imaging).

Following a clinical examination (orthopaedic and neurological), all the subjects first underwent a purely qualitative analysis of their gait (video recording). Subsequently, they were analysed through the use of the following two measurement instruments:

• an 8-camera opto-electronic system (ELITE, BTS, Milan) that reconstructs the 3D coordinates (7) of reflective skin markers appropriately positioned on the subject’s body;
• two force platforms (KISTLER, Switzerland) that measure the ground reaction forces during walking.

The markers for this study were positioned according to the Davis protocol (8), as illustrated in figure 2.

In particular, the markers were placed bilaterally on the acromion, iliac spines, great trochanter, on the end of a rod placed orthogonally to the femoral axis at mid-thigh level, on the femoral condyle, on the tibial condyle, on the end of a rod placed orthogonally to the tibial axis at mid-shank level, on the external malleolus, and on the fifth metatarsal head. The data acquired were processed (co-ordinates and forces), and the following variables were computed:

• the angles of flexion-extension, abduction-adduction, and extra-intra rotation at the various joints (calculated from the reconstructed 3D coordinates of the markers);
• the joint moments and strengths (8) (calculated from the reconstructed 3D coordinates of the markers and the ground reaction force).

Starting from a predefined point, so that they placed just one foot on each force platform, the subjects were asked to walk at their normal speed (self-selected speed). For each subject, six trials were acquired and considered for the subsequent inference process. The comparison of myelomeningocele patients (PG group) and healthy subjects (CG group) and, moreover, of groups of patients with different levels of lesion, was based on a two-tailed t-test with 0.05 (p<0.05) taken as the level of significance.

Results

Comparison of the findings showed the following parameters to be the most significant:

• flexion-extension of the knee joint. In particular, significant differences were found in the angle of knee flexion at initial contact (IC) of the foot with the ground
(hereafter indicated as KFIC), in its range of motion (ROM, difference between the relative minimum and the maximum of the curve) and in the joint moment;

• action of the pelvis on the sagittal plane, particularly the value of the pelvic tilt at IC (PTIC);
• action of the pelvis in the frontal transverse plane, in particular the ROM in the transverse plane;
• flexion-extension of the hip, particularly hip flexion at IC (HFIC);
• power at the ankle, particularly the peak of generated power normalised to body weight.
All these parameters are discussed in more detail below.

Flexion-extension of the knee

In the sagittal plane the angle of flexion-extension of the knee shows a characteristic pattern, as illustrated in figure 3 (see over).

In particular the KFIC value was analysed. Table I (over) shows the results (average values and standard deviations) relating to the patients (arranged by level of lesion) and the control group. Table II (over) evaluates the statistical significance of the results obtained.

It may be observed that the KFIC value distinguishes patients with an L4 level lesion from those with an L5 level lesion and, furthermore, patients with an L5 level lesion from those with a lesion at L5/S1 level. It does not, however, separate patients with a low lumbar level lesion from those with a sacral level lesion.

A lower-than-normal flexion-extension ROM (30±12 deg.s vs 60±8 deg.s) was observed in myelomeningocele subjects. This reduced ROM tends to become less marked, albeit not significantly, the higher the spinal lesion is. No significant differences in ROM were found when comparing the different patient groups, in fact the p value resulting from the t-test was always slightly over the limit value (0.05).

Figure 4 (over) shows the moment of flexion-extension at the knee joint in a normal subject (from the CG) and in a child with myelomeningocele (from the PG).

A lack of contraction of the soleus muscle does not allow the point of application of the ground reaction force to move forward (in healthy subjects this point is close to the metatarsal area at mid-stance), thus resulting in the long-lasting extensor moment observed in these patients (see the curve of the PG subject in figure 4). The flexor moment at the knee joint, which typically occurs at mid-stance in healthy subjects (see the curve of the CG subject in figure 4), is a feature that was never found in our PG children. The absence of flexion moment at the knee joint results in a lack of control of the advance movement of the shank, and therefore an excessive flexion of the knee joint as previously observed (Fig. 3).

Pelvic forward tilt

The course of the pelvic angle in the sagittal plane during a gait cycle in a normal subject and in a PG subject is illustrated in figure 5 (over).

The curve generated by the PG subject shows a clear forward tilt of the pelvis, throughout the whole walking cycle, caused by the weakness or absence of contraction of the extensor muscles of the hip, mainly the glutei, and the plantar flexor muscles. In fact, a marked forward tilt of the pelvis, causing a strengthening of the extensor muscles of the hip joint, makes it possible to meet, in part, the extension needs in walking. The higher the level of the spinal lesion, starting from L5/S1, the more this forward tilt increases. The peak of the maximum forward tilt of the pelvis, caused when the hip flexors are used to replace the action of the plantar flexors, occurs at around 75% of the stance phase and its amplitude increases significantly the higher the level of the spinal lesion is. It is important to note that the maximum peak of the pelvic tilt occurs after IC; this allows the leg in the mid-stance phase to move forward, and then to begin the swing phase.

Flexion-extension of the hip

Results similar to the pelvis findings were obtained when analysing the flexion-extension action of the hip joint (Fig. 6, p. 208).

For the reasons set out above, hip flexion at the beginning of the stride cycle (HFIC) increases the higher the level of the spinal lesion is. It is thus a useful tool for distinguishing between patients with different levels of damage (Tables III and IV, p. 208).
Pelvic rotation

Once again because of the weakness of plantar flexors, so typical in these patients, the swing phase can be approached by effecting a large swing of the upper body in the frontal plane. This feature was therefore studied considering the angle associated with pelvic rotation in the horizontal plane (see the curves in figure 7, over), which is so closely linked to this movement of the upper body.

Angular values much higher than normal (Tables V and VI, over) were observed in patients with lesion levels starting from above the sacral area.

Power at the ankle

Healthy subjects generate their peak of power at the ankle joint during the second part of the stance phase when the heel is lifted to allow the forefoot to exert the force on the ground that permits the forward progression of the whole body (see the CG curve in figure 8, over).
Conversely, patients affected by myelomeningocele cannot use the plantar flexor muscles (too weak or totally paralysed) to raise the heel and push against the ground. This results in a huge decrease in the peak power generated at the ankle joint (see PG curve in figure 8) and hence in serious walking anomalies. The results show (Tables VII and VIII, p. 210) that the peak power significantly decreases the higher the level of the lesion is. In particular, it was noted that the average values shown in Table VII differ significantly between pure sacral patients and those with a higher level of lesion (including the L5/S1 level). The p values, generated by the t-test for comparison of the data obtained in patients with different lesion levels, confirm the relationship between the peak power at the ankle joint and the spinal site of the lesion (Table VIII).

Discussion

This study demonstrates the typical locomotor patterns of subjects affected by myelomeningocele. The results obtained from this study on children affected by myelomeningocele are in agreement with findings already present in the literature, such as a reduced ROM at the knee joint, an unusual forward tilt of the pelvis associated with a larger flexion of the hip joint, and a rotation of the pelvis due to the large rotations of the knee joint.
Table III - Mean values and standard deviations of the HFIC in patients with different lesion levels and in healthy subjects.

<table>
<thead>
<tr>
<th>HFIC</th>
<th>PG-L4</th>
<th>PG-L5</th>
<th>PG-L5/S1</th>
<th>PG-S1/S5</th>
<th>CG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value</td>
<td>54.24910161</td>
<td>47.29549182</td>
<td>37.23536729</td>
<td>36.69904</td>
<td>20.47459</td>
</tr>
<tr>
<td>s.d.</td>
<td>10.22740163</td>
<td>6.23063044</td>
<td>6.40009359</td>
<td>8.583076</td>
<td>9.111684</td>
</tr>
</tbody>
</table>

Abbreviations: HFIC = angle of hip flexion at initial contact of the foot with the ground; PG = pathological group; CG = control group.

Table IV - Results of t-test on HFIC values between the three different lesion levels.

<table>
<thead>
<tr>
<th>HFIC</th>
<th>PG-L4 vs PG-L5</th>
<th>PG-L5 vs PG-L5/S1</th>
<th>PG-L5/S1 vs PG-S1/S5</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-test: p=</td>
<td>0.012944387</td>
<td>0.0002219</td>
<td>0.76658128</td>
</tr>
<tr>
<td>p&lt;0.05?</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

Abbreviations: HFIC = angle of hip flexion at initial contact of the foot with the ground; PG = pathological group; CG = control group.

Table V - Mean values and standard deviations of ROM associated with pelvic rotation in patients with different lesion levels and in healthy subjects.

<table>
<thead>
<tr>
<th>ROM</th>
<th>PG-L4</th>
<th>PG-L5</th>
<th>PG-L5/S1</th>
<th>PG-S1/S5</th>
<th>CG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value</td>
<td>41.35838</td>
<td>32.10918</td>
<td>20.53328</td>
<td>19.17774</td>
<td>17.86373</td>
</tr>
</tbody>
</table>

Abbreviations: ROM = range of motion; PG = pathological group; CG = control group.
the upper body that are typical in these patients. Another aspect of gait typical in these subjects, and confirmed in the literature, is the limited power generated at the ankle joint associated with a limited capacity to push on the ground in the pre-swing phase. The innovative aspect of this study is that it looks for correlations between the level of lesion and the walking performance of children affected by myelomeningocele. From a functional point of view, we found, in our patients, a significant connection between some of the gait parameters measured and the site of lesion, even though the latter was, in all these cases, located within the lumbar-

Table VI - Results of t-test on ROM associated with pelvic rotation between the different lesion levels.

<table>
<thead>
<tr>
<th>ROM</th>
<th>PG-L4 vs PG-L5</th>
<th>PG-L5 vs PG-L5/S1</th>
<th>PG-L5/S1 vs PG-S1/S5</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-test: p=</td>
<td>0.01632056</td>
<td>0.002334557</td>
<td>0.610724544</td>
</tr>
<tr>
<td>p&lt;0.05?</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

Abbreviations: ROM = range of motion; PG = pathological group.

Fig. 7 - Pelvic rotation of a normal (CG) and a pathological (PG) subject.

Fig. 8 - Ankle joint power of a normal (CG) and a pathological (PG) subject.
sacral tract (L4-S5). These results may therefore be very useful not only for a more efficient classification of the various patients on the basis of their real functional ability, but also for the assessment of possible treatments: a patient with an L4 level lesion should be treated differently with respect to a patient with an L5 level lesion, even though both of them belong to the category of patients affected by myelomeningocele in the lumbar-sacral section.

References


Table VII - Mean values and standard deviations of ankle joint peak power in patients with different lesion levels and in healthy subjects.

<table>
<thead>
<tr>
<th>AJPP</th>
<th>PG-L4</th>
<th>PG-L5</th>
<th>PG-L5/S1</th>
<th>PG-S1/S5</th>
<th>CG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value</td>
<td>2.32E-01</td>
<td>5.84E-01</td>
<td>8.27E-01</td>
<td>1.76E+00</td>
<td>4.06E+00</td>
</tr>
<tr>
<td>s.d.</td>
<td>0.164053</td>
<td>0.626245</td>
<td>2.470178</td>
<td>1.35086</td>
<td>1.194553</td>
</tr>
</tbody>
</table>

Abbreviations: AJPP = ankle joint peak power; PG = pathological group; CG = control group.

Table VIII - Results of t-test of ankle joint peak power values between pathological groups.

<table>
<thead>
<tr>
<th>AJPP</th>
<th>PG-L4 vs PG-L5</th>
<th>PG-L5 vs PG-L5/S1</th>
<th>PG-L5/S1 vs PG-S1/S5</th>
</tr>
</thead>
<tbody>
<tr>
<td>t-test: p=</td>
<td>0.06830173</td>
<td>0.4888201</td>
<td>0.017458317</td>
</tr>
<tr>
<td>p&lt;0.05?</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

Abbreviations: AJPP = ankle joint peak power; PG = pathological group.