BIOMECHANICAL EFFECTS OF ROCKERS ON WALKING IN A PLASTER CAST

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Rockers are applied to lower limb casts to assist walking but there is little information on their biomechanical effects. The performances of 10 commercially available rockers were compared. They were applied to a below-knee cast worn by a normal subject who was also tested walking in the cast alone. Gait analysis was used to evaluate kinematic and kinetic data.

The design of rocker had no effect upon the kinematics of walking. However, using new criteria for kinetic assessment of rocker function (tibial floor angular velocity and centre of pressure progression), most designs had a deleterious effect on the biomechanics of gait. Only two rockers approached the ideal kinetic criteria.

The intended function of a rocker applied to a walking cast is to allow progression of the leg over the stationary foot without ankle dorsiflexion, which is prevented by the cast. There are many designs including plaster boots, devices which resemble cams and those which provide point loading and resemble stumps. Patients wearing either long or short leg casts seem to tolerate the rockers irrespective of design but no objective comparisons have been made. Hellberg et al (1987) noted that a rocker heel permitted a longer stride than did a flat heel but at the cost of increased work.

The aim of this paper is to compare the biomechanical effects of some commercially available rockers.

MATERIALS AND METHOD

A below-knee lightweight cast (Deltacast Plus, Johnson and Johnson) was applied to the right leg of a normal female subject, with the ankle immobilised at 90°. The various rockers were applied and tested in sequence. The cast was not changed and the subject acted as her own control. After attaching each rocker she was allowed to become used to walking with it before gait analysis was performed. The subject walked at a self-selected speed.

The boot type consisted of an overshoes with a completely flat sole. The cam type had a contoured rocker sole and was attached to the cast either as an overshoes or with additional casting bandages. The traditional stump type provided a point loading rocker. A control analysis without a rocker was also performed. Ten designs of three general types were tested (Table I).

Gait analysis was performed using a Vicon motion analysis system (Oxford Metrics, Oxford, UK) and a Kistler eight-channel force plate (Kistler Instruments AG, Winterthur, Switzerland) under the control of a PDP 11 microcomputer (Digital Equipment Corporation, Massachusetts, USA). The site of the light-reflective markers remained unaltered for each analysis. Criteria of assessment. The force plate allowed calculation of the resultant of all the vertical and shear forces applied to the ground, which must equal the ground reaction force (GRF). If the position of a joint is known, the external turning moment at this joint can be calculated using the formula M = GRF x d, where M is the moment and d is the perpendicular distance of the GRF from the joint (Fig. 1). The knee moments, measured in Newton metres, and the vertical and horizontal forces were calculated.

The moments calculated by the Vicon system are external moments; they may be balanced by internal moments generated by muscular activity. A flexion moment is defined as one which tends to produce flexion at the joint. In this paper, the term 'moment' refers only to external moments, from which, in equilibrium, muscle activity may be inferred.

The end of mid-stance was defined by Sutherland (1984) as the point of reversal of the fore and aft shear forces measured by the force plate. In normal subjects it corresponds to the point of maximum vertical pelvic displacement, or pelvic high point (PHP). The PHP represents the point of maximum potential energy as up...
Table I. Rocker designs tested

<table>
<thead>
<tr>
<th>Rocker</th>
<th>Type</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Boot</td>
<td>3M Corporation, Bracknell, Berkshire</td>
</tr>
<tr>
<td>2</td>
<td>Boot</td>
<td>Plaster Boot Supplies, Exeter, Devon</td>
</tr>
<tr>
<td>3</td>
<td>Cam</td>
<td>Biomet, Bridgend, Mid Glamorgan</td>
</tr>
<tr>
<td>4</td>
<td>Cam</td>
<td>Darby, Kenton, Middlesex</td>
</tr>
<tr>
<td>5</td>
<td>Control</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>Stump (Bohler Iron)</td>
<td>Remploy, Hillington, Glasgow</td>
</tr>
<tr>
<td>7</td>
<td>Stump</td>
<td>Biomet, Bridgend, Mid Glamorgan</td>
</tr>
<tr>
<td>8</td>
<td>Stump</td>
<td>Scottish Council for Spastics, Edinburgh</td>
</tr>
<tr>
<td>9</td>
<td>Stump (Centric)</td>
<td>Biomet, Bridgend, Mid Glamorgan</td>
</tr>
<tr>
<td>10</td>
<td>Cam (Fulford)</td>
<td>Princess Margaret Rose Hospital, Edinburgh</td>
</tr>
<tr>
<td>11</td>
<td>Cam (Solo)</td>
<td>Johnson &amp; Johnson, Slough, Berkshire</td>
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</tbody>
</table>

![Diagram of GRF and moment](image)

Method of calculation of the external knee moment.

**Fig. 1**

**The Gait Cycle**

Pelvic High Point

Foot Contact

P

Pelvic Lift

Fig. 2

Foot Off

Pelvic Fall

The two phases of single foot contrast, separated by the pelvic high point – PHP (see text).

The second effect of a rocker is to determine the site of the centre of pressure, that is the point of origin of the GRF. Its design determines the progression of this point along the foot during the stance and phase. The centre of pressure progression (COPP) was devised to measure this rocker effect and it was calculated as shown in Figure 3.

At foot contact, the distance of the centre of pressure (COP) from the heel was a; the distance the COP had moved by the time PHP was reached b; COPP was the sum of these two distances (a + b). In normal subjects the COP has reached the metatarsal heads at this point (Grundy et al 1975).

Temporospatial data comprising walking speed, stride length and right and left step lengths were also recorded.

**RESULTS**

**Temporospatial variables.** There were no significant differences between any of the temporospatial variables. The mean walking speed was 1.51 m/s (SD 0.2). The mean cadence was 73 steps per minute (SD 7.4). The mean stride length was 1.24 m (SD 0.07). The mean right
step length was 0.67 m (SD 0.03) and the left step length was 0.57 m (SD 0.05). The mean double support time was 0.27 seconds (SD 0.02). This represents 21% of the gait cycle.

The only difference in the timing of the gait cycle was in the length of time taken to reach the pelvic high point in single stance. Pelvic lift accounted for a mean 57% of the single stance phase but there was wide variation (43% to 66%).

Contact. This resembles the pattern seen in normal barefoot walking, when the COP is at the level of the metatarsal heads from PHP to the end of single stance. **Tibial progression.** Only three rockers (3, 6 and 11) allowed tibial progression at a TFAV greater than 25° per second. Rocker 2 and the control had a negative TFAV, meaning that the tibia actually moved backwards. At pelvic high point the mean TFA was 75.4° (SD 2.7) which is similar to that seen in normal gait.

<table>
<thead>
<tr>
<th>Rocker</th>
<th>Minimum TFAV* (degrees/sec)</th>
<th>COPP* at PHP* (cm to heel)</th>
<th>Knee moment† (N/m)</th>
<th>Time to PHP (% of stance phase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+12</td>
<td>23.9</td>
<td>+0.5</td>
<td>63</td>
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<tr>
<td>2</td>
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<td>15.7</td>
<td>+2.5</td>
<td>65</td>
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<td>7</td>
<td>+10</td>
<td>10.9</td>
<td>−7.3</td>
<td>54</td>
</tr>
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<td>9</td>
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<td>12.9</td>
<td>−8.3</td>
<td>58</td>
</tr>
<tr>
<td>11</td>
<td>+30</td>
<td>16.2</td>
<td>−9.9</td>
<td>59</td>
</tr>
</tbody>
</table>

*TFAV, tibial floor angular velocity; COPP, centre of pressure progression; PHP, pelvic high point† + indicates a knee extension moment

Centre of pressure progression. The distance of the metatarsal heads from the heel in our subject was 17.5 cm.

Three distinct patterns were seen (Table II):

Early progression. The centre of pressure moved rapidly and reached the most forward part of the foot/rocker complex early in single stance. Two rockers showed this pattern (rockers 1 and 2).

Delayed progression. Five rockers, all the stump types and one cam rocker, showed delayed progression of the COP. Rockers 7 and 10 prevented any progression; in these the COP was fixed and its site was determined by the point of application of the rocker to the cast. Rockers 6, 8 and 9 prevented COPP until late in the single stance phase when there was rapid forward movement of the COP as the load was transferred to the metatarsophalangeal joints.

Normal progression. The remaining three rockers and the control allowed a more normal pattern of COPP. At PHP the centre was within 2.5 cm of the measured distance of the metatarsal heads from the heel. Rockers 3, 4, 11 and the control allowed progression during pelvic lift but further progression was delayed until opposite foot

Vertical forces. In normal subjects there are two peaks in the vertical component of the ground reaction force during single stance. Both are normally greater than body-weight. If the second peak does not exceed body-weight it is due either to muscle weakness or to excessive load and the gait effectively collapses (Meadows 1984). In two cases (rockers 7, 8 and 9) the second peak of vertical force did not reach body-weight. Knee moment. At pelvic high point in normal gait the knee moment approximates to zero. In this study only the cam type, rocker 3, achieved a near zero knee moment. The four stump rockers caused large knee flexion moments throughout single stance. The boot type rockers (1, 2 and 5) produced knee extension moments early in single stance which persisted until opposite foot contact. Of the cam type rockers, number 4 produced an early knee extension moment and numbers 10 and 11 large and persistent knee flexion moments. The effect of the cam was to lessen the magnitude of the moments compared to the other two types.

COPP and knee moment. The knee moment measured at pelvic high point correlated directly with the distance of
the COP from the heel ($r = 0.85, p < 0.001$). In those rockers where there was a change from a flexion to an extension moment (1 to 5), there was a direct correlation between the rate of change of the knee moment and the rate of progression of the COP ($r = 0.84, p < 0.05$). A rapid forward progression of the COP was associated with a rapid change of knee moment from flexion to extension.

**Tibial progression and knee moment.** In those rockers which induced extension moments at the knee during pelvic lift (1, 2, 4, 5), there was either arrest of tibial progression or, in two cases, the tibia moved backwards. The point of tibial arrest (minimum TFAV) coincided with the point at which the knee moment changed from flexor to extensor. If the knee moment at pelvic high point was near zero (rocker 3) tibial progression was not delayed. There was a significant negative correlation between the rate of change of knee moment and the rate of tibial progression ($r = -0.91, p < 0.05$).

In those cases with a knee extension moment there was delay in reaching pelvic high point; in these, pelvic lift took up a mean 64% of single stance (range 61% to 66%). If there was a knee flexion moment the mean time to pelvic high point was 51% of the single stance phase (range 43% to 59%). This indicates a significant delay if a knee extension moment is present ($p < 0.05$, rank sum test).

Of the six rockers with which large flexion moments developed, tibial progression was normal in three (6, 10 and 11) and delayed in three (7, 8 and 9). In these, tibial arrest occurred at or after pelvic high point in contrast to the cases associated with a knee extension moment. In the latter all tibial arrests occurred during pelvic lift, at the time that the knee moment became extensor.

We found no correlation between the rate of change of the COP and the degree of tibial arrest ($r = 0.81$).

**TFAV and vertical force.** In three cases the gait collapsed as the second peak of vertical force failed to reach body-weight (rockers 7, 8 and 9). There were large knee flexion moments and arrest of tibial progression in all three. Neither large knee flexion moment alone nor an arrest of tibial progression by itself produced a collapsing gait.

**DISCUSSION**

An ideal rocker should allow tibial progression over the stationary foot by producing heel lift in the absence of ankle dorsiflexion. It should also control the origin of the GRF to minimise moments at the knee and allow maximum biomechanical efficiency. Our method of assessing rocker function, taking the TFAV together with the knee moment and COPP, provides a useful measure of biomechanical efficiency.

This study has shown that commercially available rockers have varied effects upon the forces imposed on the leg, effects which are not apparent from consideration of temporospatial variables usually measured in gait analysis. Indeed, if these variables are considered in isolation there would appear to be no need either to consider rocker design or to provide a rocker at all. This underlines the need for kinetic gait analysis, since a subject can walk with a nearly normal gait despite serious biomechanical inefficiency which imposes abnormally high demands on the muscles and ligaments and may lead to fatigue.

Two deleterious biomechanical effects of inappropriate rockers have been demonstrated. A rocker which allows rapid progression of the COP imposes a knee extension moment and tibial arrest, and this produces delay in achievement of the PHP. A rocker which prevents COPP causes a large knee flexion moment requiring excessive quadriceps activity, and may result in a collapsing gait.

It is apparent that there must be a compromise. Of the commercially available rockers the biomechanical ideal was most closely approached by rockers 3 and 11. Rocker 3 imposed a small extension moment and had a small rate of change from flexion to extension. Rocker 11 caused a significant knee flexion moment and therefore required some extra quadriceps activity to compensate.

**Conclusion.** Temporospatial variables are inadequate criteria for assessing the efficiency of rockers. Most of the commercially available rockers tested had a deleterious effect on the biomechanics of walking in a cast and only two permitted a reasonably efficient walking pattern.

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**REFERENCES**


