Static Rear Stability of Conventional and Lightweight Variable-Axle-Position Wheelchairs

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Wheelchair users with high or posteriorly placed centers of mass often complain of rear tipping on inclines or when accelerating. In this study we compared the rear stability of occupied conventional and lightweight wheelchairs and determined the effect of various rear axle positions. Ten normal subjects were studied in both a conventional (22.6kg) and a lightweight (12.3kg) wheelchair. Twenty-one experienced wheelchair users were also studied in their own wheelchairs. Stability points were determined with brakes unlocked on a tilt platform. Inter- and intraobserver test-retest reliabilities were 0.97 and 0.974, respectively. For the normal subjects the mean (±1SD) stability point in the conventional chair was 28.6 (± 2.7)°. In the lightweight chair their mean stability points ranged from 21.7 (± 2.6)° to 9.4 (± 2.9)°, depending upon axle position. The mean difference between the conventional chair and the lightweight chair in its most stable position was 6.9 (± 1.7)° (t=13.04, p<0.0001) and in its least stable position 19.3 (± 2.4)° (t=24.97, p<0.0001). Experienced wheelchair users in their own lightweight wheelchairs were less stable than users of conventional chairs (t=2.16, p<0.05) or chairs with posteriorly offset axles (t=3.64, p<0.01).

KEY WORDS: Equipment design: Equipment safety: Wheelchairs

People who use wheelchairs are of a wide variety of body types. A sitting center of mass which is higher or more posterior than normal, as in the person with bilateral above-knee (AK) amputations, leads to decreased rear stability. This increases the likelihood of the chair accidentally tipping backward when accelerating forward, climbing slopes, or decelerating when moving backward.

Persons with good upper-body strength and control can prevent rear-tipping accidents by body positioning and by applying counterforces to the hand rims. People with poor trunk stability and inadequate arm strength may find it difficult to compensate for reduced rear stability in a wheelchair, and a more stable chair may be desirable. Methods of improving the rear stability of wheelchairs include the use of a posteriorly positioned rear axle, moving the center of mass forward with a seat insert or sandbags on the front footrests, and the use of antitipping levers.

However, too much rear stability may detract from ease of handling a wheelchair particularly when negotiating obstacles such as curbs, or on soft surfaces where the front casters may sink. The user of such a wheelchair may find it difficult to balance on the rear wheels to descend curbs or steep slopes or to make low radius turns.

Recently, lightweight wheelchairs with adjustable rear-axle positions have become increasingly available and popular. However, our early clinical experiences with these chairs led us to hypothesize that occupied lightweight wheelchairs have substantially less posterior stability than conventional wheelchairs, despite the wide range of axle positions available on the lightweight chair.

METHODS

We studied ten able-bodied subjects—five men and five women—in both a lightweight and a conventional wheelchair. The mean (±1SD) age of the subjects was 33.7 (± 7.8) years; mean height was 166.8 (± 5.8)cm, and mean weight was 65.5 (± 7.19)kg.

Fig 1—Static testing of rear stability on a testing platform. The platform was constructed of plywood with side safety rails and a 12-cm rear stop to prevent the chair from rolling or sliding off the platform during determination of the stability point. The lightweight wheelchair with the axle in the lower anterior position is shown. Note the spotter for safety.

The conventional wheelchair was a collapsible model weighing 22.6kg, equipped with swinging detachable footrests, removable desk arms, and 20-cm solid casters. The rear-wheel diameter on both chairs was 60cm. The lightweight wheelchair was a titanium, rigid-frame sports model weighing 12.3kg. It had a one-piece footrest, 10-cm urethane front casters, and no armrests. The rear axle position on this chair was adjustable by a 16-hole grid plate which allowed a total of 5cm in vertical adjustment and 5cm in anteroposterior adjustment. We tested the lightweight chair with the axle in four different positions corresponding to the four corners of the grid plate.

In addition, we studied 21 experienced wheelchair users in
Fig 2—The mean (±1SD) rear stability points of ten normal subjects in the conventional wheelchair (CWC) and in the lightweight wheelchair with the axle in the low posterior position (LW-LP), high posterior (LW-HP), low anterior (LW-LA) and high anterior (LW-HA) positions. The tendency of the lightweight chair to "recline" with the axle in the high position is shown.

their own wheelchairs. Thirteen of these subjects had spinal cord disorders (four quadriplegia, nine paraplegia) and eight were amputees (five bilateral AK, two mixed above- and below-knee and one BK level). Six of the experienced wheelchair users used a conventional-weight wheelchair with a posteriorly offset rear axle. Nine used lightweight wheelchairs similar or identical to our test chair, and the remainder used a variety of conventional wheelchairs.

Each subject sat in the wheelchair on the testing platform, hands in lap and wheelchair brakes unlocked (fig 1). The pitch of the platform was slowly increased, using a locking block and tackle. The stability point, the platform angle at which both front casters lifted off the platform, was measured to the nearest 0.5° using a pendular clinometer. The inter- and intraobserver test-retest measurement reliabilities were assessed with all ten normal subjects in the same chair.

Matched pairs t-tests were used to compare the stability points of the normal subjects in the different chairs and axle positions. Two sample t-tests were used to make comparisons among the stability points of the experienced wheelchair users in chairs with posteriorly offset rear axles, conventional wheelchairs, and lightweight wheelchairs.

**RESULTS**

The table displays the comparative data among test settings for the normal subjects. Figure 2 illustrates their stability points.

<table>
<thead>
<tr>
<th>Rear Stability Points in Conventional and Lightweight Wheelchairs Occupied by Normal Subjects (n = 10)</th>
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<tr>
<td><strong>Wheelchair</strong></td>
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<tr>
<td>Conventional (CWC)</td>
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<td>Lightweight, axle low posterior (LW-LP)</td>
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<td>Lightweight, axle high posterior (LW-HP)</td>
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<td>Lightweight, axle low anterior (LW-LA)</td>
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<td>Lightweight, axle high anterior (LW-HA)</td>
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*Mean difference from matched pairs t-tests; all were significant at the \( p<0.0001 \) except as noted. **\( p<0.01 \).

DISCUSSION

Determining the stability points with this method was rapid, reliable, easily performed, safe and well tolerated by test subjects.

Our results on both normal subjects and experienced wheelchair users corroborate our hypothesis that occupied lightweight wheelchairs have substantially less rear stability than

Fig 3—The mean (±1SD) rear stability points of 21 experienced wheelchair users in conventional wheelchairs with posteriorly offset axles (POA), conventional wheelchairs (CWC) and lightweight wheelchairs (LWC). The number of subjects in each group appears in parentheses.

The occupied lightweight wheelchair demonstrated significantly less rear stability at all axle positions than the conventional chair. Among the axle positions tested with the lightweight chair, the stability was the greatest with the axle in the low posterior position, decreasing incrementally through the high posterior, low anterior, and high anterior positions. Each increment was statistically significant.

In the group of experienced wheelchair users (fig 3), the subjects in lightweight chairs showed significantly less rear stability than those using conventional chairs with \( t=3.64, p<0.01 \) or without \( t=2.16, p<0.05 \) posteriorly offset rear axles. There was no statistically significant difference between subjects using conventional wheelchairs with and without posteriorly offset rear axles.

The inter- and intraobserver test-retest measurement reliabilities were 0.97 and 0.974, respectively.
conventional wheelchairs, although the multiple axle positions of the lightweight chair did provide a wide range of stability points. The results with experienced wheelchair users did not lend themselves to a more detailed analysis, due to the variety of body morphologies and wheelchairs found.

Raising the center of mass by elevating the seat height (the low axle positions) produced greater rear stability than with the seat in the lower positions. We expected the reverse. Since the front casters were not adjustable in height, the chair "reclined" when the seat was lowered and less rear angulation was required to initiate tipping. Further development of lightweight wheelchairs should include both adjustable-height front casters and a wider range of rear-axle settings.

The use of living subjects is a departure from previously published investigations. Other groups found an earlier-generation lightweight wheelchair to have less rear stability than a conventional chair, although these groups used inert loads rather than subjects. Most other static wheelchair stability tests have also used dummies or test loads.

In our study the rear stability was tested with the wheelchair brakes unlocked. The Veterans Administration has recommended that the brakes be locked during testing. When the brakes are locked the axis of rotation around which tipping takes place is the contact point of the rear wheels with the ground, while when the wheels are unlocked the axis is the rear axle of the chair. Testing with the wheels unlocked would seem to be a more valid measure of rear stability since most rear tipping accidents occur with the wheels unlocked and the chair in motion.

Limitations of the current study include the small number of experienced wheelchair users used to validate our findings on normal subjects, the assumption that measures of static rear stability will provide insight into the problems of dynamic stability, and the assumption that our results can be generalized to other lightweight or conventional wheelchairs.

Standards for optimal wheelchair stability have not been well defined. The process of determining the amount of rear stability that will provide each wheelchair user with the best balance between safety and performance continues to be a matter of trial and error which depends largely on the person using the chair and the style of wheelchair use.


- Application of a vibrator of 80 Hz and 2.5 mm amplitude to the lower surface of the glans penis caused ejaculation in less than 20 minutes (usually less than 3 minutes) in 48 of 81 men with spinal cord injuries (mostly complete) of more than 6 months duration. It failed in all the 19 of the 81 who lacked reflex hip flexion on scratching the soles of the feet, and in 14 others. It failed in 11 of 12 men with injuries of less than 6 months' duration. From 21 of 34 men for whom the vibrator failed, semen could be obtained by electroejaculation, which is just as successful within 6 months of injury as subsequently and may succeed even if reflex hip flexion is absent. Eleven pregnancies where the father had a complete or nearly complete spinal cord lesion are reported. Nine healthy children have been born.

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References

Suppliers
a. Theradyne Marquis. Therapeutic Corp., 21730 Hanover Ave., Lakeville, MN 55044
b. Quadra-the-Rigid. Quadra Wheelchair, Inc., 31125 Via Colinas, Westlake Village, CA 91362

ABSTRACTS of selected literature


- Of 100 patients consecutively admitted to a rehabilitation hospital, 25 were cognitively impaired. On two brief tests of intellectual function, they scored below the criteria selected by the originators of those tests for clinically significant mental impairment. Nineteen of the 25 had vascular disease of the heart, brain, or peripheral vessels; two had cardiac valvular disease; three had head trauma; and one was mentally retarded. Mental impairment appears to be relatively common among the hospitalized elderly who do not carry the primary diagnosis of "dementia" or "organic brain syndrome." It appears to be particularly common among those with cardiovascular disease, even without frank stroke. Brief mental status examinations should be part of the routine evaluation of such patients.