Fatigue Testing of Selected Suspension Manual Wheelchairs Using ANSI/RESNA Standards

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ABSTRACT. Kwarciak AM, Cooper RA, Ammer WA, Fitzgerald SG, Boninger ML, Cooper R. Fatigue testing of selected suspension manual wheelchairs using ANSI/RESNA standards. Arch Phys Med Rehabil 2005;86:123-9.

Objectives: To evaluate the durability and value of 3 common suspension manual wheelchairs and to compare the results with those of previously tested lightweight and ultra-lightweight folding-frame wheelchairs.

Design: Standardized fatigue testing and cost analysis of 3 suspension manual wheelchairs from 3 different manufacturers.

Setting: A rehabilitation engineering center.

Specimens: Nine suspension manual wheelchairs.

Interventions: Wheelchairs were fitted with a standardized wheelchair test dummy and tested on a series of fatigue tests, consistent with those developed by the International Organization for Standardization.

Main Outcome Measures: Fatigue life (measured as the number of equivalent cycles completed) and value (equivalent cycles divided by cost) were compared among all wheelchairs.

Results: Analysis of variance revealed significant differences ($P \leq .05$) in the number of equivalent cycles among the suspension wheelchairs tested. When compared with previously tested ultra-lightweight and lightweight wheelchairs, the suspension wheelchairs failed to show significant improvements; however, significant improvements were found between individual suspension and lightweight wheelchairs.

Conclusions: We found little evidence to suggest that suspension manual wheelchairs provide advantages in terms of durability or value over standard lightweight and ultra-lightweight folding-frame wheelchairs.

Key Words: Durable medical equipment; Materials testing; Rehabilitation; Wheelchairs.

WHEELCHAIR USERS ARE subjected to a variety of whole-body vibrations that are suspected to cause rider discomfort and a number of harmful physiologic effects.[1] Further, studies on vibration exposure have shown that repeated whole-body vibrations compromise the ability of the spine and back muscles to absorb and distribute suddenly applied loads.[2,3] For wheelchair users, these responses can cause pain and increase their vulnerability to secondary spinal injuries. The associated risk of developing such an injury may be exacerbated through daily ambulation. VanSickle et al[4] reported that wheelchair propulsion produces vibration loads that exceed the International Organization for Standardization (ISO) 2631-1 standards at the seat of the wheelchair and at the head of the user. The potential danger from extensive exposure to these and other common loads has motivated the development of better-adapted wheelchairs. In efforts to prevent secondary injuries, manufacturers of manual wheelchairs have integrated rear suspension into their designs. By positioning suspension elements between the axle and the seat, they have intended to reduce the transmission of vibrations to the user.

Several approaches to wheelchair suspension have been introduced, each offering a different type and configuration of the suspension element. So far, 3 types of suspension elements are most common: elastomers, springs, and spring and damper units. Elastomers are natural rubber or rubber-like materials that exhibit linear viscoelastic behavior and provide internal damping, which increases with the frequency of vibration.[5] Metal springs ideally exhibit linear load-deflection curves, as governed by Hooke's Law, and provide effective shock and vibration control; however, they transmit high-frequency vibrations and offer little damping.[5] The spring and damper unit is a combination device capable of reducing shock vibrations and their resulting oscillations.

Of equal importance to the type of suspension element is its configuration on the wheelchair. A particular configuration can enable the suspension element to adequately suppress vibrations; however, depending on the orientation of the wheelchair, it can also inhibit the effectiveness of the suspension element. A previous study of 3 different suspension manual wheelchairs suggested that the positioning of the suspension elements rendered the wheelchairs unable to reduce the magnitude of vibrations transmitted to users during curb descents.[6] In terms of vibration reduction, the wheelchairs failed to show significant improvement over standard folding-frame wheelchairs. Another study[7] of manual wheelchair suspension systems reported that although wheelchairs with rear suspension systems provided some vibration reduction, they tended to transmit peak acceleration in the natural frequency range of humans (4–12Hz) and were not superior to traditional designs.

To assess the structural integrity of wheelchairs, the American National Standards Institute (ANSI) in cooperation with the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) has developed a set of testing standards, consistent with those created by the ISO.[8] Section 8 of these standards includes 2 fatigue tests: the double-drum test and the curb-drop test. These 2 tests, when performed in

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succession, simulate 3 to 5 years of use by an active individual. Previous studies[9-11] have used these fatigue tests to evaluate the durability of standard manual wheelchairs. Currently, the fatigue life of the common suspension manual wheelchair is unknown. Despite this lack of data, they are regularly provided for active individuals who place high structural demands on their wheelchairs.

The purpose of this study was to use ANSI/RESNA fatigue tests to determine the durability and value of 3 common suspension manual wheelchairs and to compare the results with those previously obtained from lightweight and ultra-lightweight wheelchairs. It was hypothesized that (1) the total number of equivalent cycles for each of the 3 suspension wheelchairs would not differ significantly, (2) the inclusion of suspension elements would significantly increase the total number of equivalent cycles over both lightweight and ultra-lightweight wheelchairs, and (3) the equivalent cycles per dollar for the suspension wheelchairs would be significantly higher than that for both lightweight and ultra-lightweight wheelchairs.

METHODS

A total of 9 suspension manual wheelchairs, 3 from each manufacturer (fig 1), were used in this study. The cost of each wheelchair was $2475 (Invacare A-6S[a]), $3087 (Permobil Colours Boing[b]), and $2325 (Sunrise Medical Quickie XTR[c]). Each wheelchair represents the base model that was purchased anonymously from the manufacturers. Before testing, each wheelchair was measured and adjusted (where applicable) to meet similar critical dimensions (table 1) and fitted with factory-issued rear wheels and casters. All rear tires were inflated to their rated pressure and verified with a calibrated gauge. For the following tests, a 100-kg (220lb) ANSI/RESNA wheelchair test dummy was secured in each wheelchair.[8]

The first test performed in the series was the double-drum test (DDT). The DDT consists of 2 metal cylindrical drums (diameter, 200mm), each fitted with two 12-mm slats positioned 180° apart. The slats are designed to simulate vibrations experienced by traversing such obstacles as door thresholds and sidewalk cracks. During testing, the drums are rotated at a constant surface velocity of 1m/s. The front drum is rotated 5% to 7% faster than the rear drum to avoid harmonic vibration patterns. A swing arm is attached to the wheelchair to keep it balanced over the drums. One full revolution of the rear roller is defined as a single cycle on the DDT. The second test, the curb-drop test (CDT), is designed to simulate forces sustained during curb descents. The CDT lifts the wheelchair 5cm and then allows it to drop onto a concrete floor. The height is calibrated and checked throughout the course of testing.

Each wheelchair was first tested on the DDT for 200,000 cycles. On completion, each wheelchair was inspected for incidences of catastrophic failure, which is defined as any permanent damage or deformation that impairs the operability or safety of the wheelchair. If cleared of such failures, the wheelchair was transferred to the CDT and run for 6666 drops. Successful completion of 1 full set of the DDT and CDT is required to meet ISO standards. For this study, the sequence of tests was repeated until failure. All wheelchairs were inspected at least every 10,000 double-drum cycles, and 300 curb drops and testing logs were kept to record progress and note any problems. The double-drum and curb-drop cycles chosen for these tests are those described in ISO 7176-8.[12]

As a means of comparing performance and value, the equivalent number of cycles completed by each model was calculated by using the following equation:

$$\text{Equivalent cycles} = (\text{DDT cycles}) + 30 \times (\text{CDT drops})$$

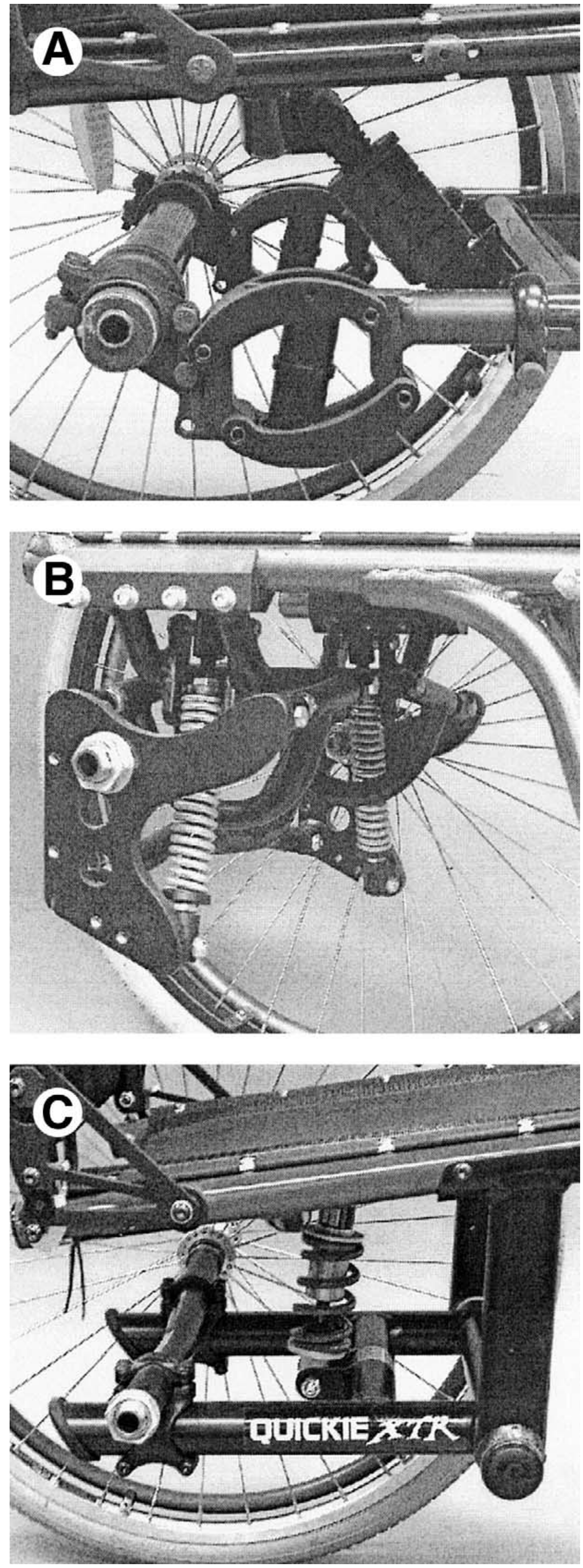

Fig 1. Three suspension manual wheelchairs used in this study: (A) Invacare A-6S, (B) Permobil Colours Boing, and (C) Sunrise Medical Quickie XTR.