# Characterization of Pediatric Wheelchair Kinematics and WTORS Loading During Rear Impact

Susan I. Fuhrman, BSME[1], Patricia Karg MSBME[1], Gina Bertocci, PhD[2]
[1] University of Pittsburgh, Pittsburgh, PA [2] University of Louisville, Louisville, KY

ABSTRACT
Historically, wheelchair transportation safety has researched frontal impact. This study is a first, examining pediatric wheelchair response and wheelchair tiedown and occupant restraint system (WTORS) loading under rear impact. Two identical manual pediatric wheelchairs that comply with ANSI/RESNA WC19, *Wheelchairs used as seats in motor vehicles,* were sled tested using a proposed 26 km/h, 10 g rear impact test pulse, Hybrid III 6-year old anthropomorphic test device (ATD), and surrogate WTORS. WTORS rear impact loads differed from frontal impact loads, with peak frontal tiedown loads (3473-4000 N) greatly exceeding peak rear tiedown loads (346-1117 N). This outcome has implications for tiedown design and highlights the need for all four tiedowns to have an equally robust design.

KEYWORDS: wheelchair transportation safety; rear impact; tiedown; kinematics; occupant restraint

## INTRODUCTION

Many wheelchair users are unable to transfer to a motor vehicle seat and instead remain seated in their wheelchairs during transportation. Our goal is to provide information needed to make transportation in a motor vehicle as safe for those who travel in wheelchairs as it is for those who travel in original manufacturer installed automobile seats [1]. To date, most wheelchair transportation safety research has focused on frontal impact events. Few efforts have been dedicated to describing rear impact effects on the wheelchair or wheelchair-seated occupant. The purpose of this investigational baseline study was to characterize the kinematics of the wheelchair and describe wheelchair tiedown and occupant restraint system (WTORS) loading during rear impact for a pediatric wheelchair and occupant.

## METHODS

Two identical Quickie Zippie pediatric manual wheelchairs (17.9 kg) that comply with ANSI/RESNA WC19 [2] were sled tested with the Hybrid III 6-year old ATD using a proposed rear impact crash pulse (25.8 km/h, 10g). The crash pulse is proposed for use in developing a draft voluntary industry standard evaluating wheelchair performance in rear impact. Wheelchairs were equipped with a planar seat and seat back. The test used a four-point surrogate WTORS [2]. While the tests were instrumented to measure loads and accelerations of the ATD, this study focused on WTORS loads and wheelchair kinematics. The occupant restraints and the rear wheelchair tiedown loads were measured using belt load cells; the front wheelchair tiedown loads were measured using the rod end load cells. High contrast targets were placed on the wheelchair at the: center of gravity, rear axle, caster hub, seat pan (2), and seat back (Figure 2). High speed video cameras (1000 frames/sec) were used to record the test. A strobe flash was used to synchronize the video data with instrumentation output. Both tests had the identical experimental set up with the exception of the seat back location. In the first test (WC0535) the bottom edge of the seat back was located 25 mm above the seat cushion; in the second test (WC0536) the bottom edge of the seat back was in contact with the seat cushion. Data from the instrumentation were recorded every 0.1 ms and filtered according to SAE J211. Peak WTORS loads were compared against Ha's previously measured loads [3] for the same model wheelchair and ATD using the ANSI/RESNA WC19 frontal impact crash pulse [2]. Kinematic data from test WC0536 were used to describe wheelchair response to the rear impact crash pulse. A program was written in Matlab to acquire the coordinates of nine target locations from the video images [4]. Graphs were generated from the image data for the seat back to seat angle, caster excursion, and seat back excursion.

## RESULTS

In both tests, the sled reached the target accelerations and changes in velocity (delta-V), with sled plateau average levels of -9.6g and -9.8 g, sled deceleration peaks of -11.0g and -11.3 g (Figure 1), and sled delta-V's of 25.4 km/h and 25.3 km/h (15.9 and 15.8 mph).

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Figure 1 goes here: Sled accelerations for rear impact tests

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The Zippie wheelchairs remained structurally intact and the ATD maintained an upright posture in both rear impact tests. The tests produced some unexpected wheelchair kinematics. In both tests the wheelchair rotated rearward and the casters rose off the sled platform at the time that the sled reached its maximum horizontal excursion and reversed direction. The wheelchair continued to rotate until the caster vertical excursion reached its peak and remained in this position for the remainder of the test.

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Figure 2 goes here: Photos of the experimental set up before and after the crash test

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The caster vertical excursion was measured from the initial caster target position. The maximum vertical excursion was 103 mm at 147 ms and the wheelchair casters remained at this height for the remainder of the test (Figures 2 and 3).

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Figure 3 goes here: Caster vertical excursion for rear impact test WC0536

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While the wheelchair was rotated rearward, the ATD pushed rearward, loading the seat back. In test WC0536, the seat back canes flexed rearward sustaining a small amount of plastic deformation as evidenced by the seat back angle's failure to return to 90 degrees (Figure 4). Maximum seat back to seat angle is 99.6 degrees at 94 ms. The seat back hardware did not fail and remained attached to the canes. The hardware, however, did permit the seat back to slide upward before returning to its original position (Figure 5). Maximum seat back upward excursion along the seat back canes was 23.0 mm at 133 ms.

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Figure 4 goes here: Seat back to seat angle for rear impact test WC0536

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Figure 5 goes here: Seat back excursion upward along the seat back canes for rear impact test WC0536

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Figure 6 shows the peak wheelchair tiedown and occupant restraint loads for the two rear impact tests from this study and three frontal impact tests conducted by Ha [3]. The graph highlights the large peak front tiedown loads (3472 – 4000 N) that occurred during rear impact. These loads were somewhat higher than the peak rear tiedown loads (2830-3890 N) measured by Ha during her frontal impact study. Front tiedown loads were not measured during Ha's frontal impact tests, yet it was expected that those loads would have been small. Rear tiedown loads (345-1117 N) were substantially lower than the front tiedown loads measured during our rear impact tests. In contrast to the large shoulder belt loads (3411-3884 N) measured during frontal impact, during rear impact the shoulder belt carried almost no load (69–79 N) and were slack during most of the test. Since during rear impact the lap belt is loaded only during rebound, the lap belt loads were much lower during rear impact (1125-1267 N) than during frontal impact (2134-2766 N).

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Figure 6 goes here: A comparison of wheelchair tiedown and occupant restraint loads for rear.

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DISCUSSION

The rear impact test pulse used for this sled test was chosen based on its correspondence in severity to the ANSI/RESNA WC19 frontal impact standard [2]. Similar to the frontal impact crash pulse (48 km/h, 20g), the rear impact crash pulse (26 km/h, 10 g) represents an impact that would be more severe than 99% of NASS rear impact field crash data. While the rear impact test pulse was less severe than the frontal impact pulse, slightly higher maximum tiedown loads were measured – albeit on opposite tiedowns. The test wheelchair is representative of a pediatric manual wheelchair. It is a noteworthy finding that the wheelchair remained intact and the ATD in an upright posture. This indicated that commercial pediatric manual wheelchairs that comply with WC19 have the potential to meet rear impact test requirements. In addition, the choice of this model wheelchair provided the opportunity to make direct comparison to Ha's frontal impact study.

The rearward rotation of the wheelchair can be attributed to the location of the securement points on the wheelchair for the tiedowns. The front tiedown securement points' low frame location may have contributed to the wheelchair rotation during the test. The wheelchair securement point locations are not adjustable by the consumer; thus, this is a design issue. This exploratory study of tiedown loads during rear impact demonstrates that the tiedown loads levels are comparable, but reversed, in frontal and rear impacts, with front tiedowns carrying the larger load in a rear impact. This is critical since front tiedowns frequently have a less robust design. This would be of particular concern for larger wheelchairs and adult occupants. In addition, the large front tiedown loads found in rear impact reinforce the need to use all four tiedown straps every time the wheelchair is used as a vehicle seat during transportation.

Some of the limitations of this study include inaccuracies when identifying the target locations as the targets became obscured from view. An additional study limitation is that the tiedowns are not tightened to a specified tension for the test.

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Susan I. Fuhrman, Department of Rehabilitation Science and Technology
2310 Jane Street, Suite 1300 / Pittsburgh, PA 15203
(412) 586-6920, (412) 586-6910 (fax), sif3@pitt.edu

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Figure 1: Sled accelerations for rear impact tests
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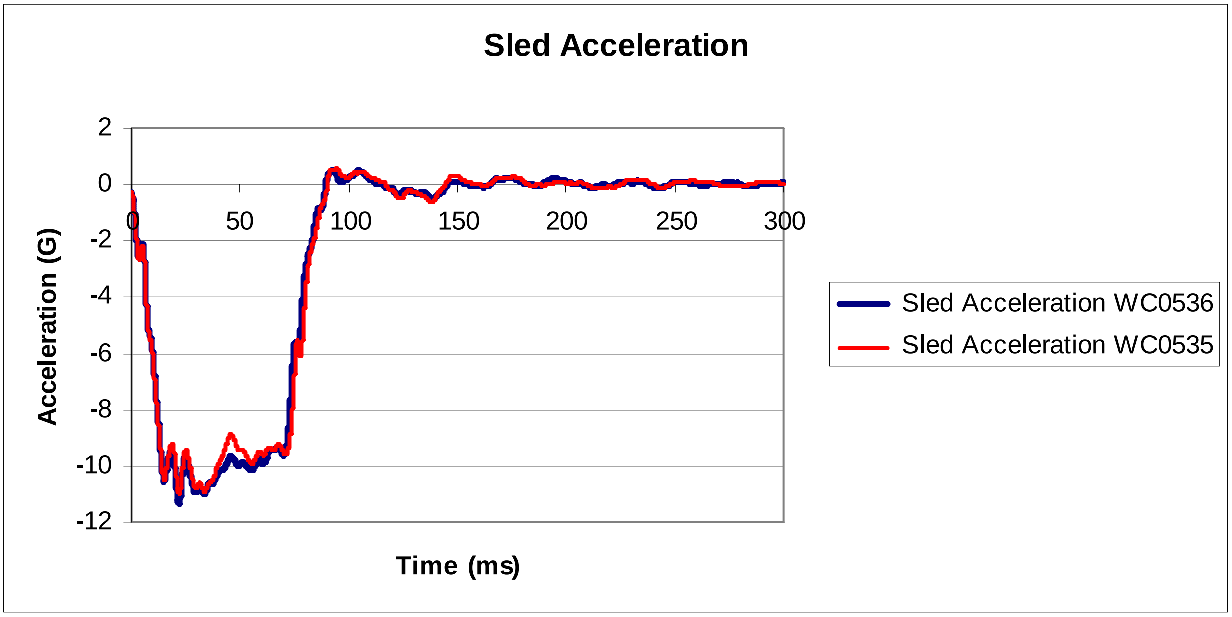


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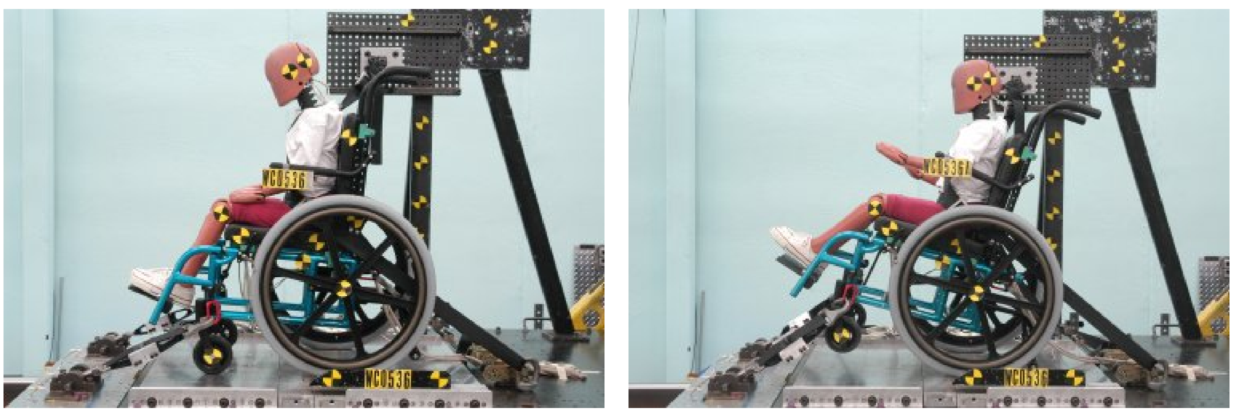

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Figure 3: Caster vertical excursion for rear impact test WC0536
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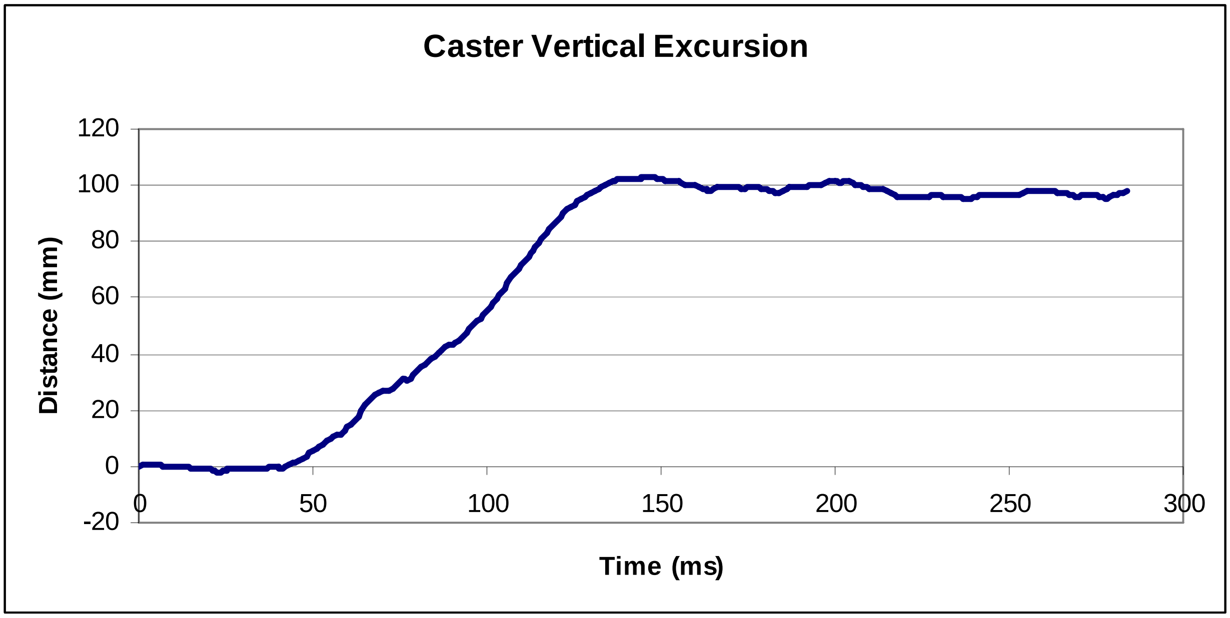


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Figure 4: Seat back to seat angle for rear impact test WC0536
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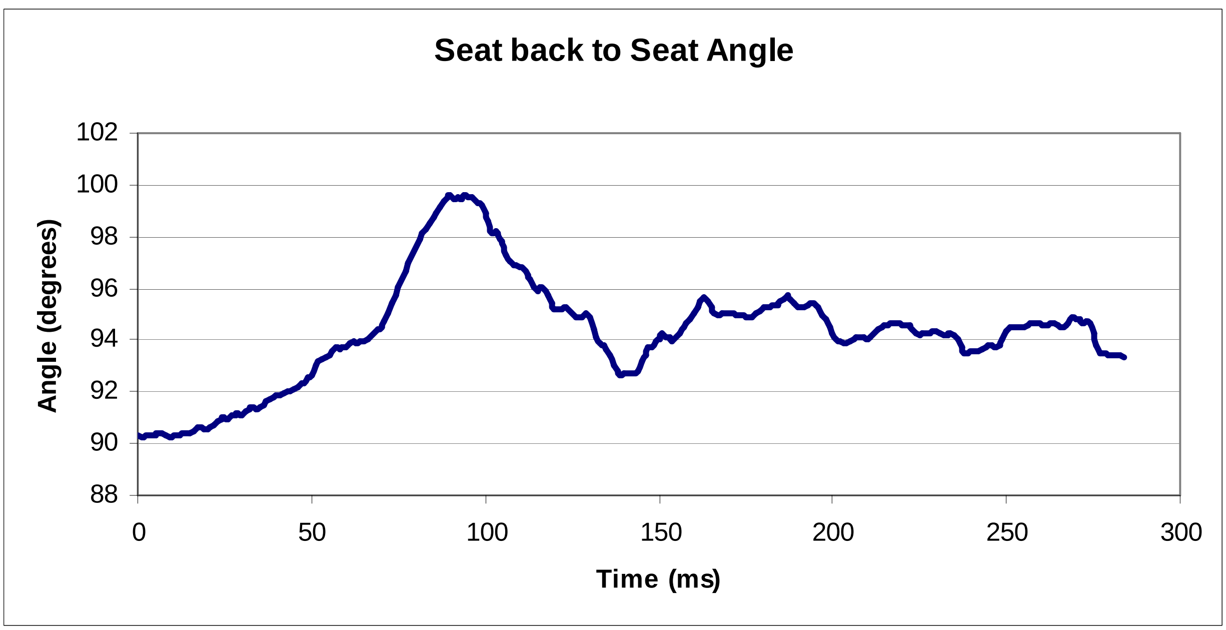


**Figure 4: Seat back to seat angle for rear impact test WC0536**

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Figure 5: Seat back excursion upward along the seat back canes for rear impact test WC0536
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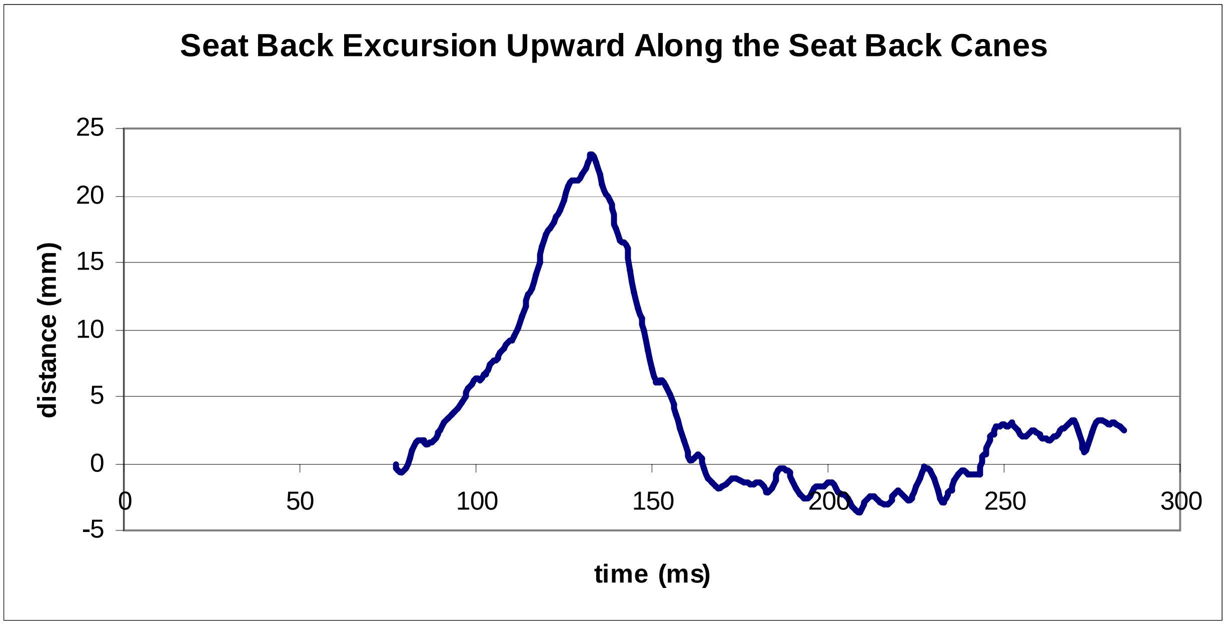


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Figure 6: A comparison of wheelchair tiedown and occupant restraint loads for rear and frontal impact
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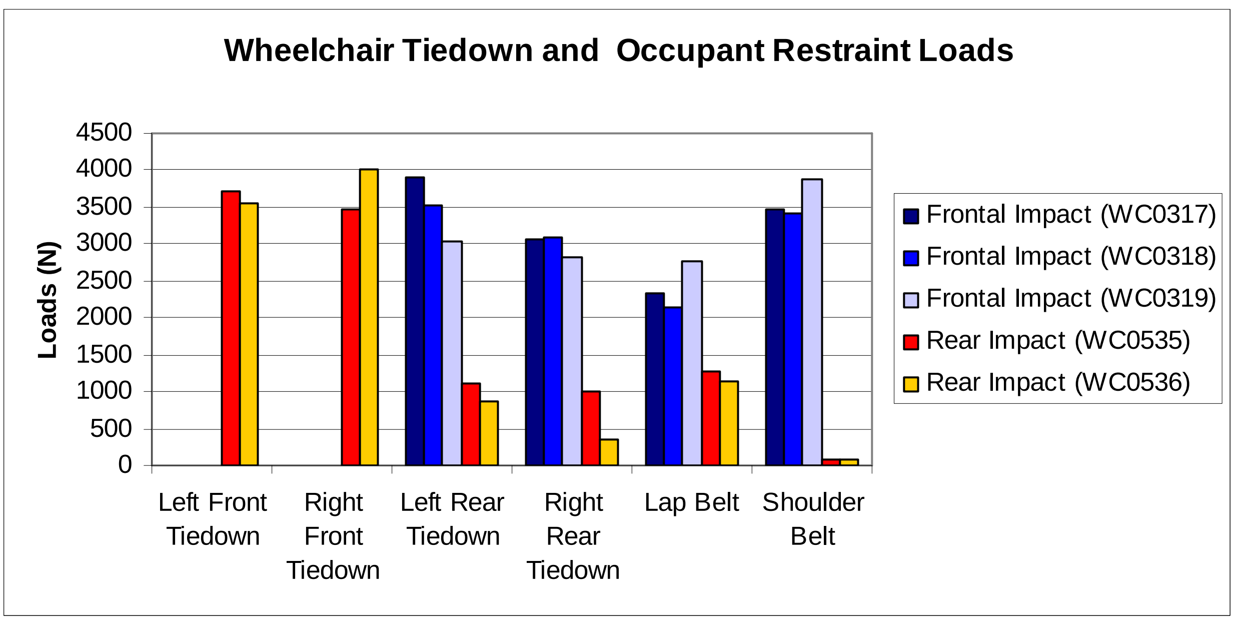


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