# Motorcyclist pelvis interaction with the fuel tank in frontal crashes – a laboratory test method

Tom Whyte[1,2,3], Julie Brown[1,2,3]

[1] Neuroscience Research Australia, Randwick, NSW, 2031, Australia
[2] The George Institute for Global Health, Newtown, NSW, 2042, Australia
[3] Faculty of Medicine, The University of New South Wales, Kensington, NSW, 2052, Australia

## Abstract

Pelvic injury is common among hospitalised motorcyclists. The primary mechanism is contact with the fuel tank. Injury outcome likely relates to the design of the fuel tank and may also be influenced by the posture of the rider. There is a need to understand the interaction between tank design and initial pelvis posture as this varies by motorcycle type. Currently there is no accepted physical test method for studying this. This study aimed to develop a physical test method for replicating pelvis-fuel tank impacts in frontal motorcycle crashes and to investigate changes in initial pelvic posture.

A mini-sled was affixed to the sled table of a deceleration sled. A frame was attached to the mini-sled, to which a surrogate pelvis was attached. The frame allows the surrogate to rotate and translate upward. A rigid fuel tank surrogate was mounted to the main sled table at 3 different angles. The pelvis surrogate was a THOR dummy pelvis and upper legs. New soft tissue, separating the pelvis and upper legs was molded from silicone rubber. Two triaxial accelerometer arrays were mounted to the surrogate to measure peak acceleration and rotational velocity due to fuel-tank impact.

The pelvis surrogate, clothed in standard jeans was tested in an initial upright posture, a forward, sport-bike posture and a reclined, cruiser posture. In each test condition, the sled table was accelerated to 20 km/h and decelerated. The mini-sled and surrogate frame continued at 20 km/h causing impact between the pelvis surrogate and the fuel tank surrogate

This study indicates both tank angle and rider posture likely play a role in pelvic injury risk in fuel tank impacts that result from frontal motorcycle crashes.

## Introduction

Injury to the pelvic region is common among crash involved motorcyclists, occurring to 13% of riders in a large in-depth crash investigation study of 900 accidents [1] and even more common among riders hospitalized after crashing [2]. The more serious of these injuries can have significant long-term health implications such as chronic pain and quality of life impairments [3].

The primary mechanism for crash-related pelvic injuries to motorcyclists is direct contact with the motorcycle fuel tank, occurring in more than 85% of pelvic injury cases [1,2]. This typically occurs when the motorcycle is involved in a frontal impact with another vehicle where the motorcycle abruptly stops and the rider continues forward at the initial travelling speed. The impact between the pelvis of the rider and the motorcycle fuel tank is often clearly evidenced by post-crash damage and markings to the fuel tank. In a previous analysis of hospitalized riders exhibiting this ‘fuel tank syndrome’, injury to the pelvic region was most commonly of moderate or greater severity (AIS 2+) [2]. This type of injury has been shown to relate to impact speed with more severe injuries generally occurring in higher speed crashes [1,2].

Previous work has indicated that pelvic injury risk may also relate to the characteristics of the motorcycle fuel tank. Suggested strategies for reducing injury risk have included that fuel tanks be designed to: minimise the angle of incidence the fuel tank makes with the seat of the motorcycle [1,4–7], distribute the impact over a wider area and longer time [1], promote ejection of the rider [8] and not be wedge shaped [5]. Other researchers have suggested covering the fuel tank with padding or yielding foam [4,5,7]. However, there has been little work confirming whether these suggested strategies would actually mitigate pelvic injury risk.

Rider posture likely also influences pelvic injury mechanism and risk in fuel tank impacts as different rider postures likely alter the initial loading condition. As noted previously by Ouellet & Hurt, different riding postures may also result in different pelvis structures (e.g. pelvic arch vs ischium) contacting the fuel tank [1]. In a collection of hospitalized motorcyclists in Australia, pelvic injury occurred most often among cruiser riders compared to other motorcycle types [9,10], with cruiser type motorcycles shown to position the rider in a more upright, legs forward, relaxed seating position than sports style motorcycles [11]. To date there has been no rigorous examination of the potential impact of different rider postures and/or initial pelvic positions on injury risk and the dynamic interaction between the fuel tank and rider's pelvis.

These current gaps in evidence for how the pelvis interacts with the fuel tank and what fuel tank design strategies might best ameliorate pelvic injury risk need to be addressed. A major barrier to addressing these gaps is the current lack of a physical test method to systematically investigate the effects of rider posture, fuel tank characteristics and potential countermeasures on pelvic injury risk during crash impacts with the fuel tank. The aim of this study was to develop a repeatable physical test method to simulate the interaction between a rider's pelvis and the fuel tank in a frontal crash. A preliminary investigation of the effect of tank angle and rider posture on dynamic interactions between a pelvis surrogate and the fuel tank was undertaken.

## Methods

A test apparatus was designed and constructed to simulate pelvis-fuel tank impacts using a mini-sled mounted on a deceleration crash sled (see Figure 1). A steel frame was attached to the mini-sled (the surrogate frame), to which a pelvis surrogate was attached by a steel bar. The surrogate frame was designed to allow the pelvis surrogate to rotate in the sagittal plane and translate upward from the sled table upon impact with the fuel tank. Another steel frame (the tank frame) was fixed to the main deceleration sled table, onto which a wooden fuel tank surrogate was attached at one of three angles of incidence to the sled table (30°, 37.5°, 45°). A wooden fuel tank surrogate was used for this study to provide a repeatable relatively rigid impact surface whereby the tank surrogate would not be damaged in successive impacts.

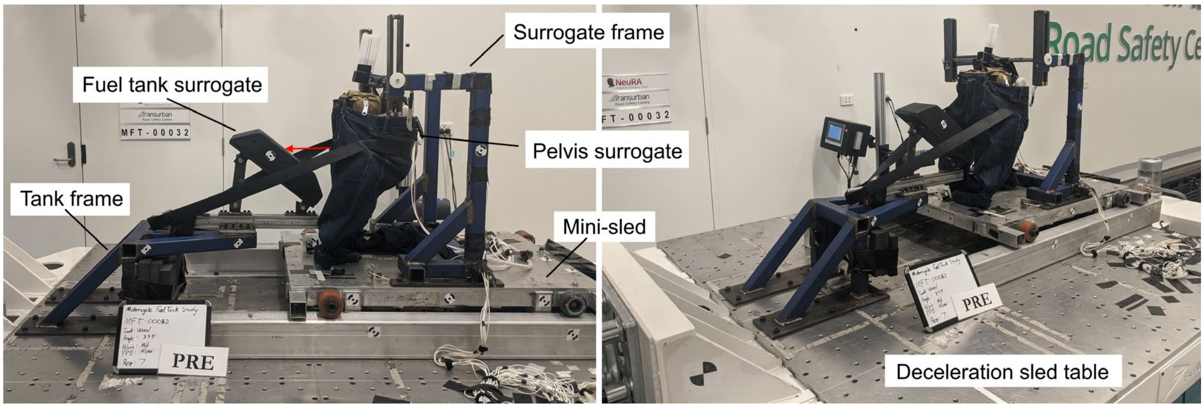

Figure 1 Test apparatus showing mini-sled, pelvis surrogate and surrogate frame, and fuel tank surrogate and tank frame. The red arrow indicates the direction of travel of the pelvis surrogate to impact the fuel tank surrogate.

For the impact tests in this study, the main deceleration sled table was accelerated to an impact speed of 20 km/h and decelerated to a stop. The mini-sled and surrogate frame continued at the impact speed resulting in a 20km/h impact between the pelvis surrogate and the stationary fuel tank surrogate. The mini-sled then impacted energy absorbing foam on the tank frame, stopping the mini-sled.

The pelvis surrogate consistent of the THOR dummy lumbar spine, pelvis and upper leg components with the soft tissue removed. New soft tissue components, separating the pelvis and upper legs were molded from silicon rubber previously used to replicate the impact response of human thigh tissue [12]. The pelvis surrogate was clothed in standard jeans. The initial posture of the pelvis surrogate was varied by changing the anterior-posterior location of the steel bar relative to produce three postures (forward, upright and reclined) intended to represent postures on different motorcycle styles (sports, standard, cruiser).

Two triaxial accelerometer arrays were mounted to the rear of the lumbar spine pelvis surrogate. Data from the accelerometers were used to calculate the peak resultant acceleration of the pelvis surrogate at the lumbar spine and the peak rotational velocity. The pelvis response was analysed from the initial impact with the fuel tank to the time point when the mini-sled contacted the tank frame. High-speed cameras captured a lateral view of each impact at 1000 frames per second.

At least 2 impacts were performed in each test condition. The test matrix is shown in Table 1. The variations in tank angle and rider posture are shown in Figure 2.

Table 1 Test matrix varying fuel tank surrogate angle and pelvis posture.

| Test condition | Number of impacts | Impact speed (km/h) | Tank surrogate angle (°) | Pelvis posture |
|---|---|---|---|---|
| 1 | 2 | 20 | 30 | Forward |
| 2 | 3 | 20 | 30 | Upright |
| 3 | 2 | 20 | 30 | Reclined |
| 4 | 2 | 20 | 37.5 | Forward |
| 5 | 7 | 20 | 37.5 | Upright |
| 6 | 2 | 20 | 37.5 | Reclined |
| 7 | 2 | 20 | 45 | Forward |
| 8 | 3 | 20 | 45 | Upright |
| 9 | 2 | 20 | 45 | Reclined |

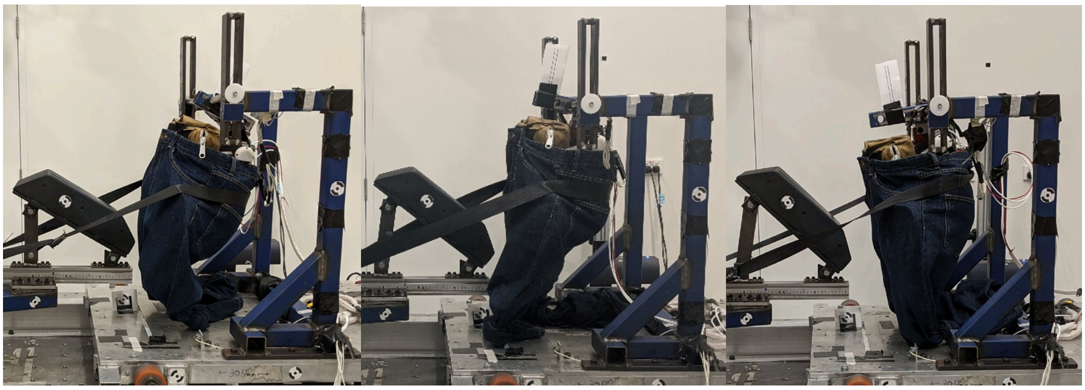

Figure 2 Variations in fuel tank surrogate height (left to right, 30°, 37.5°, 45°) and pelvis surrogate posture (left to right, reclined, upright, forward).

## Results

The impact kinematics of the pelvis surrogate in an initially upright posture against a fuel tank with a tank angle of 37.5° are shown in Figure 3.

The peak pelvis surrogate responses are provided in Table 2. Increasing surrogate fuel tank angle saw an increase in peak pelvis acceleration and rotational velocity, see Figure 4 and 5. The reclined posture generally provided the highest pelvis surrogate responses.

The coefficient of variation in each test condition was less than 9% for peak pelvis acceleration and less than 11% for peak pelvis rotational velocity in all test conditions, see Table 2.

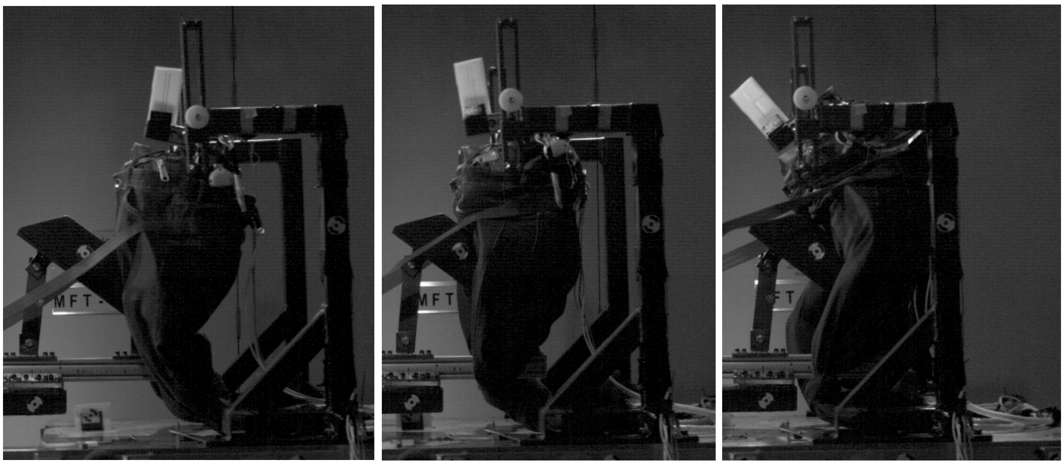

Figure 3 Pelvis surrogate rotating and the lumbar spine translating upward from the sled table as a result of the simulated fuel tank impact.

Table 2 Peak pelvis surrogate responses in each test condition.

| Test condition | Tank surrogate angle (°) | Pelvis posture | Peak pelvis acceleration (g) | | Peak pelvis rotational velocity (rad/s) | |
|---|---|---|---|---|---|---|
| | | | Mean | St. dev. | Mean | St. dev. |
| 1 | 30 | Forward | 53.8 | 4.5 | 1490 | 163 |
| 2 | 30 | Upright | 64.9 | 0.3 | 1522 | 107 |
| 3 | 30 | Reclined | 71.4 | 0.2 | 1667 | 72 |
| 4 | 37.5 | Forward | 61.6 | 3.7 | 1636 | 24 |
| 5 | 37.5 | Upright | 80.5 | 3.3 | 1709 | 50 |
| 6 | 37.5 | Reclined | 99.5 | 6.8 | 1885 | 159 |
| 7 | 45 | Forward | 76.2 | 4.3 | 1825 | 66 |
| 8 | 45 | Upright | 87.7 | 2.4 | 1791 | 112 |
| 9 | 45 | Reclined | 106.2 | 7.6 | 1923 | 186 |

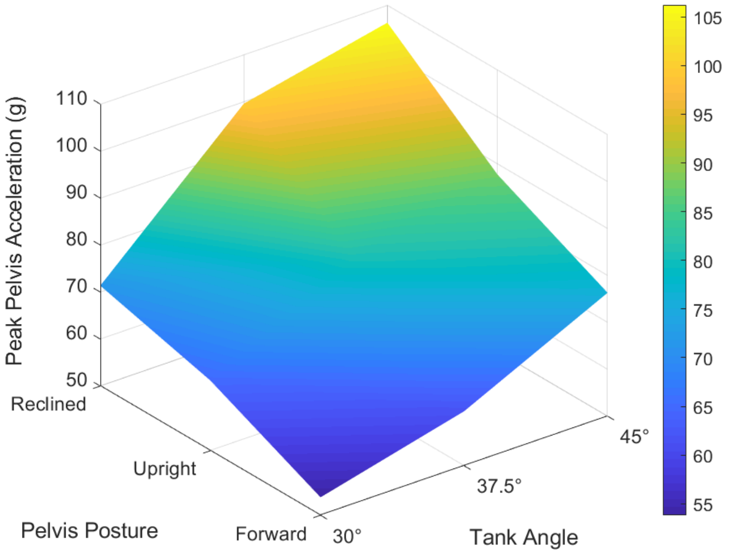

Figure 4 Mean peak pelvis acceleration response for each combination of initial pelvis posture and tank angle.

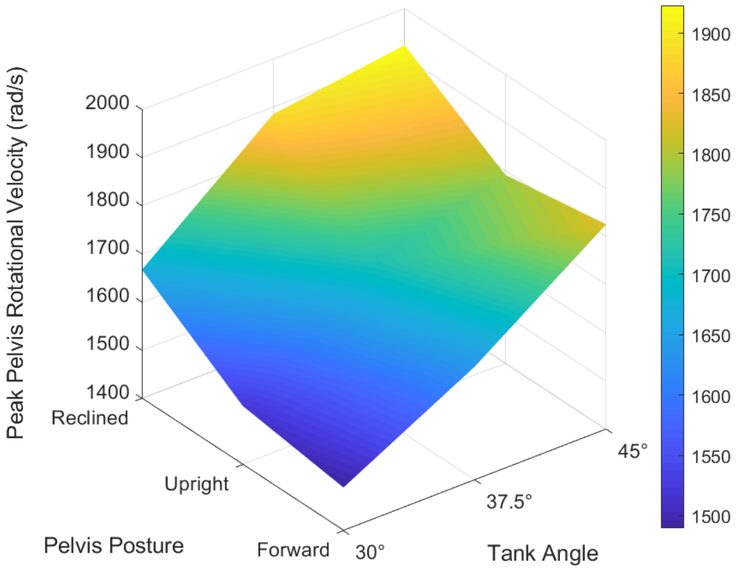

Figure 5 Mean peak pelvis rotational velocity response for each combination of initial pelvis posture and tank angle.

## Discussion

The objective of this study was to design a physical test method for simulating impacts between a motorcyclist's pelvis and the fuel tank in a frontal motorcycle crash. The kinematics of the pelvis surrogate (Figure 3) are consistent with that previously described for full scale motorcycle crash tests where the fuel tank impact initiates forward pitching of the dummy [7,8]. Impact test results indicate that the measured response variables of peak acceleration and rotational velocity exhibited an acceptable coefficient of variation (<11%) in repeated tests under the same conditions. These responses were also sensitive to the varied test conditions suggesting the test method is promising for studying potential countermeasures for pelvis injury risk mitigation such as fuel tank design changes or personal protective clothing for riders.

Changes to fuel tank angle and pelvis posture influenced the pelvis surrogate impact response. Increasing tank angle led to larger peak accelerations and rotational velocities, in agreement with a previous computational study which found larger impact forces at higher tank angles [6] and real crash investigations that found tanks with an abrupt rise contribute to pelvic injury [1]. The reclined posture produced the highest pelvis responses at each tank angle, with peak responses generally reducing as the posture moved from upright to forward. This posture effect may explain why cruiser riders had a high incidence of pelvic injury in a collection of Australian cases despite cruiser style motorcycles generally having lower tank angles than other types of motorcycle [9,10]. The peak pelvis acceleration in a reclined posture at a 30° tank angle potentially representative of a cruiser tank and rider posture was similar to the forward posture and a 45° tank angle that might be present on a sports style motorcycle. However, these observations should be viewed as preliminary and further work is required to confirm real world implications.

There are a number of limitations to this study to keep in mind. To our knowledge there is no dynamic biomechanical impact data to ascertain the response and tolerance of the pelvis in anterior-posterior loading like that would occur in a motorcycle fuel tank impact. There are two implications of this lack of data. Firstly, the rider surrogate consisting of a metallic pelvis and silicone rubber soft tissue may not adequately simulate the pelvis impact response in this type of loading. Secondly, the pelvis surrogate impact response variables that were measured at the lumbar spine (peak acceleration and rotational velocity) may not be the parameters that most closely relate to pelvis injury risk. Nevertheless, the results presented here in combination with previous literature suggest the test method developed demonstrates expected responses and aligns with real world observations.

Further limitations include the fact that the fuel tank surrogate in this study was essentially rigid whereas real fuel tanks are often deformed in real crashes [2]. A rigid tank surrogate was chosen in this study for repeatability, however this would produce a more severe impact than a real fuel tank at the same impact velocity. There is also the possibility that different motorcycle styles incorporate different fuel tank construction which was not accounted for in this study. The physical test method developed will allow future work examining the impact of these variables. The impact with the stationary fuel tank simulated in this study also neglects any pitching of the motorcycle that might occur in a frontal collision Further study of pelvic kinematics in full scale crash tests using human cadavers and volunteers would help determine the importance of incorporating this in future developments of the test method. Finally, the variations in initial pelvis posture were not based on real rider postures. While differences in torso and leg angles have been documented for different motorcycle styles [11], more detailed data is needed to accurately determine the pelvis orientation relative to the fuel tank among motorcyclists with varying anthropometry and motorcycle design.

## Conclusion

The physical test method developed for this study provides a means of systematically investigating the interaction between the pelvis of a motorcyclist and the fuel tank in a frontal crash. The test showed good repeatability and the ability to monitor the pelvis response which was sensitive to changes in test conditions that have been linked to pelvis injury risk in previous studies. In the future, the test method could be used to aid in improving crashworthiness of motorcycle fuel tanks and in the design of protective equipment for riders.

## Acknowledgement

This paper is part of a project that has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement N° 769054, project PIONEERS (Protective Innovations Of New Equipment for Enhanced Rider Safety).

## References

[1] Ouellet J V and Hurt H J 1981 Groin injuries in motorcycle accidents *Association for the Advancement of Automotive Medicine (AAAM)* 24th Annual Proceedings, Association for the Advancement of Automotive Medicine (AAAM) (San Francisco, CA)

[2] Meredith L, Baldock M, Fitzharris M, Duflou J, Dal Nevo R, Griffiths M and Brown J 2016 Motorcycle fuel tanks and pelvic fractures: A motorcycle fuel tank syndrome *Traffic Inj Prev* **17** 644–9

[3] Gerbershagen H J, Dagtekin O, Isenberg J, Martens N, Ozgür E, Krep H, Sabatowski R and Petzke F 2010 Chronic pain and disability after pelvic and acetabular fractures--assessment with the Mainz Pain Staging System *J Trauma* **69** 128–36

[4] Bothwell P W, Knight R E and Peterson H C 1971 *Dynamics of motorcycle impact. Volume I: summary report - results of crash test program and computer simulation. Final report.*

[5] de Peretti F, Cambas P M, Hovorka I, Veneau B and Argenson C 1994 Motorcycle petrol tanks and their role in severe pelvic injuries *Injury* **25** 223–5

[6] Wobrock J L, Mal A, Kraus J and Wu B 2006 Pelvic injury potential and motorcycle gas tanks *Proceedings of the International Research Council on the Biomechanics of Injury conference* vol 34 (International Research Council on Biomechanics of Injury)

[7] Bothwell P W, Knight R E and Peterson H C 1971 *Dynamics of motorcycle impact. Volume II: motorcycle crash test program. Final report.*

[8] Ruter G, Hontschik H and Jessl P 1980 Investigations into the kinematics and loads of motorcycle riders in frontal crashes Proceedings of the International Motorcycle Safety Conference, vol. 2 (Washington, D.C.) pp 599–614

[9] Meredith L, Baldock M, Fitzharris M and Brown J 2014 Pelvic Injury Mechanisms among Motorcyclists *IRCOBI Conference Proceedings* (Berlin, Germany)

[10] Meredith L, Baldock M, Fitzharris M and Brown J 2014 The motorcycle fuel tank and pelvic injury in crashed motorcyclists *Forschungshefte Zweiradsicherheit*

[11] Hale A, Pelowski D and Bhise V 2007 Commonality and Differences between Cruiser, Sport, and Touring Motorcycles: An Ergonomics Study SAE World Congress & Exhibition pp 2007-01–0438

[12] Hrysomallis C 2009 Surrogate thigh model for assessing impact force attenuation of protective pads *Journal of science and medicine in sport* **12** 35–41