C20 Progress in Tribometer Characterization Since the Bucknell University/ASTM Workshop

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After attending this presentation, attendees will learn about the progress that has been accomplished since the 1991 Bucknell/ASTM workshop, including the progress in methodology and instrumentation.

This presentation will impact the forensic science community by demonstrating how the use of an instrumented force plate and real-time position sensors can help to better understand the operating characteristics of a walkway-safety tribometer. This data will allow tribometer comparison with biomechanical parameters to assess biofidelity.

Background: The 1991 ASTM F-13/Bucknell University Tribometer workshop tested a number of then-current tribometers against an instrumented force plate, in order to compare the tribometers. In that workshop, the force plate served as a Gold Standard for measuring friction. If this standard is accepted, then the 'best' tribometer would be the one that measured closest to the friction values measured with the force platform. As was reported after the workshop,[1] different tribometers gave different values for the amount of friction between the test shoe and the test surface. In a follow-up paper[2], it was suggested that the "disagreement" between results of different tribometers was less an issue of instrument accuracy than it was a disagreement on exactly what was being measured, i.e., not only the material properties, but the systemic properties of the measuring system.

In addition to the instrumented force plate, similar to the one used at the Bucknell/ASTM workshop, we have equipped the tribometer's test foot with a three-dimensional position sensor. Together, the force plate and the position sensor allow us to track what the tribometer 'foot' is actually doing, and what forces it is exerting on the ground. By using this additional information, we may be better able to evaluate the biofidelity of tribometric testing.

Instrumentation: The testing was conducted using a modified Slip-Test Mark II tribometer, (a portable inclinable articulated strut tribometer) and two test surfaces (Official Vinyl Composition Tile (OVCT) and Porcelanosa Ferroker Ceramic tile). The Mark II tribometer was modified such that the tribometer setting could be varied by very small angular increments (0.01° for angles up to 10°, and 0.1° above 10°). Rather than reading the tangent of the friction angle directly off the instrument scale, the angle of inclination was determined using a SPI-Tronic Pro 3600 Digital Protractor affixed to the inclinable carriage of the tribometer. This allowed us to determine the friction angle with an order of magnitude more precision than one can obtain using an unmodified tribometer.

The tribometer was mounted over (but not on) a biomechanical force platform (AMTI model OR6-5, Newton, MA). This is a six degree-of-freedom (three forces along the X, Y and Z axes and three moments about these axes) platform using strain gage load cells in the four corners of the platform to measure ground reaction forces. The test surfaces were mounted to the surface of the force plate; the tribometer was mounted such that only the test foot of the tribometer would impact the test surface (the frame of the tribometer was supported above the force plate). Thus, all forces measured by the plate were those exerted by the test foot on the test surface. Ground reaction forces were collected at 1000 Hz.

An electromagnetic tracking system (Polhemus Liberty system, Colchester, VT) was used to record the motion of the test foot of the tribometer. A small sensor (1.1 cm on a side; <5 grams) was attached via an 18 cm long 6 mm diameter carbon fiber tube and vertical strut to the front of the test foot (smooth neolite). The tube was kept horizontal to the test surface during testing. The tracking system was used to collect position data at 120 Hz; these data were low-pass filtered at 6 Hz, then differentiated to get test foot's pre-contact velocity.

Data were collected with the tribometer in the 0° position (strut vertical), and then the tribometer angle was increased until a slip occurred. The angle was slightly decreased and then multiple trials (usually 10) were collected at small (0.1° to 0.5°) increments. Probability of slip was determined from these multiple trials to be used in other analyses[3]. This paper will concentrate on the motion of the 'foot' just before foot contact, and its possible effect on slip behavior.

Foot velocity at initial contact: One of the characteristics of variable-angle tribometers (including the Slip Test Mark II that is the subject of our tests) is that the test foot is in motion before coming into contact with the test surface, and it is the contact with the surface that decelerates the foot. This is certainly a more 'biofidelic' model than a drag-sled (for example, a Horizontal-Pull Slipmeter) or an articulated- strut tribometer (for example, a James Tribometer). A pedestrian who slips is usually not standing still and being dragged across the floor; rather, s/he slips when his/her foot contacts the ground (dynamically) and lacks sufficient traction (friction) to prevent sliding. The tribometer foot velocity was measured in the direction of motion immediately pre- contact; results are shown in the graph below:

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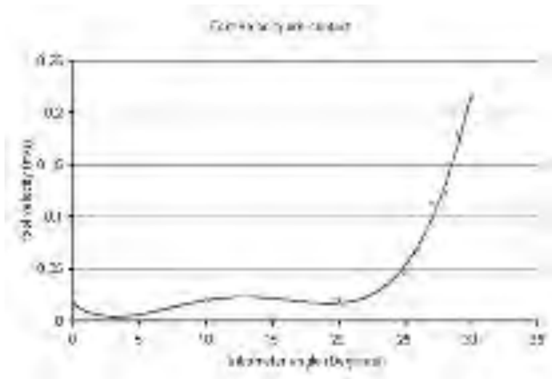
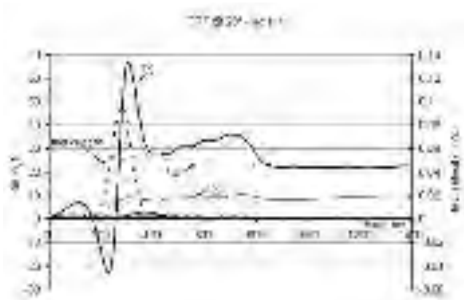
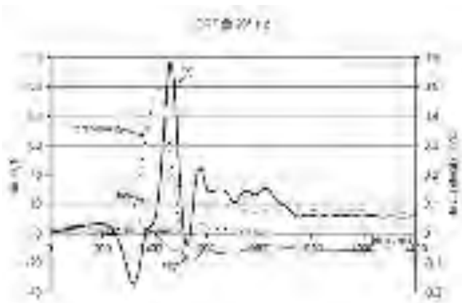


Discussion: In the trials depicted above, slipping first occurred at a friction angle of 27°, and became more likely as the tribometer angle was increased (P(slip| friction angle = 27°) = 0.20); (P(slip| friction angle = 30°) = 0.90)). An increase in the foot velocity was noted as the tribometer angle was increased. The human analog to this would be an increase in walking speed. As such an increase in speed increases the likelihood of a slip in humans, the change in foot speed with change in tribometer angle must be considered when considering if a tribometer measurement is biofidelic.

Ground reaction forces: Ground reaction force curves for a no- slip and a slip trial are shown below:





Discussion: Returning for a moment to the Bucknell workshop, a drag-sled tribometer would exhibit a constant vertical force, with a gradually increasing horizontal force, which would plateau when slip occurred. But considering the "real-world" slip, which usually occurs at initial contact, we can see that the characteristics of the ground reaction force is not the quasi-static, gradual application of a force, but instead is an active impulsive

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loading, that must be considered when assessing slip.

Conclusion: The kinematics and dynamics of loading when using a tribometer must be considered to assure biofidelity when measuring friction and resistance to slip.

References:

1. Marpet, M. Comparison of walkway-safety tribometers (1996) *Journal of Testing and Evaluation*, 24 (4), pp. 245-254.
2. Marpet, M., Fleischer, D. Comparison of walkway-safety tribometers: Part 2 (1997) *Journal of Testing and Evaluation*, 25 (1), pp. 115-126.
3. See: Medoff, HP., Besser, MP., Marpet, MI. (2007): "The Characterization of the Slip-Test PIAST Tribometer by Characteristic Functions Based Upon Logistic Regression", Conference proceedings of the *59th Annual Meeting of the American Academy of Forensic Sciences*, San Antonio, TX, February, 2007, p. 172.

Tribometer, Slip and Fall, Verification