Report to Congress

2026

This report to Congress summarizes the progress the National Highway Traffic Safety Administration has made with advanced small female anthropomorphic test devices, THOR-05F and WorldSID-05F, and provides the status of broader female crash safety research efforts at NHTSA.

Progress with THOR-05F, WorldSID-05F, and Female Crash Safety Research

Purpose

This report is prepared pursuant to direction in the House Report 117-99 which accompanied the Transportation, Housing and Urban Development, and Related Agencies Appropriations Act, 2022 (H.R. 4550),[1] pages 53-54, which states:

The Committee understands that developing, testing, and fully vetting an advanced anthropomorphic test dummy is complicated and time consuming. However, NHTSA has been working on such research and development for almost 15 years. The Committee is anxiously awaiting the adoption of the Test Device for Human Occupant Restraint (THOR) 50th percentile test dummy, as well as the eventual adoption of the THOR 5th percentile female and the Worldwide Harmonized Side Impact Dummy (WorldSID) side impact test dummies. In order to adequately address the gender inequities in crash testing data, the updates must ensure equitable frontal crash tests for both male and female drivers. Within eighteen months of enactment of this Act, the Committee directs NHTSA to issue the long overdue New Car Assessment Program (NCAP) proposed rule that adopts the most technologically advanced safety equipment, including the most advanced anthropomorphic test dummies. Subsequently, the Committee directs NHTSA to report on, and make public, an analysis addressing the findings on and progress to adopt the THOR 50th and THOR 5th percentile test dummies, including an accounting of all relative studies, as well as any efforts NHTSA has made to address gender disparities in crash testing and accident effects.

Introduction

The mission of the National Highway Traffic Safety Administration (NHTSA) is to save lives, prevent injuries, and reduce economic costs due to road traffic crashes through education, research, safety standards, and enforcement. Activities in support of the safety mission at NHTSA included the use of crash test dummies since the 1970s when the first anthropomorphic test device (ATD) was codified into regulation (49 CFR part 572). Early ATDs centered on developing a dummy representative of a midsize male as well as capturing more extreme anthropometries by scaling to a small 5th percentile female and a large 95th percentile male. Safety standards leveraging the midsize male and small female ATDs have advanced general occupant safety for all occupants. However, recent studies have shown that females, in some cases, face a statistically significantly higher relative risk or odds of injury or fatality compared to males.[2,3] To understand better the causal factors behind the sex-based disparities in injury and fatality odds or risk such that further improvements could be implemented, NHTSA has continued research into female crash safety.

In fall 2022, NHTSA released a Female Crash Safety Research Plan describing core research areas to improve knowledge on sex-based differences in occupant protection and to inform future

[1] https://appropriations.house.gov/sites/evo-subsites/republicans-appropriations.house.gov/files/documents/HMKP-117-AP00-20210716-SD004.pdf.

[2] Craig, M. J., Atwood, J. R. E., Liu, C., Zhang, F., Rudd, R., Benedetti, M. H., Enriquez, J., Sex-based differences in odds of motor vehicle crash injury outcomes, National Highway Traffic Safety Administration, Report No. DOT HS 813 754 (Jan. 2026).

[3] Kahane, C. J., Injury vulnerability and effectiveness of occupant protection technologies for older occupants and women (Report No. DOT HS 811 766), Washington, D.C.: National Highway Traffic Safety Administration (2013), available at: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811766.

agency decisions.[4] Progress on these core research areas was reported in 2024.[5] Research under this plan helped inform the development of the long-term roadmap with projected timelines for incorporating the THOR 5th percentile female (THOR-05F) and the WorldSID 5th percentile female (WorldSID-05F) ATDs into the New Car Assessment Program (NCAP).[6] The current strategy for implementing advanced female dummies in NCAP seeks to adhere to, and potentially surpass, the deadlines outlined in the NCAP Roadmap. Advancing core female crash safety research areas at NHTSA is critical to supporting the long-term inclusion of the advanced small female ATDs into NCAP vehicle crash safety ratings.

This report summarizes progress with the THOR-05F and WorldSID-05F advanced small female ATDs and provides the status of broader female crash safety research efforts at NHTSA along four main research areas: *Field Data Analysis, Advanced ATDs and Experimental Biomechanics, Human Body Modeling,* and *Fleet Testing and Countermeasures*.

Research Overview

Field Data Analysis

Using data from the Fatality Analysis Reporting System (FARS), the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS), the Crash Investigation Sampling System (CISS), and the Crash Injury Research and Engineering Network (CIREN) databases, real-world motor vehicle crash injury and fatality incidence, odds, and risk for females versus males were analyzed. Multiple NHTSA studies using real-world crash data have examined comparative fatality risks for females and males. In a 2013 study, the examination of fatal crash data found that females had an overall 17 percent increased fatality risk relative to males for motor vehicle crashes with similar characteristics.[7] The main finding derived from historical fatal crashes involving vehicle model years since the 1960s was dominated by crashes in vehicles that predate generations of crashworthiness improvements, such as seat belts and air bags, introduced in newer model year vehicles.

Differences in fatality and injury risk for females versus males in similar physical crashes in recent model year vehicles were updated by using the latest crash data, which included newer model year vehicles equipped with seat belts, dual advanced air bags, and other countermeasures

[4] NHTSA Female Crash Safety Research Plan, November 2022, available at https://www.regulations.gov/document/NHTSA-2022-0091-0002.

[5] Lafferty, E., Current Status of Female Crash Safety Research at NHTSA, Proceedings of SAE Government-Industry Meeting (2024), available at https://www.nhtsa.gov/sites/nhtsa.gov/files/2025-10/16180-NSR-231208-002-SAE-Current-Status-Female-Crash-Safety-Research-NHTSA-v2-tag.pdf.

[6] https://www.nhtsa.gov/sites/nhtsa.gov/files/2024-11/NCAP-Final-Decision-Notice-Advanced-Driver-Assistance-Systems-Roadmap-11182024-web.pdf.

[7] Kahane, C. J., Injury vulnerability and effectiveness of occupant protection technologies for older occupants and women, National Highway Traffic Safety Administration, Report No. DOT HS 811 766 (2013), available at: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811766.

designed to protect a broader range of occupants.[8] This study evaluated relative fatality risk between females and males using 1975–2019 FARS data and evaluated fatality as the dependent outcome to estimate the relative risk for females versus males. Newer vehicle designs showed statistically significant reductions in relative risk for females. For example, the relative fatality risk difference between females and males was estimated to be 6.3 percent for front row occupants of 2010–2020 model year vehicles and was found to be significantly lower ($p \leq 0.05$) than the 18.3 percent relative fatality risk for 1960-2009 model year vehicles. Thus, when considering current vehicle technologies (such as dual-stage air bags and load-limited seat belts) in recent model years, the difference in fatality risk between males and females has reduced significantly.

NHTSA has continued to explore real-world motor vehicle crash data to evaluate differences in injury and fatality odds or risks between females and males. To assess injury odds further, NHTSA developed multivariable logistic models using the NASS-CDS and CISS data to describe injury odds ratios for females versus males, given a comprehensive set of covariates including crash type, occupant restraint conditions, and seating positions.[9] The study found that:

- Females have significantly higher odds ($p \leq 0.05$) for most moderate severity or greater injuries (Abbreviated Injury Scale [AIS] 2 or greater severity or AIS 2+) in models that evaluated the overall population of planar (all non-rollover) crash types. This trend was also observed for frontal crashes.
- For side and rear impact crashes, most AIS 2+ injury odds findings for females versus males were not statistically significant ($p > 0.05$).
- Findings for frontal crashes included higher estimates for lower extremity injuries, consistent with earlier studies.[10] Similarly, for certain moderate or greater (AIS 2+) injuries (e.g., neck, thorax, and abdomen) and most serious or greater (AIS 3+) injuries (e.g., head, neck, thorax, abdomen, and thoracolumbar spine), differences in odds between females and males found in both frontal crashes and overall planar crashes were not statistically significant ($p > 0.05$).

NHTSA has also supported or led efforts that have utilized available real world crash injury and fatality datasets to complete case studies. The CIREN database was used to examine risk factors and to understand the causes of apparent female/male differences in crash-related injury outcomes. Recent work evaluated sex-based disparities in lower extremity, abdominal, and thoracic injuries.[11] NHTSA also completed a case study-focused report on fatal crashes from CIREN, CISS, and NASS -CDS in the presence of modern restraints (air bags, seat belts, etc.). The case study evaluated influential factors contributing to fatal outcomes for males and females.

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[8] Noh, E. Y., Atwood, J. R. E., Lee, E., Craig, M. J., Female crash fatality risk relative to males for similar physical impacts, National Highway Traffic Safety Administration, Report No. DOT HS 813 358) Washington, D.C (2022), available at: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813358.

[9] Craig, M. J., Atwood, J. R. E., Liu, C., Zhang, F., Rudd, R., Benedetti, M. H., Enriquez, J., Sex-based differences in odds of motor vehicle crash injury outcomes, National Highway Traffic Safety Administration, Report No. DOT HS 813 754 (Nov. 2025).

[10] Forman, J., Poplin, G.S., Shaw, C.G., McMurry, T.L., Schmidt, K., Ash, J., Sunnevang, C., Automobile injury trends in the contemporary fleet: Belted occupants in frontal collisions, Traffic Injury Prevention, 20(6): 607-612 (2019).

[11] Devane, K. S., et al., Sex-Specific Differences in Thoracic Injury Prevalence and Causation: a CIREN Database Investigation, Proceedings of the International Research Council on the Biomechanics of Injury, Stockholm, Sweden (2024), available at: https://www.ircobi.org/wordpress/downloads/irc24/pdf-files/2442.pdf.

Occupant-specific factors such as age, stature, restraint use, and seat positioning affected a higher number of female occupants (32 percent) compared to male occupants (18 percent) in the study.[12]

Advanced ATDs and Experimental Biomechanics

To predict and prevent fatalities and injuries among female motor vehicle occupants, NHTSA has focused on developing advanced crash test dummies, also known as ATDs, that are more human-like than currently regulated dummies and that feature improved instrumentation and measurement capabilities. The advanced female ATDs use available female-specific data for design (including size and shape), response, and injury criteria. The current female ATDs under development are 5th percentile in size, known as the THOR-05F frontal impact ATD and WorldSID-05F side impact ATD.

Female-specific response and injury tolerance or risk are being determined through experimental biomechanics and anthropometric studies that run in parallel with ATD development and that consider occupant factors such as seating position (including reclined positions) and size (50th percentile).

Advanced ATDs.

THOR-50M—50th Percentile Male Frontal ATD. In addition to female ATDs and injury disparity research efforts, NHTSA was directed to provide an update on the progress of the THOR 50th percentile male frontal ATD (THOR-50M). NHTSA issued a notice of proposed rulemaking in 2023 to add the THOR-50M to 49 CFR part 572 and is considering comments received to determine next steps.[13]

THOR-05F—5th Percentile Female Frontal ATD. Research and development efforts supporting the THOR-05F ATD have focused on four primary areas: 1) injury risk prediction and biofidelity, 2) improved durability, 3) repeatability and reproducibility of ATD response, and 4) ATD documentation. These efforts have required extensive experimental ATD testing, post-mortem human subject (PMHS) data collection, and computer-aided engineering. The goal is to ensure that the THOR-05F is representative of a small female occupant in a crash and is an improvement over the currently regulated small female frontal dummy, the Hybrid III 5th female ATD (HIII-05F).

Injury risk curve development and biofidelity assessment. Research into injury risk prediction and biofidelity primarily involves performing laboratory experiments (full-body and component-level) on female PMHS to establish female-specific responses and to conduct matched-pair tests with the THOR-05F. The results of these tests are used to relate THOR-05F responses (e.g., forces and deflections) with PMHS responses to assess THOR-05F biofidelity and create injury criteria performance metrics for use in crash

[12] Firey, L. M., Rudd, R. W., Lockerby, J., Craig, M. J., Identification of Influential Factors Among Fatalities of Restrained First-Row Occupants in Recent Frontal Crashes, Proceedings of the International Research Council on the Biomechanics of Injury, Cambridge, U.K. (2023), available at: https://www.ircobi.org/wordpress/downloads/irc23/pdf-files/2311.pdf.

[13] https://www.federalregister.gov/documents/2023/09/07/2023-19008/anthropomorphic-test-devices-thor-50th-percentile-adult-male-test-dummy-incorporation-by-reference.

tests. Where possible, the development of injury risk prediction tools will consider covariates such as age. Injury criteria development is underway using data from recent and ongoing efforts in body regions including the neck, thorax, abdomen, pelvis, knee-thigh-hip, tibia, and ankle.

a. *Neck*: Ongoing work involves collecting female PMHS data to facilitate an improved assessment of THOR-05F neck biofidelity.[14] Tests have been performed with PMHS, THOR-05F, and THOR-50M to match Naval Biodynamics Laboratory (NBDL) sled tests. Ongoing work will perform human body model simulations of these conditions with the Global Human Body Models Consortium (GHBMC) 5th percentile female (F05). Collected data will support the development of injury criteria and human-to-ATD mapping based on previously conducted THOR-05F tests in tension, compression, flexion, extension, torsion, and lateral bending.

b. *Thorax*: The thoracic injury criterion is being improved by comparing female PMHS data to matched-pair ATD data during frontal and oblique simplified sled and vehicle buck tests that replicate the loads experienced by vehicle occupants in a crash. Previously, NHTSA collected small female PMHS and HIII-05F data using a simplified sled test and is currently repeating this test mode with the most current version of the THOR-05F ATD for comparison. Additional small female PMHS and matched-pair THOR-05F tests are being conducted in a more complex sled test condition intended to represent a modern vehicle environment with advanced seat belts and air bags.

c. *Abdomen*: NHTSA performed female PMHS abdomen tests to determine responses and injuries that could occur from interactions between the occupant and the vehicle (seat belt and steering wheel). Both response and injury risk aspects of female PMHS data have been analyzed.[15,16] To support abdomen injury risk curve development and establish biofidelity, NHTSA is testing additional PMHS and will perform matched-pair testing on the most recent design of the THOR-05F ATD. Additional ongoing work is evaluating the effects of numerous parameters (e.g., pulse, seat/seat belt geometry, and presence of advanced restraints) on loading abdomen pressure sensors in THOR-05F FE models and ATD. The effects these parameters have on submarining occurrence and on the overall kinematics of the lower torso (i.e., lumbar) will be explored.

[14] Espelien, C., Gallaher, M., Donlon, J.P., Forman, J., Head and T1 angle analysis of small female PMHS, mid-size male PMHS and mid-size male NBDL volunteers, Proceedings of International Research Council on the Biomechanics of Injury, Stockholm, Sweden (2024), available at: https://www.ircobi.org/wordpress/downloads/irc24/pdf-files/2437.pdf.

[15] Ramachandra, R., Stammen, J., Kang, Y. S., Hutter, E., Watkins, L., Moorhouse, K., Abdominal biofidelity assessment of 5th percentile female ATD responses relative to recently developed belt and bar loading corridors, Traffic Injury Prevention, 24(sup1), S16–S22 (2023).

[16] Ramachandra, R., Kang, Y.S., Stammen, J., Lee, E., Moorhouse, K., Bolte IV, J., Biomechanical responses of small female PMHS subjected to abdominal loading, Proceedings of International Research Council on the Biomechanics of Injury, Porto, Portugal (2022), available at: https://www.ircobi.org/wordpress/downloads/irc22/pdf-files/2233.pdf.

d. *Pelvis*: An ongoing effort collecting female PMHS and matched THOR-05F pelvic loading data is being used to develop pelvic injury criteria for small female occupants.

e. *Knee-Thigh-Hip*: Previously collected knee-thigh-hip female PMHS and ATD data are being analyzed for use in THOR-05F injury criteria for the hip joint.

f. *Tibia*: Ongoing tasks are collecting female PMHS and ATD data. Combined-loading tests are being conducted on female PMHS, each with similarly loaded THOR-05F tests. The resulting data will be incorporated into injury criteria development.

g. *Ankle*: Several tasks are aimed at collecting female PMHS and THOR-05F data at the ankle to provide response and tolerance data suitable for the development of injury risk curves and determination of injury assessment reference values (IARVs) for the ankle joint under frontal crash loading conditions.

Design improvements for durability. It is crucial that the THOR-05F is durable enough to withstand crash-level loading repeatedly. While the initial THOR-05F design fared well in the front seat during full vehicle crashes (three at 30 km/h and three at 56 km/h), rear seat sled testing (56 km/h) identified significant thorax durability issues, resulting in damaged parts, broken sensors, and data loss. As a result, extensive THOR-05F design improvements were made to address the durability concerns.[17, 18, 19, 20, 21, 22] The thorax design was improved by optimizing materials, geometry, and sensor placement while maintaining acceptable biofidelity. The improved ATD was evaluated again in the rear seat test condition, and no damage occurred.

Repeatability and reproducibility. The evaluation of the improved THOR-05F for repeatability and reproducibility (R&R) has been recently completed to ensure that the ATD responds consistently in standard qualification test conditions. Good R&R performance helps ensure different THOR-05F ATDs would respond appropriately similar under the same test conditions across crash laboratories and helps ensure crash test results reflect vehicle performance rather than a potential outlier from a specific ATD.

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[17] Hutter, E., Panel 3: Female Crash Safety, NHTSA Public Research Meeting (2021), available at: https://static.nhtsa.gov/nhtsa/downloads/Events/Research/2021/Day-3/Female Crash Safety.mp4.

[18] Hutter, E., Panel 6: Occupant Protection and Advanced Crash Test Dummies, NHTSA Public Research Meeting (2022), available at: https://usdot.zoomgov.com/rec/play/l6pB87bBMs8JZtlYU2Qm31faEE__-3hu1TJhlDmJN5vXKt-wazcirAM3CqqEzh6TipFPgh9zMPTRkpL7.fH0AXFsxeSGj2Etg.

[19] Hutter, E., Panel 3: Advanced Crash Test Dummies, NHTSA Public Research Meeting (2024), available at: https://downloads.regulations.gov/NHTSA-2024-0040-0005/attachment_3.pdf.

[20] Hutter, E., Louden, A., Moorhouse, K., Stammen, J., Wetli, A., Watkins, L., Evaluation of THOR-05F in a Full Vehicle Crash Series, Proceedings of SAE Government Industry Meeting (2023), available at: https://www.nhtsa.gov/sites/nhtsa.gov/files/2023-03/15874-SAE%20GIM%202023%20THOR05F%20for%20distrib_032223-tag_1.pdf.

[21] Hutter, E., Moorhouse, K., Carlson, M., Hagedorn, A., NHTSA's THOR-05F Design Update, Proceedings of SAE Government-Industry Meeting (2024), available at: https://www.nhtsa.gov/sites/nhtsa.gov/files/2024-02/16180-NSR-231211-006_SAE_NHTSAs%20THOR-05F%20Design%20Update-tag.pdf.

[22] Hutter, E., NHTSA's THOR-05F R&R Update, Proceedings of SAE Government-Industry Meeting (2025)

NHTSA tested three THOR-05F ATDs in-house and one THOR-05F ATD at three external labs in fifteen different modes to evaluate the ATD across body regions. Data from more than 570 tests were analyzed for repeatability and reproducibility, and no concerns were identified. Additional fleet crash testing is planned to evaluate the ATDs in frontal crash conditions to assess durability, reproducibility, and feasibility of use in frontal test programs in the near future.

ATD documentation. NHTSA has published the documentation required to support the incorporation of THOR-05F ATD into CFR 49 part 572 and to support corresponding use in regulatory or consumer information programs [e.g., Federal Motor Vehicle Safety Standards [FMVSS] and U.S. NCAP]. This documentation includes a drawing package; a manual covering assembly, disassembly, and inspection (PADI) of the ATD; manual detailing qualification test procedures; and individual reports for the durability evaluation, and the repeatability and reproducibility (R&R) evaluation. [23]

In-progress documentation includes injury criteria, and seating procedures, and an updated biofidelity report. Documentation related to THOR-05F is available through the public dockets.[24] [25]

WorldSID-05F—5th Percentile Female Side ATD. WorldSID-05F research and development efforts have focused on two primary areas: 1) improving biofidelity and pelvis bone retention and 2) collecting female-specific data to develop biofidelity corridors and injury risk functions.

Design improvements for biofidelity and pelvis bone retention. Initial testing with the WorldSID-05F identified insufficient thorax biofidelity and unacceptable retention of pelvic bones within the pelvis flesh.[26] NHTSA is working with the manufacturer to address the biofidelity deficiency and pelvis flesh fit while maintaining acceptable durability. The first redesigned physical parts were not durable, which led to a second redesign using a different rib material. An update given by NHTSA in 2024[27] showed the second redesign to have improved biofidelity response and acceptable durability using computer aided engineering. The dummy parts are now being manufactured.

Injury risk function development and biofidelity assessment. Currently, most of the ongoing experimental PMHS tests for females in side impact focus on the thorax and pelvis, which are body regions important to side impact occupant safety. Lateral and oblique thorax biofidelity corridors based on historical rigid impactor test conditions were generated from small female PMHS data and are being used to aid thorax

[23] https://www.nhtsa.gov/file-downloads?p=nhtsa/downloads/THOR-05F/Drawing-Package/November-2025/

[24] https://www.regulations.gov/docket/NHTSA-2019-0107

[25] https://www.regulations.gov/docket/NHTSA-2025-0622

[26] Rhule, H. and Stricklin, J., Biofidelity Evaluation of WorldSID-05F with Mod Kit and SID-IIs BLD, Proceedings of SAE Government-Industry Meeting (2022), available at: https://www.nhtsa.gov/research/public-meetings-research#2022-68566.

[27] Rhule, H., Panel 3: Advanced Crash Test Dummies, NHTSA Public Research Meeting (2024), available at: https://www.nhtsa.gov/events/nhtsa-safety-research-portfolio-public-meeting-fall-2024.

redesign.[28, 29, 30] Small female PMHS have been tested in new pelvis and thorax impactor conditions that better replicate the crash environment, with more planned in the future.[29] The small female data from new thorax and pelvis tests will be used to generate additional biofidelity response corridors and to aid thorax redesign. After an acceptable redesign has been achieved, injury criteria will be developed using data from these experimental tests with small female PMHS and matched-pair tests, among other data.

ATD documentation. Next steps include receiving and evaluating the revised physical dummy for biofidelity, durability, qualification, and repeatability, along with evaluating the chest deflection measurement system and injury risk function development. Upon receipt of additional units, further evaluation including reproducibility, seating procedures updates, and fleet testing can begin, along with documentation needed to support ATD federalization and corresponding use in testing programs [i.e., FMVSS and U.S. NCAP]. As documentation is finalized, it will be made available to the public.[31]

Experimental Biomechanics.

In addition to studies supporting advanced female ATD biofidelity and injury risk curve development, NHTSA has experimental injury research underway that supports broader female injury response and virtual model development. These studies will help NHTSA address sex-based disparities in crash testing.

a. *Female seated anthropometry and seating preference.* Ongoing work collecting occupant seated anthropometry includes posture and seating assessments for females and males, driver foot placement studies, thoracic geometry studies, and a new/expanded seated anthropometry study covering the 5thth through 95th percentiles for both sexes.[32] Data will be collected from volunteers and ATDs in various seated postures ranging from upright to reclined positions. Results will support seating procedure development and seated assessments of ATDs and human body models (HBMs).

b. *High-speed, reclined seating.* High-speed, forward-facing, reclined seating crash research includes sled tests with female PMHS in test configurations similar to male PMHS to identify differences in kinematics and injury risk. Comparable high-speed rear-facing crash research includes sled tests with female PMHS in test configurations similar to male PMHS to evaluate kinematics and injury risk differences in rear-facing impacts with standard and reclined seating. In addition to documenting injury risk differences between

[28] Agnew, A.M., Thoracic Response Corridors of Small Female PMHS in Simplified Frontal and Side Impacts, Proceedings of SAE Government Industry Meeting (2023), available at: https://www.nhtsa.gov/sites/nhtsa.gov/files/2023-03/15874-Agnew%20SAE%20GI%202023%20final_032223.pdf.

[29] Rhule, H., Panel 2: Experimental and Computational Biomechanics & Injury, NHTSA Public Research Meeting (2024), available at: https://www.nhtsa.gov/events/nhtsa-safety-research-portfolio-public-meeting-fall-2024.

[30] Agnew, A.M., Baker, G.H., Marcallini Jr., A., Bendig, A., Moorhouse, K., Rhule, H., Bolte IV, J.H., Kang, Y.S., Small Female Post-mortem Human Subject (PMHS) Thoracic Responses to Simplified Oblique and Lateral Loading, Proceedings of International Research Council on the Biomechanics of Injury, Stockholm, Sweden (2024), available at: https://www.ircobi.org/wordpress/downloads/irc24/pdf-files/2440.pdf.

[31] https://www.regulations.gov/docket/NHTSA-2019-0109.

[32] https://www.federalregister.gov/documents/2024/12/30/2024-30932/agency-information-collection-activities-notice-and-request-for-comment-female-occupant#addresses.

females and males, the kinematics data are being used for biofidelity assessments of crash testing tools such as advanced ATDs and HBMs.[33, 34, 35, 36]

c. *Non-standard anthropometries*. Additional frontal impact sled testing is needed to support 50th percentile female-specific biofidelity corridors for validating 50th percentile female HBMs and, if needed, 50th percentile female ATDs. This data collection and assessment would, in part, support analysis related to the potential need for 50th percentile female ATDs. Data from older (70 years and older) and obese (body mass index of 30 kg/m^2 or greater) females are also being collected to support biofidelity corridors for validating non-standard HBM anthropometries.

d. *Whiplash.* A 50th percentile female rear impact ATD (EvaRID) finite element model and initial prototype have been developed externally to assess automotive seats and head restraint performance. Future work will further assess and develop tools needed to predict whiplash injuries in females.

e. *Thorax.* Multiple thorax studies are underway to address female thoracic response and fracture risk: (1) identifying rib and thorax biomechanical response corridors for female occupants to improve HBM injury prediction accuracy; (2) developing analytic methods to derive material property parameters required to improve HBM rib biofidelity; (3) quantifying the contributions of thoracic structures (ribs, viscera, breast tissue) to overall thoracic response across demographics including female, pediatric, and older occupants; and (4) collecting PMHS data from older small females (60 years and older) with poor bone quality in a side impact condition with seat belt and air bag to generate an older small female thoracic injury risk curve and to assess WorldSID-05F biofidelity relative to older small female response corridors.

f. *Foot/ankle injury sensitivity.* Finally, research is underway to understand kinematic and kinetic differences in foot, ankle, and leg response when the foot is on the brake pedal versus the accelerator pedal using female ATDs and PMHS.

Human Body Modeling

NHTSA supports the GHBMC in developing finite element HBMs and using them to study injury causation. NHTSA uses HBMs to investigate causes of sex-based differences in injury

[33] Pradhan, V., DeWitt, T., Ramachandra, R., & Kang, Y. S., Comparison of thorax and upper-extremity responses between GHBMC M50-OS and M50-O in a high-speed, rear-facing, frontal impact, In Conference Proceedings, International Research Council on the Biomechanics of Injury, IRCOBI (2023).

[34] Pradhan, V., Ramachandra, R., & Kang, Y. S., Comparison of the Responses of the Thorax and Pelvis of the GHBMC M50-O Using Two Different Foam Materials in a High-Speed Rear Facing Frontal Impact Scenario, SAE Technical Paper No. 2024-01-2647 (2024).

[35] Pradhan, V., Ramachandra, R., Stammen, J., Kracht, C., Moorhouse, K., Bolte, J. H., & Kang, Y. S., Biofidelity Assessment of the GHBMC M50-O Seated in a Honda Accord Seat in a Rear-Facing Configuration during a High-Speed Frontal Impact, SAE International Journal of Transportation Safety, 12(09-12-03-0014) (2024).

[36] Pradhan, V., et al., Biofidelity assessment of the GHBMC M50-O in a rear-facing seat configuration during high-speed frontal impact, Computer Methods in Biomechanics and Biomedical Engineering, 27(10), 1287-1302 (2024), available at: https://doi.org/10.1080/10255842.2023.2239417.

risk, to assess potential benefits of new physical crash dummies, and to build a virtual testing framework. These efforts improve understanding of differences in motor vehicle crash injury and fatality risk between females and males, and they help predict and prevent injuries and fatalities for females involved in motor vehicle crashes. These studies will help NHTSA address sex-based disparities in crash testing and accident effects.

a. *Model Development and Evaluation*. Through the GHBMC, NHTSA is supporting the development and evaluation of a 50th percentile female human body model. This model has been used in parametric analyses to examine female injury risk. NHTSA plans to complete research supporting extended validation and demonstrated application of the new 50th percentile female HBM.

b. *Parametric Modeling Studies.* To investigate causes of increased risk for females, NHTSA is conducting internal parametric studies using HBMs. One study evaluated how variability within mid-sized females affects injury risk in frontal crashes and potential countermeasures.[37] Another study analyzed ankle injuries between sexes using HBMs by varying factors such as velocity change, principal direction of force (PDOF), knee-to-dash distance, brake pedal stiffness, and stop angle with the right foot on the brake pedal.[38] A third study showed how differences in HBM skeletal geometry and seating position influenced thoracic injury response between sexes in frontal crashes. Finally, a fourth study used average male and female HBMs to identify restraint systems that minimize brain and thoracic injuries in frontal crashes.

c. *Geometry and Shape Studies.* Additional research sponsored by NHTSA studied the effect of variability in rib cage and pelvis geometry on injury outcomes for average males and females. This project involved developing statistical geometry models for the rib cage and pelvis from CT scan data, incorporating these rib cage and pelvis geometry variations into HBMs, and evaluating injury risks in different crash conditions.

Fleet Testing and Countermeasures

After development and refinement of advanced dummies, NHTSA would conduct fleet testing to assess how the THOR-05F and WorldSID-05F interact with vehicle systems. Fleet testing supports two objectives: (1) assesses ATD fitness for use in regulation, and (2) justifies and sets injury assessment reference values (IARV) for the ATD. Additional research will conduct restraint countermeasure studies to understand how advanced seat belts and air bags can be optimized for female safety. This work will aid in prediction and prevention of fatalities and injuries for females involved in motor vehicle crashes.

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[37] Hasija, V., Ruparel, T., Kelkar, R., Craig, M.J., Takhounts, E.G., Injury Risk Evaluation for Mid-sized Females using Finite Element Human Body Models. International Research Council on the Biomechanics of Injury, Cambridge, U.K. (2023), available at:https://www.ircobi.org/wordpress/downloads/irc23/pdf-files/2346.pdf.

[38] Ruparel, T., Hasija, V., Takhounts, E.G., Simulation based ankle injury evaluation using GHBMC modular human body models, Proceedings of International Research Council on the Biomechanics of Injury, Cambridge, U.K. (2023), available at: https://www.ircobi.org/wordpress/downloads/irc23/pdf-files/2375.pdf.

Fleet Testing. Passenger vehicle crash tests utilizing the THOR-05F in FMVSS No. 208 frontal driver and passenger positions and frontal rear seat conditions are planned for the current version of the THOR-05F that includes durability-related design updates. To date, six baseline frontal tests have been completed with the THOR-05F (2018 build) in driver and right front passenger positions, in both belted and unbelted conditions.[39, 40, 41] The updated THOR-05F is planned for use in near-term full-scale fleet evaluation crash tests. Passenger vehicle crash tests using the WorldSID-05F in FMVSS No. 214 moving deformable barrier (MDB) and NCAP oblique pole conditions are also planned after biofidelity improvements.

a. *ATD fitness.* Fleet testing will evaluate THOR-05F and WorldSID-05F fitness for use in regulatory testing. The established seating procedures will be followed and evaluated for comprehensiveness. The ATD kinematics will be reviewed to ensure responses are realistic. Durability will be confirmed by assessing components from higher energy exposures. The fleet tests will be used to verify that instrumentation setup, collection, and processing could be followed with explainable results. These tests will also provide a check to the qualification process, ensuring there are no significant setbacks or failures.

b. *ATD injury assessment reference values (IARVs).* Fleet tests for the THOR-05F will be matched with FMVSS No. 208 (belted and unbelted) and NCAP crash tests of the same vehicle with the HIII-05F. These matched tests will be used to compare the THOR-05F and HIII-05F responses relative to their respective injury risk levels to verify reasonable IARVs. Fleet tests for the WorldSID-05F will be matched with FMVSS No. 214 and NCAP MDB and oblique pole crash tests of the same vehicle with the SID-IIs 5th percentile female ATD. These matched tests will be used to compare WorldSID-05F and SID-IIs responses relative to their respective injury risk levels to verify reasonable IARVs.

Countermeasure Studies. Parametric experimental studies are planned that will explore optimized restraint system designs that provide equivalent injury risk mitigation for females compared with males. A parametric buck is currently being designed and fabricated for driver and passenger positions to perform these optimization tests. The study will evaluate current system design performance and consider changes in design parameters targeting 5th and 50th percentile females. Countermeasure studies are also planned with FE models to complement experimental testing. The FE studies will evaluate restraint optimization for HIII-05F, THOR-05F, and 5th and 50th percentile female HBMs in frontal impacts as well as for SID-IIs, WorldSID-05F, and 5th and 50th percentile female HBMs in side impacts. The experimental parametric results can be used to verify and validate ATD FE model results, while HBM studies can explore a greater number of optimization variables.

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[39] Hutter, E., Panel 3: Female Crash Safety, NHTSA Public Research Meeting (2021), available at: https://static.nhtsa.gov/nhtsa/downloads/Events/Research/2021/Day-3/Female Crash Safety.mp4.

[40] Hutter, E., Louden, A., Moorhouse, K., Stammen, J., Wetli, A., Watkins, L., Evaluation of THOR-05F in a Full Vehicle Crash Series, Proceedings of SAE Government-Industry Meeting (2023), available at: https://www.nhtsa.gov/sites/nhtsa.gov/files/2023-03/15874-SAE%20GIM%202023%20THOR05F%20for%20distrib_032223-tag_1.pdf.

[41] NHTSA Vehicle Database tstno: V14356-V14361, available at: Research Testing Databases | NHTSA.