

DEVELOPMENT OF A BIOFIDELIC PEDESTRIAN LEGFORM IMPACTOR - INTRODUCTION OF JAMA-JARI LEGFORM IMPACTOR Ver. 2002 -

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ABSTRACT

The Japan Automobile Manufacturers Association, Inc., (JAMA) and the Japan Automobile Research Institute (JARI) are collaborating to develop a biofidelic pedestrian legform impactor because the current major pedestrian legform impactor, the Transport Research Laboratory (TRL) legform impactor, lacks biofidelity. JAMA and JARI have been developing a biofidelic legform impactor since 2000. This report introduces the JAMA-JARI legform impactor ver. 2002. This version has two major improvements: it properly simulates human bone flexibility and human knee joint characteristics.

The above improvements are quite important for ensuring biofidelity of the legform impactor.

INTRODUCTION

In 1994, the European Experimental Vehicles Committee Working Group 10 (EEVC/WG10) proposed a pedestrian legform impactor [1]. The impactor was proposed to assess the car-induced damage to a pedestrian leg in car-to-pedestrian impacts. However, the developed legform impactor, the Transport Research Laboratory (TRL) legform impactor, does not simulate human bone flexibility and its knee joint is composed of a steel bending plate. These characteristics are quite different from human characteristics. EEVC/WG17 modified the TRL impactor but just added a damper to reduce the impactor knee shearing vibration [2].

The TRL legform impactor's lack of the biofidelity caused the leg response to differ from that of a human leg [3][4][5]. Trials were proposed to obtain a transfer function between the TRL legform impactor and the human leg [4][5]. However, the transfer function may not apply to all impact situations, especially for different bumper heights.

The Japan Automobile Manufacturers Association, Inc., (JAMA) and the Japan Automobile Research Institute (JARI) decided to develop a more biofidelic legform impactor that does not need a transfer function and can be used for most pedestrian leg impact situations.

This report introduces the latest JAMA-JARI developed legform impactor and shows its validation test results.

SPECIFICATIONS OF THE JAMA-JARI BIOFIDELIC LEGFORM IMPACTOR

The first version of the JAMA-JARI legform impactor was developed in 2000 (JAMA-JARI legform impactor ver. 2000) [6]. The first model introduced a knee ligament restraint system using the Polar pedestrian dummy knee ligament system. Its response was more biofidelic than that of the TRL legform impactor, but its bone part was still rigid so the impact energy tended to concentrate in the knee joint.

In 2002, JAMA and JARI developed a new legform impactor that had the knee ligament restraint system, was much more compact than ver. 2000, and had bone flexibility in the tibia and femur. Figure 1 illustrates the JAMA-JARI legform impactor ver. 2002. Its length and weight of the tibia and femur were the same as the TRL legform impactor because the values were derived from human data. However, the knee joint system and the bone flexibility differed considerably from the TRL impactor.

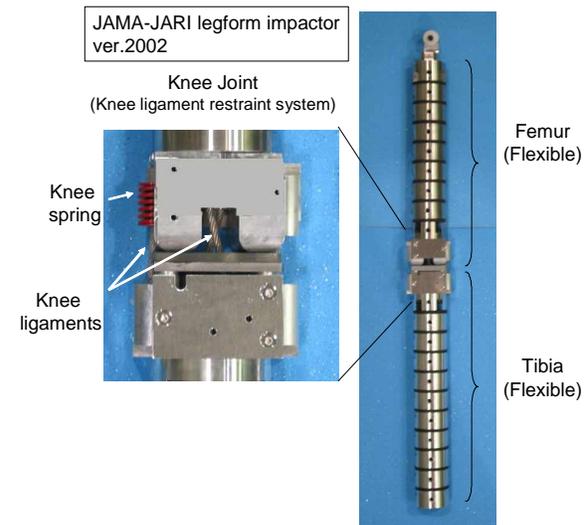


Figure 1. Overview of the JAMA-JARI legform impactor ver. 2002.

VALIDATION METHODOLOGY

The authors validated the impactor under quasi-static and dynamic loading conditions in the tests below.

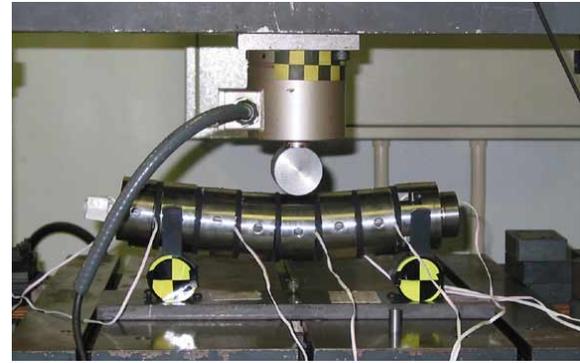
- Quasi-static Bone Bending Test
- Quasi-static Knee Bending Test
- Dynamic Bone Bending Test
- Dynamic Knee Bending Test
- Dynamic Knee Shearing Test

The quasi-static bone bending test result was compared with Yamada [7], and the quasi-static knee bending test result was compared with Ramet et al. [8]. The dynamic bone bending test result was compared with Nyquist et al. [9], and the dynamic knee bending and knee shearing test result was compared with Kajzer et al. [10]. The quasi-static knee shearing test was not performed due to time constraints.

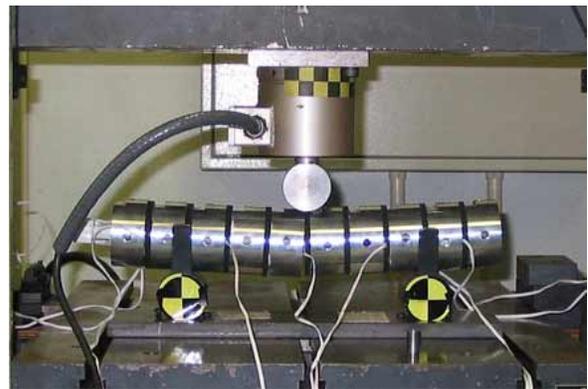
RESULTS

Quasi-static Bone Bending Test

Figure 2 depicts the states of the quasi-static bone bending test. It is clear that the femur and the tibia of the new legform impactor can be bent against the lateral force. Figure 3 compares the bending characteristics of the legform impactor and PMHS. In the initial and intermediate loading phase, the legform bone bending characteristics are quite similar to the PMHS data. However, there were differences in the ultimate loading phase. The legform bone parts increase the bending force linearly relative to the bone deflection but the PMHS bone does not. The legform bone parts are composed of a Fiber Reinforced Plastic (FRP) and it has a wide range of the elastic region, however, the human bone has a narrow range of the elastic region, transit to the plastic region after around the 7 mm deflection in Figure 3. In order to simulate the plastic region phenomenon of human bone, the legform impactor must use a material which has a narrow range of elastic region not like FRP for its bone parts. The legform impactor must simulate the human bone bending characteristics yet must have durability for the impact test. If the bone parts break in each test, they will have to be repaired each time. The TRL legform impactor knee joints must be repaired after each test, so testing is expensive. Furthermore, the authors found that the plastic phenomenon does not significantly affect the bending curve in dynamic testing, so we kept the elastic material for the bone parts.



(1) Femur Bending Test



(2) Tibia Bending Test

Figure 2. Quasi-static Bone Bending Test.

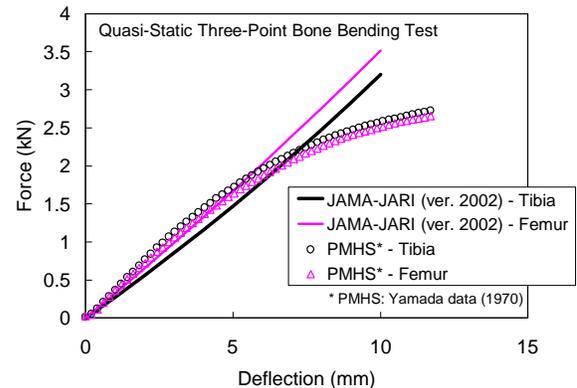


Figure 3. Comparison of the Quasi-static Bone Bending Characteristics between the JAMA-JARI Legform Impactor and PMHS.

Quasi-static Knee Bending Test

Figure 4 presents the states of the quasi-static knee bending test. The knee parts were fixed by a fixation device, and a bending moment was applied using a long bending lever arm. Figure 5 compares results of the knee bending characteristics for the JAMA-JARI legform impactor and PMHS, as well as the TRL knee joint stiffness. The JAMA-JARI legform impactor knee bending characteristics are comparable to PMHS characteristics.

The TRL legform knee is quite stiff compared to the PMHS knee, i.e., stiffer than the JAMA-JARI legform impactor. The TRL legform impactor uses a steel bending plate, therefore, its moment-angle response in the initial phase is too stiff. The bending stiffness in the plastic bending phase is set at around 400Nm, and Kajzer et al.'s data support this value [11]. However, the authors believe the human knee bending stiffness is not so high even under dynamic loading conditions.

Kajzer et al. stated that the knee joint bending stiffness is calculated using their PMHS test data (knee support force (F_k), trochanter support force (F_t), length from knee joint level to knee support (l_k), and length from knee joint level to trochanter support (l_t)), but they did not show their equation clearly. It seemed that the high bending moments were derived from the formula, $|F_t l_t| + |F_k l_k|$, but it is quite incomprehensive. If the test is assumed as a simple, two point supported, pin end and roller end, bar bending test, the maximum bending moment should be generated at the knee support, $|F_t| |l_t - l_k|$, and the bending moment at the knee joint level should be $|F_t l_t| - |F_k l_k|$. The formula, $|F_t l_t| + |F_k l_k|$, leads to a bending moment more than two times higher than the maximum at the knee support, therefore, the equation is inappropriate. Even when a built-in end is assumed at the trochanter support, the moment at the knee joint level should not be $|F_t l_t| + |F_k l_k|$. The authors therefore concluded that their formula, i.e., the high bending moment, is simply incorrect.

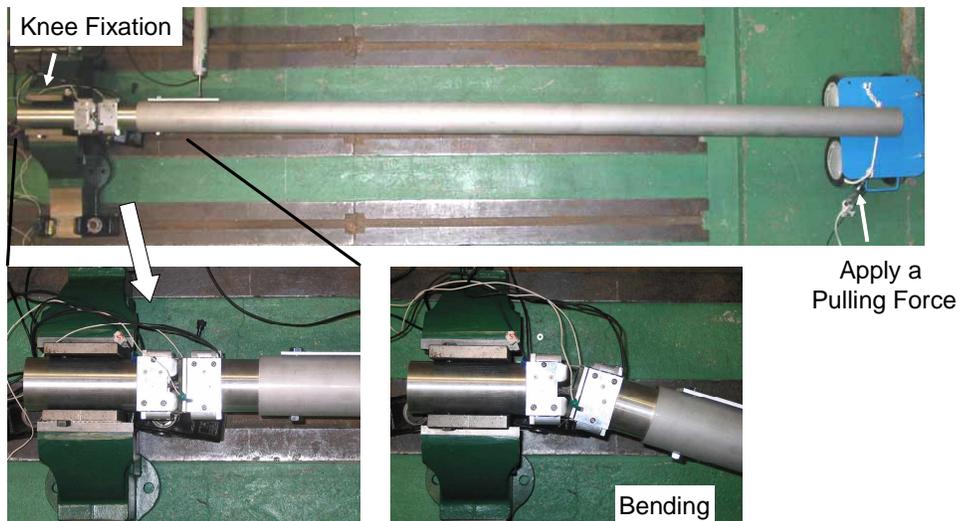


Figure 4. Quasi-static Knee Bending Test.

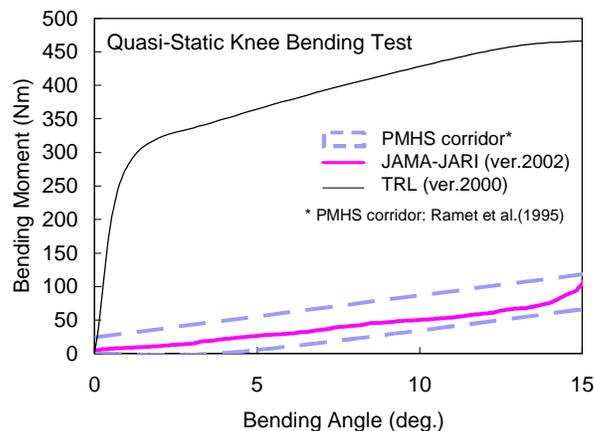


Figure 5. Comparison of the Quasi-static Knee Bending Characteristics between the JAMA-JARI Legform Impactor, TRL legform Impactor, and PMHS

Dynamic Bone Bending Test

Figure 6 describes the states of the dynamic bone bending test for the tibia. Nyquist et al. conducted dynamic bone bending test to the tibia. Authors conducted the same test for the tibia part of the JAMA-JARI legform impactor. Nyquist et al. conducted impact test on the tibia with the fibula and flesh part. The JAMA-JARI legform impactor does not have the fibula part because including it leads to a very complex construction for the legform impactor. Furthermore, a fibula fracture alone does not cause serious injury to the pedestrian. It is therefore, the tibia fracture assessment is set as a first priority and concentrated the tibia bending responses. The JAMA-JARI impactor retained the flesh part characteristics by using Memory foam™ as in the TRL legform impactor. We conducted the bone bending

test with flesh buffer between the legform bone parts and the ram, and examined the total response of the tibia part of the JAMA-JARI legform impactor.

Figure 7 compares the results of the dynamic bone (with flesh) bending characteristics for the JAMA-JARI legform impactor and PMHS. The initial slope is less than that of the PMHS, but the second slope is quite comparable. The initial slope is determined by the flesh and fibula part, suggesting that the Memory foam™ is slightly softer than the combined PMHS flesh and fibula. The second slope is primarily determined by the tibia bending stiffness, so the bone parts of the impactor compare favorably to the PMHS characteristics. The flesh part should exhibit much stiffer characteristics, but the tibia parts can remain as they are.

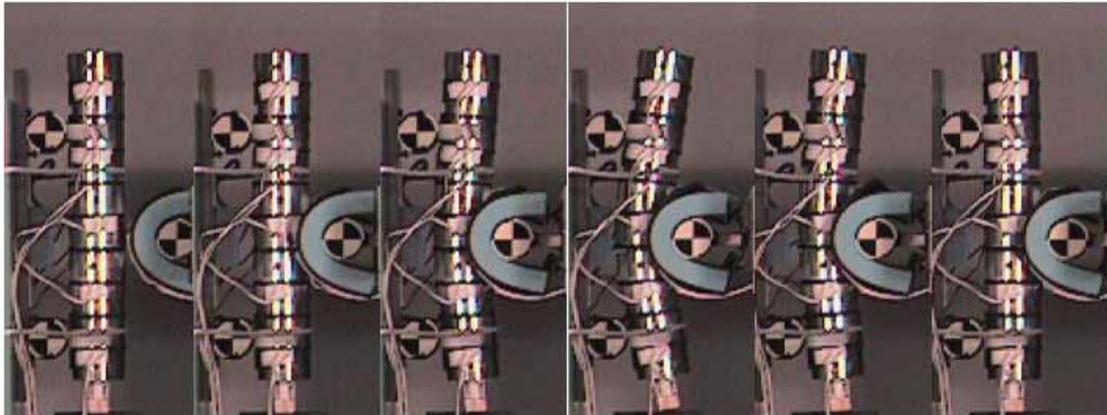


Figure 6. Dynamic Bone Bending Test.
-Tibia- .

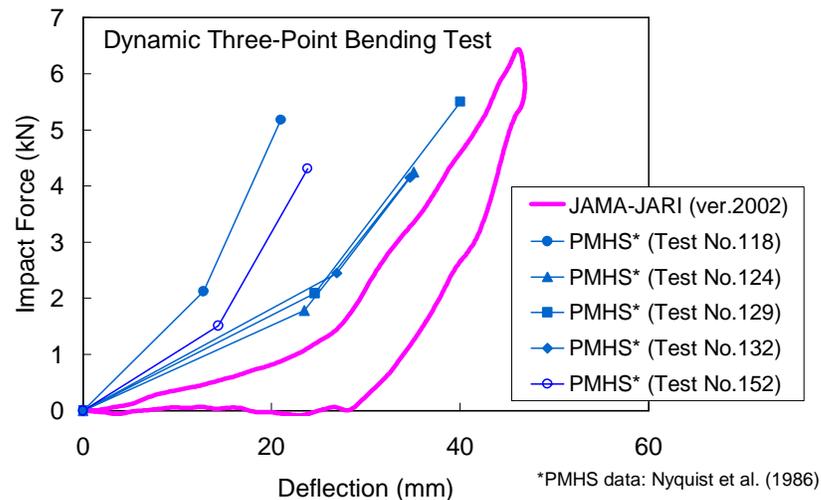


Figure 7. Comparison of the Dynamic Bone Bending Characteristics between the JAMA-JARI Legform Impactor and PMHS.

Dynamic Knee Bending Test

Figure 8 details the states of the dynamic knee bending test comparing the JAMA-JARI legform impactor and the TRL legform impactor. The bending angle of the TRL legform impactor is smaller than that of the JAMA-JARI one. Figure 9 compares the dynamic knee bending responses of the JAMA-JARI legform impactor, TRL legform impactor, and PMHS. As for the TRL legform impactor, the impact force is quite high and the knee bending angle is less than that of the PMHS. On the other hand, the JAMA-JARI legform impactor response is comparable to that of the PMHS.

TRL impactor bone parts do not deform in the test. This means the impact energy concentrates on the knee joint, i.e. the knee joint is subject to larger bending moment. However, the generated bending angle is lower than that of the PMHS one. It means clearly that the TRL knee joint has inappropriate knee joint stiffness.

It is true that the initial phase of the bending angle of JAMA-JARI impactor is also lower than the PMHS corridor, however, the difference is lead by the fresh characteristics. Therefore, it can be modified by using another material for the fresh part.

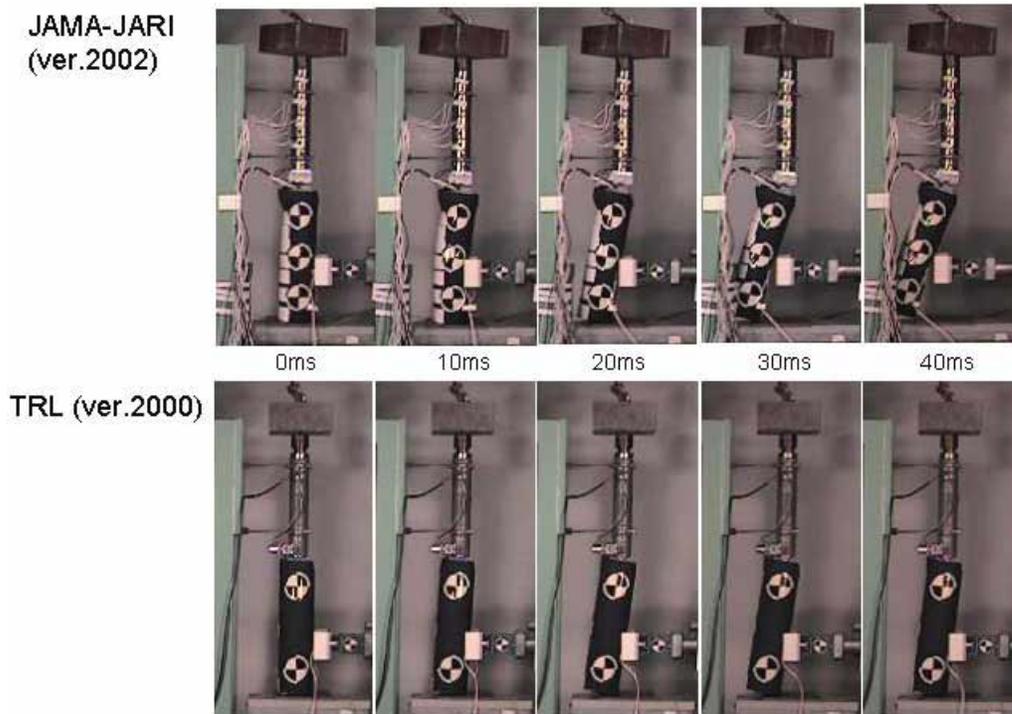


Figure 8. Dynamic Knee Bending Test.

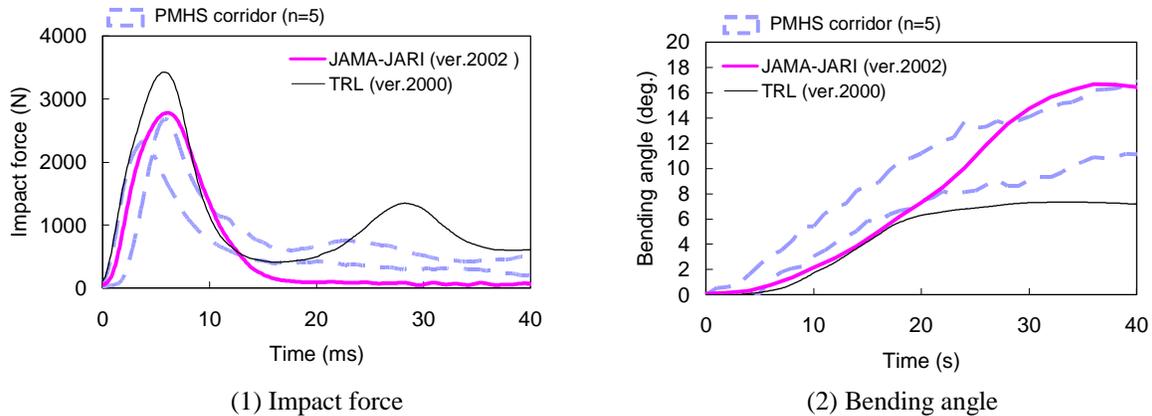


Figure 9. Comparison of the Dynamic Knee Bending Characteristics between the JAMA-JARI Legform Impactor, TRL Legform impactor, and PMHS.

Dynamic Knee Shearing Test

Figure 10 presents the states of the dynamic knee shearing test comparing the JAMA-JARI legform impactor and the TRL legform impactor. The TRL legform impactor can only move its knee shear spring inside the femur. The total kinematics around the knee is thus quite different from that of the JAMA-JARI legform impactor.

impactor, the impact force response is extremely high and the knee shearing displacement is quite low. It means the TRL impactor is quite stiff not only for bending but also for shearing. And the rigid bone also may affect the difference from the PMHS response. As for the JAMA-JARI legform impactor, only the unloading curve after the initial loading of the impact force differs from that of the PMHS. In that phase, however, the shearing displacement already reached to the injury level. Therefore, authors believe the difference does not affect to the proper ligament injury assessment.

Figure 11 compares the dynamic knee shearing responses of the JAMA-JARI legform impactor, TRL legform impactor, and PMHS. On the TRL legform

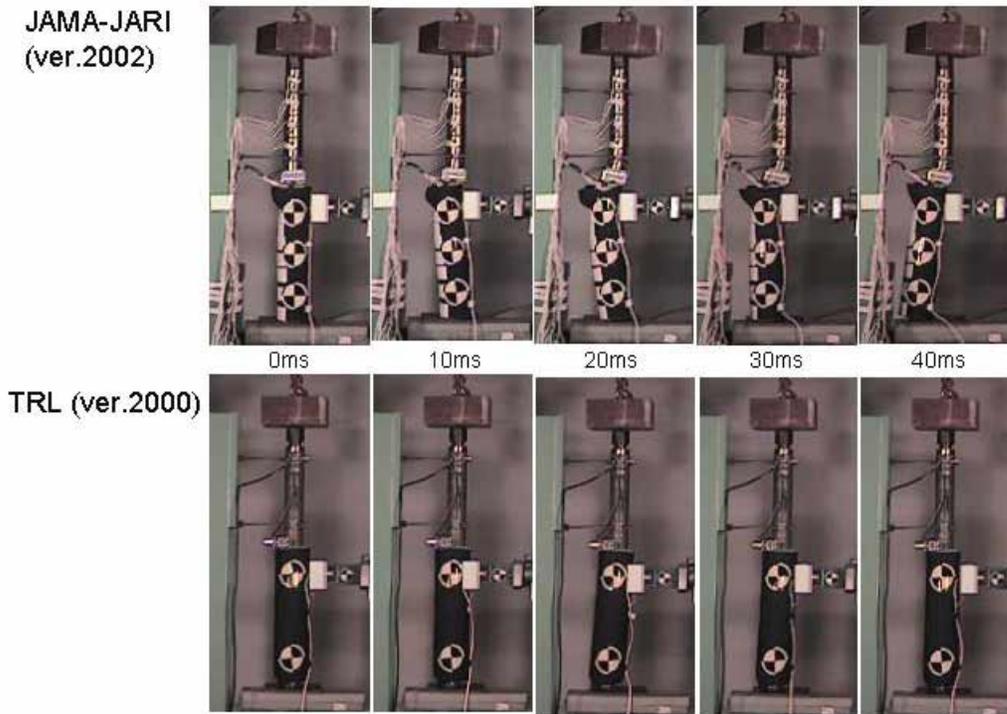


Figure 10. Dynamic Knee Shearing Test.

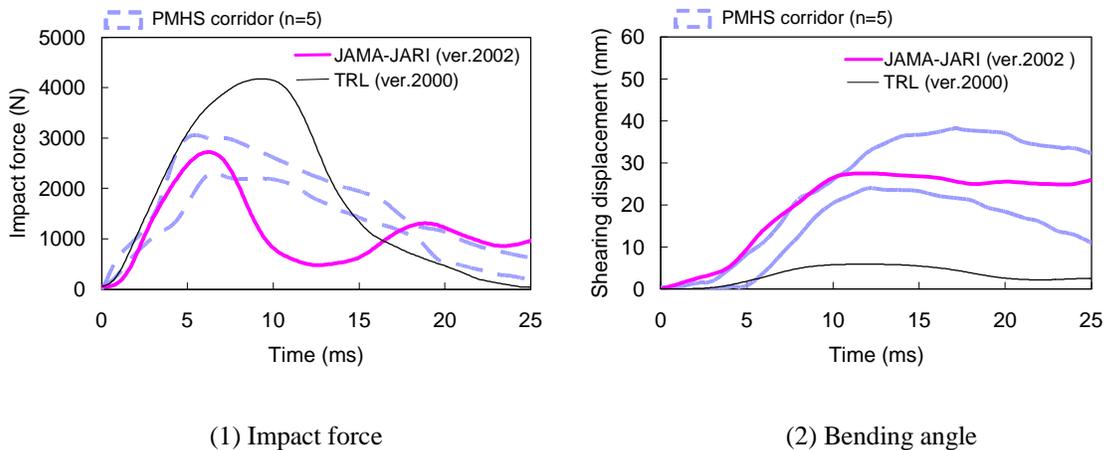


Figure 11. Comparison of the Dynamic Knee Shearing Characteristics between the JAMA-JARI Legform Impactor, TRL Legform impactor, and PMHS.

DISCUSSION

The JAMA-JARI legform impactor (ver. 2002) achieved high biofidelity not only at the component parts level but also at the assembly level. The TRL legform impactor cannot simulate bone flexibility and has a very stiff knee joint; therefore, its biofidelity is quite low. It may be possible to improve its knee bending response by using softer bending material for its knee joint, but the lack of bone flexibility is a fatal flaw in properly estimating bone fractures. Proper bone fracture assessment is required because the current accident data show high rates of bone fractures with quite low rates of knee ligament injuries. The TRL legform impactor is barely able to assess upper tibia fractures by using a built-in accelerometer, but it is quite difficult to assess the severity of bone injuries in other locations. Even if accelerometers are installed in other bone locations, the output differs significantly from the PMHS response [4]. Moreover, using a flexible legform impactor that can generate the proper acceleration at all bone location, bone fractures can be assessed by measuring the strain on a flexible leg (bone severity can be assessed directly). Therefore, the JAMA-JARI legform impactor which has flexible bone has a high potential for producing proper pedestrian leg injury assessments. JAMA and JARI will therefore continue to develop a flexible legform impactor.

CONCLUSIONS

1. JAMA-JARI legform impactor ver. 2002 has high biofidelity at both the component and assembly levels.
2. JAMA-JARI legform impactor ver. 2002 has a high potential for producing proper pedestrian leg injury assessments.

ACKNOWLEDGEMENTS

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