EVALUATION OF THE RISK OF INJURY CAUSED BY A KNEE AIRBAG IN OUT-OF-POSITION

Tiphaine Leport, Pascal Baudrit,
CEESAR, France
Philippe Petit, Xavier Trosseille,
LAB PSA Peugeot Citroën RENAULT, France
Guy Vallancien
Université René Descartes, France

ABSTRACT

As of today, active knee bolsters called knee airbags are available in some vehicles. However no assessment of the risk in Out-of-Position (OOP) conducted on Post Mortem Human Subject could be found in the literature. In total, 3 tests were performed in OOP on the Hybrid III 50th percentile dummy and 2 on two 50th percentile PMHS using a rigid subsystem based on the geometry of a commercially available mid-size European vehicle equipped with a knee airbag. The distance between the tibia and the airbag module ranged between 55 and 67 mm on the Hybrid III and was equal to 53 and 54 mm on the PMHS. The tests conducted on Hybrid III resulted in tibial drawer measurements in good agreement with the injury assessments since no injury was observed except bruises and abrasions (AIS 1). The results from the tests were compared to 36 real world frontal accident cases reported in France where drivers sustained only AIS 1 injuries (abrasion, contusion and bruise) during knee airbag deployment. The conclusions of this study are limited by the size of the sample (only 2 PMHS). However, the consistency between the outcome of the dummy and PMHS tests and the information from real world accidents provides a good confidence in the very low risk of injury associated with the knee airbag tested in OOP. Furthermore, the use of the Hybrid III dummy and the knee injury criteria based on the tibial drawer was appropriate in the tests conducted.

INTRODUCTION

Information on the different kinds of knee solicitations in car accidents is provided in the literature. Prior to the implementation of knee bolsters in the vehicles, the knee used to impact rigid elements such as the dashboard or the steering column, resulting in patella and femoral condyles injuries [1] [2] [3] [4] [5] [6]. Today, the knee bolsters have softened the contact between the knees and the vehicle and the solicitations are more distributed. Therefore, frequency of patella and femoral condyles injury occurrence has decreased and consequently, hip and knee ligament injuries have become of higher relative importance [7] [8] [9] [2] [5] [10] [11] [12] [13]. The development of active knee bolsters (knee airbag) brought a new type of loading, with an unusual range of impact. The literature does not report the existence of any tests on PMHS with such devices. Moreover, dummies have not been validated for this kind of tests [14] [15].

A study was performed on 36 real world frontal accident cases with knee airbags deployment reported in France between 2004 and 2008. The only injuries reported were abrasions, contusions and bruises (AIS1).

MATERIAL AND METHODS

As no assessment of the risk of knee airbag in Out-of-Position (OOP) conducted on Post Mortem Human Subject (PMHS) could be found in the literature, PMHS and dummy tests were performed. The tests were performed in a rigid subsystem based on the geometry of a commercially available mid-size European vehicle equipped with a knee airbag.

Specimen Preparation

For the dummy tests, the Hybrid III 50th percentile male was used. It was instrumented with a femur load cell (Fz), a knee ball slider assembly with linear potentiometer (Dx), a biaxial knee clevis load cell (Fz), a biaxial upper tibia load cell (Mx, My) and a three-axis lower tibia load cell (Fy, Fz, Mx).

The PMHS were obtained through the Body Donation to Science at the Saints Pères University of Medicine in Paris Vth after approval of the experimental procedure by the ethics committee of the university. The PMHS were tested for Cytomegalovirus (CMV), Human T cell Leukemia/lymphoma Virus (HTLV), Hepatitis C Virus (HCV), Hepatitis B Virus (HBV) and Human Immunodeficiency Virus (HIV), and a medical survey was documented. PMHS suspected of bone fragility (long bed stay, bone cancer, metastasis, etc.) were excluded. The PMHS were frozen and then thawed at ambient temperature during 48 hours before preparation. They were chosen to be as close as possible to a 50th percentile male. Their anthropometry, age and sex are reported in Table 1

Table 1 : PMHS Main Characteristics

PMHS #	586	588
Age	74	88
Sex	M	M
Total weight (kg)	77	69
height (m)	1.76	1.67
Thigh height (m)	0.46	0.46
Lower leg height (m)	0.55	0.52

A clinical examination of the knees was performed prior to and after the tests, to exclude the subjects presenting an abnormal laxity. In addition, prior to and after test, X-rays were taken while the thighs were fixed and a force was applied to the tibia by means of a weight of 4.5kg (Figure 1) in order to assess the range of anteroposterior tibial drawer laxity.

The effect of the test on the knee laxity was evaluated through the comparison of the range of laxity prior to and after testings. Finally, a dissection of the knees was performed to check the articular capsule and the knee ligaments.

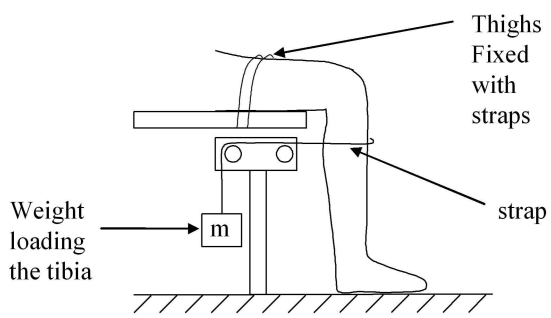


Figure 1 : Assembly for the radiographic examination

Test setups

A rigid subsystem based on the geometry of a commercially available mid-size European vehicle equipped with a knee airbag was used (Figure 3). The surrogate was seated in a standard car seat with the foot laying on a footrest. As in the car, the seat position was adjustable in height and in the antero-posterior direction. The angle of the backrest was 25° relative to the vertical plane. The knee airbag was fixed to a rigid plate placed in front of the knees and with an angle of 38° relative to the vertical plane. A rigid profile of the steering column was fixed to the plate with an angle of 35° with regard to the plane of the plate.

The coordinate system was defined as following: the YZ plane was the plane of the plate, the Z-axis corresponded to the lateral edge of the plate, the center was the left upper corner of the hole of the airbag. The X-axis was positive towards the subject, the Y-axis was positive towards the right and the Z-axis was positive upward.

Positioning procedure

The dummy was installed in the worst but realistic case of Out of Position. It was seated with the knees together, the feet on a rigid foot rest and the heels in contact with a fixed horizontal plan. The seat was initially adjusted in the lower vertical position and was then moved forward until the knees and the profile of the column were in contact. The left-right symmetry was verified. The femur and tibia angles and the distance between the plate and the tibias were used as guidelines for the PMHS positioning.

The PMHS were seated in the car seat with the knees together, the feet on a rigid foot rests and the heels in contact with a fixed horizontal plan. The heels were spread of 240 mm. The seat was positioned to obtain the following target position (Figure 2): the knees in contact with the profile of the column, a distance (D) of 55 mm between the tibias and the center of the airbag (measurement taken perpendicularly to the plate), the femur tilted by 22° and the tibia by 57° with regard to the horizontal plane.

A 3D measuring arm (Romer type 100) was used to digitize the targets and the bone landmarks during the specimen positioning

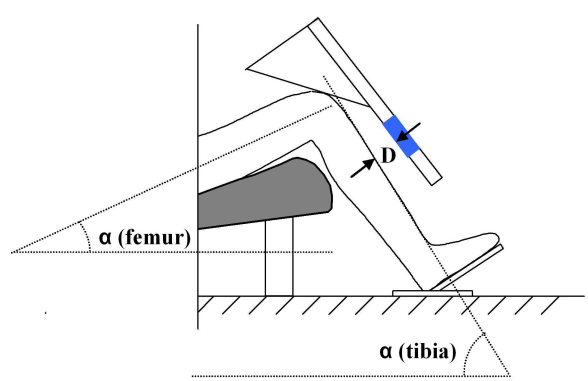


Figure 2 : Leg position

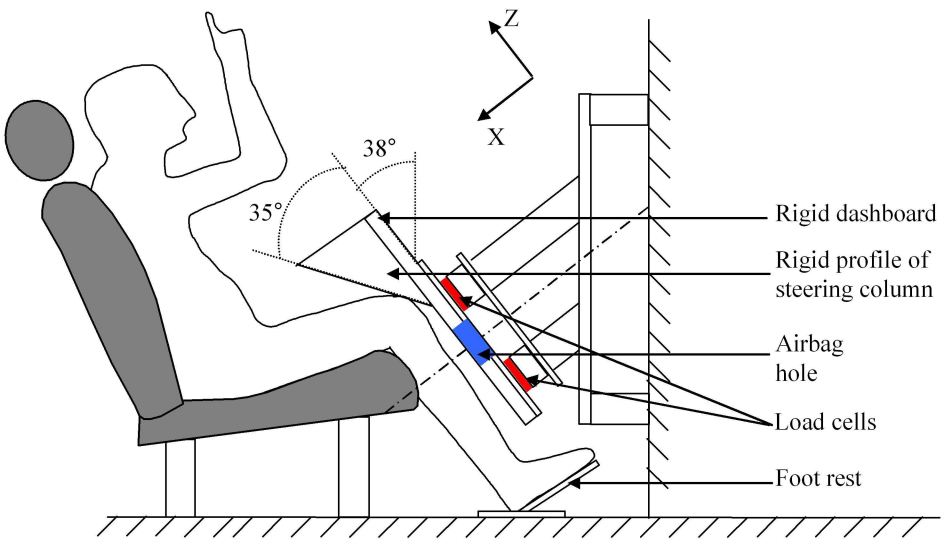


Figure 3 : test setup

Test matrix

The test configurations are described in Table 2. Two reference tests (HIII-C1 and HIII-C2) were performed with the dummy in the realistic OOP. A dummy test (HIII-F) was also performed by increasing the distance D while keeping the knees in contact with the profile of the column.

The PMHS were positioned to obtain the same position than for the dummy in the reference tests.

Table 2 : test matrix

Test #	Subject		D (plate -tibia) (mm)	Tibia angle (°)	Femur angle (°)
HIII-C1	HIII 50th	L	58	57	21
		R	57	58	23
HIII-C2	HIII 50th	L	55	58	23
		R	55	57	22
HIII-F	HIII 50th	L	66	57	20
		R	68	57	23
PMHS-1	MS586	L	51	55	23
		R	54	56	26
PMHS-2	MS588	L	54	55	24
		R	54	54	28

Instrumentation and data processing

Instrumentation. Four load cells were mounted between the airbag plate and a rigid fixed frame, to measure the forces applied onto the legs.

Filtering. The data were filtered CFC180.

High speed video. The tests were recorded using three high-speed cameras at 2000 frames-per-second (fps). The views consisted of a global view (right side), a zoom view centered on the left leg and a ¾ general view (back-above).

RESULTS

Deployment phases

The deployment of the airbag was composed by several phases, showing alternately falls and ascents of the plate forces. These phases are described below and illustrated by a sequence presented in Figure 4.

Phase 1 (F ↑): After the firing, the airbag fabric and the cover were expulsed.

Phase 2 (F ↓): the cover movement in X was stopped.

Phase 3 (F ↑): the airbag deployed against the tibias.

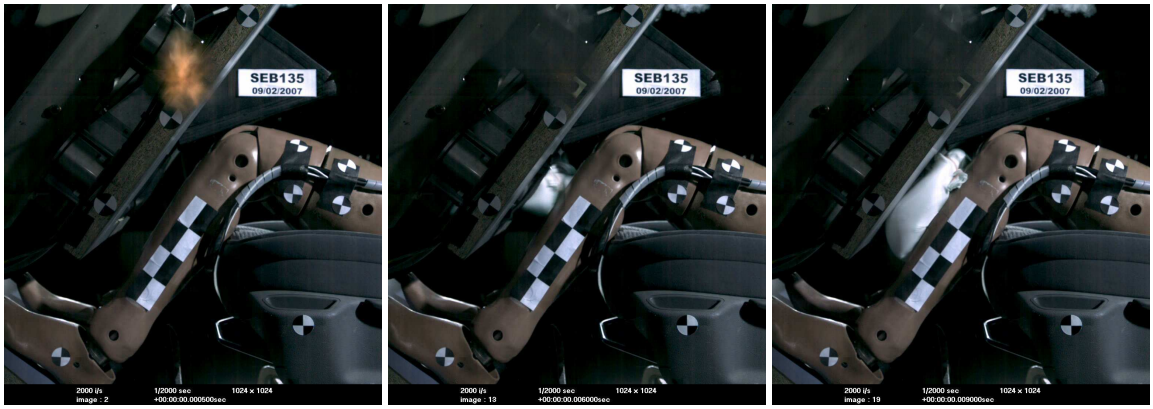
Phase 4 (F ↓): the airbag spread on sides.

Phase 5 (F ↑): the deployment on sides was ended, the airbag pushed on the knees backwards.

Phase 6 (F ↓): the upward unfolding and deployment of the bag. Vent holes opening.

Phase 7 (F ↑): the airbag continued to unfold and pushed on the knees.

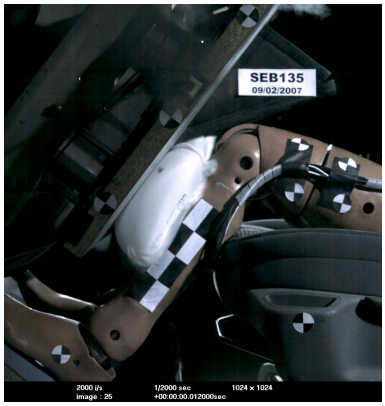
Phase 8 (F ↓): the airbag passed over the knees and freely completed its upward deployment.



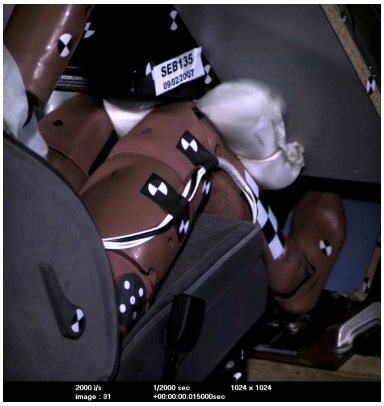
1- cover reaction

2- free deployment

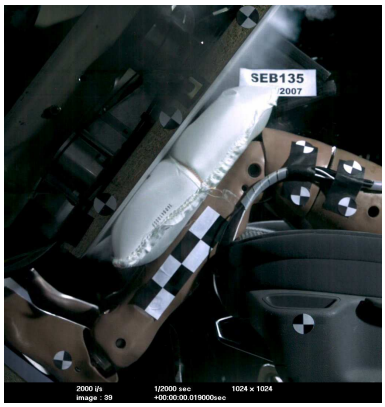
3- unfolding against the tibias



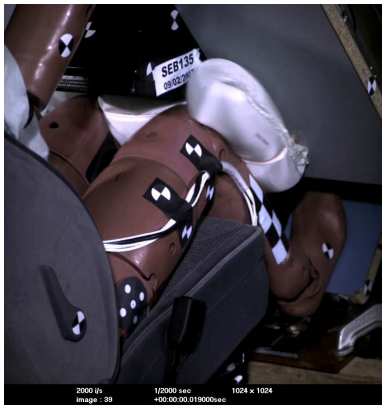
4- lateral deployment



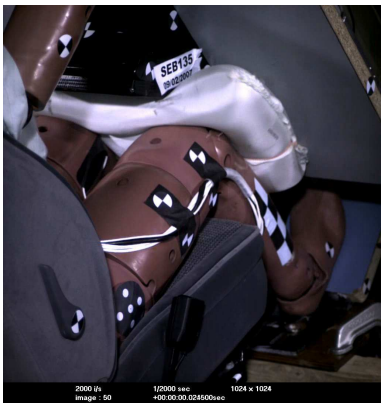
5- knee contact



6- opening of the vent holes



7- unfolding continuation and knee contact



8- airbag over the knees

Figure 4 : Pictures of airbag deployment phases

Plate forces

As the plate was rigid and still, once the fabric was in contact with the lower leg, the plate reaction force can be assumed to be equal to the fabric/leg force. The forces are shown Figure 5. Eight phases of the deployment of the airbag are annotated in Figure 5.

The maximum plate forces and the impulse are presented in Table 3. The dummy tests HIII-C1 and HIII-C2 were very similar in amplitude and in profile. The oscillations observed at the various phases of the unfolding were synchronous. The forces of the PMHS-1 and PMHS-2 tests were also comparable in amplitude and in profile. The curve

profiles were also comparable between the dummy and the PMHS, with synchronous oscillations, but more marked for the PMHS tests. The maximum forces showed no significant difference between the PMHS and the dummy tests. The forces decreased more rapidly for the PMHS than for the dummy, so the total impulse was 30% lower for the PMHS, while at 22 ms, the impulses had the same order of magnitude.

Table 3 : Plate reaction

	Maximum plate force (X-axis) (kN)	Total plate impulse (N.s)	Impulse at 22ms (N.s)
HIII-C1	7.7	218	80
HIII-C2	8.4	240	85
HIII-F	7.0	219	67
PMHS-1	8.0	137	74
PMHS-2	7.6	168	69

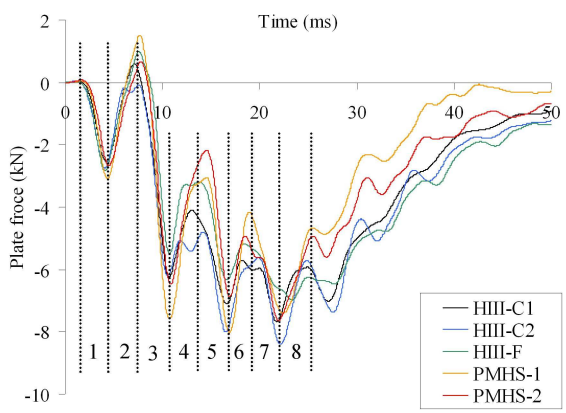


Figure 5 : Plate reaction forces

Injury assessments

The lower limbs of the subject MS586 and MS588 showed no bone or ligament injury. The ranges of knee laxity were not increased by the tests for none of the two specimens. Abrasions were found at the level of the third superior of the tibia or of the joint on each of the knees. (AIS1). The subject MS586 presented a bruise of the semi-membranous muscles at the lower level of the right and left femurs (AIS1). Abrasions and bruises were also observed in the real world accident cases.

Knee injury criterion

According to the bibliography, with the implementation of the knee bolsters in the vehicles, the injuries of the hip and the ligaments of the knee became dominant. It can reasonably be assumed that in OOP, the intrinsic aggressivity of the active systems concerns first the injuries of the ligaments of the knee. The dummy criterion associated with the knee injury is the tibial drawer. This translation was measured during the tests on the Hybrid III (Figure 6). The maximum values are presented in

Table 4 and ranged between 6.3 mm and 11 mm, while it was less than 5mm in the reference car. The threshold of the tibial drawer is 15 mm in the European regulation [16] and 6 mm for the EuroNCap. The translation is lower for the HIII-F test than for the two others where the dummy was positioned closer to the plate. The translation was systematically greater for the left than for the right knee. The femur forces are presented Figure 7.

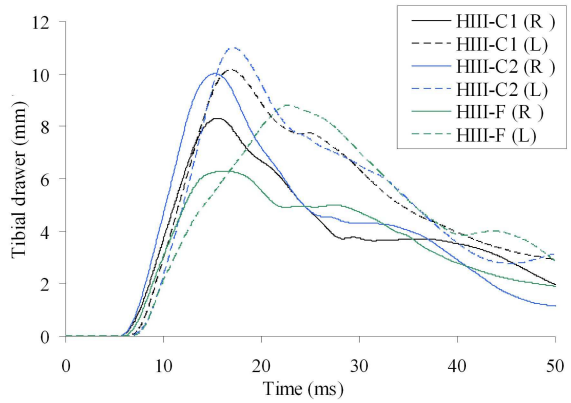


Figure 6 : Tibial drawers

Table 4 : Dummy tests results

	HIII-C1		HIII-C2		HIII-F	
	L	R	L	R	L	R
Max. plate force (kN)	3.9	2.6	4.3	4.1	3.8	3.2
	7.7		8.4		7.0	
Max. tibial drawer (mm)	10.1	8.3	11	10	8.8	6.3
Max. femur force (kN)	2.6	2.5	2.8	2.7	2.4	2.2

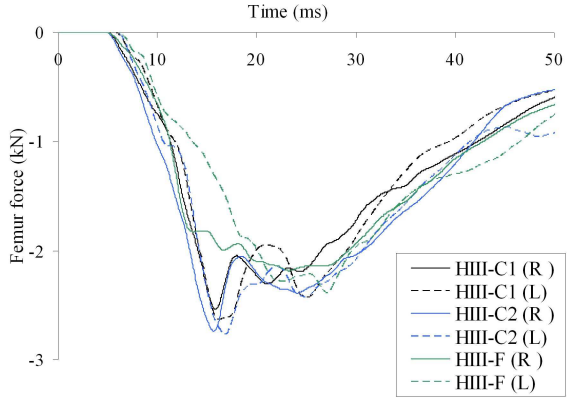


Figure 7 : Femur forces

Bibliographic comparison

Several studies on PMHS were performed to estimate tibial drawer injury threshold. Viano et al. [7], Balasubramanian et al.[12] and Meyer et al.[11] reported that the posterior crossed ligament (PCL) is damaged for an average translation of 16 mm of the tibia relative to the femur. This tibial drawer ranged between 9.5 mm and 30 mm depending on the specimen (Table 5). An injury risk curve for the posterior crossed ligament was calculated as a function of the tibial drawer using the data provided in the literature (Figure 8). Since the tibial drawer value is available at the injury occurrence, the survival method was used. Meyer et al. [11] performed tests with and without axial tibia loading. Balasubramanian et al. [12] performed tests on specimen with knees either intact or with the PCL only. As there is no statically significant difference of the tibia sliding in cases of PCL trauma between the different series of tests for each study, all the data were included to calculate the injury risk curve.

Table 5 : Tibial drawer for PCL injury – bibliographic data

Reference	PCL injury translation (mm)
Viano [7]	9.5
	10.7
	18
	30
Meyer [11]	19.9
	14.5
	17.9
	20.9
	16.1
	9.5
	10
	13.1
Balasubramanian [12]	16.3
	15.9
	21.5
	19.7
	15.3
	14.5

Balasubramanian et al. [12] compared the behavior of the Hybrid III 50th percentile and the PMHS. They found that apart from an initial higher stiffness, the overall response of the ball bearing knee slider of the Hybrid III dummy lay within the corridors for the PCL rupture.

Assuming the HIII dummy to be biofidelic, the tibia sliding of the HIII-C1 and HIII-C2 tests was associated to the PMHS, as the tests were performed in the same conditions and have shown plate forces similar in amplitude. The tibia sliding of the subjects was thus estimated to be equal to 10 mm. According to the injury risk curve, the risk associated with 10mm of tibia sliding is 11 %. It has to be noticed that the injury risk is overestimated compared to the reference car, as the subsystem was rigid, and then the force applied to the femur was higher than in real car tests.

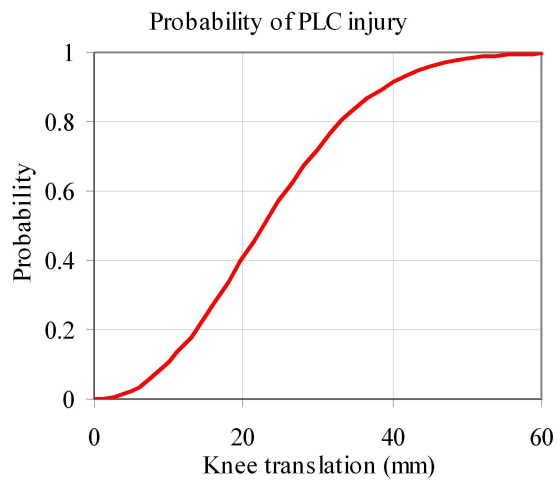


Figure 8 : Injury risk as a function of the tibial drawer

CONCLUSION

The objective of this study was to estimate the intrinsic aggressivity of the knee airbag in OOP. Based on the literature review, it was assumed that the risk due to the system in OOP concerns essentially the knee ligaments.

Three tests on HIII 50th percentile were performed in an Out-of-Position configuration using a rigid subsystem based on the geometry of a commercially available mid-size European vehicle equipped with a knee airbag. Two cadaver tests were performed in the same conditions. A 10mm translation was estimated for these tests. No bone or ligament injury was observed. This is in agreement with the literature tests, from which an injury risk curve was calculated. According to the injury risk curve, the risk associated with a 10mm translation is 11 %. Furthermore, this injury risk overestimated the real car performance since the subsystem was rigid, and then the force

applied to the femur was higher than in real car. Abrasions and bruises were observed on the cadavers. They were in agreement with the real world accident reports.

The conclusions of this study are limited by the size of the sample. However, the consistency between the outcome of the dummy and PMHS tests and the information from real world accidents provides a good confidence in the very low risk of injury associated with the knee airbag tested in OOP. Furthermore, the use of the Hybrid III dummy and the knee injury criteria based on the tibial drawer was appropriate in the tests conducted.

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Agreement concerning the adoption of uniform technical prescriptions for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal ecognition of approvals granted on the basis of these prescriptions