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Article

Assessment of Nanobag as a New Safety System in the Frontal Sled Test

Jan Špička [1],*, Tomasz Bońkowski [1], Luděk Hynčík [1] and Alojz Hanuliak [2]

[1] New Technologies—Research Centre, Department of Biomechanical Human Body Models, University of West Bohemia, Univerzitní 8, 301 00 Pilsen, Czech Republic; tomasz@ntc.zcu.cz (T.B.); hyncik@ntc.zcu.cz (L.H.)
[2] EB Safety Systems, Bohunická 517/55, Horní Heršpice, 619 00 Brno, Czech Republic; hanuliak.a@seznam.cz
* Correspondence: spicka@ntc.zcu.cz

Abstract: Objective: The future mobility challenges lead to considering new safety systems to protect vehicle passengers in non-standard and complex seating configurations. The objective of this study is to assess the performance of a brand new safety system called nanobag and to compare it to traditional airbag performance in the frontal sled test scenario. **Methods:** The nanobag technology is assessed in the frontal crash test scenario and compared with the standard airbag by numerical simulation. The previously identified material model is used to assemble the nanobag numerical model. The paper exploits an existing validated human body model to assess the performance of the nanobag safety system. Using both the new nanobag and the standard airbag, the sled test numerical simulations with the variation of human bodies were performed in 30 km/h and 50 km/h frontal impacts. **Results:** The sled test results for both the nanobag and the standard airbag based on injury criteria show a good and acceptable performance of the nanobag safety system compared to the traditional airbag. **Conclusions:** The results show that the nanobag system's performance is comparable to the standard airbag's, which means that, thanks to the design, the nanobag safety system has high potential and an extended application for multi-directional protection against impact.

Keywords: advanced vehicle safety; standard airbag; nanobag; frontal sled test

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1. Introduction

The vehicle safety is as old as mobility started. The improvement of vehicle occupants' safety was approached in different ways, where all of them led to enforcement through vehicle manufacturers by embedding safety standards into legislation and policies. Whilst the history of safety belts dates back to the early 20th century, the airbag came more than 50 years later [1]. Although the active systems strongly support present vehicles' safety, the passive systems still play a main role. Nowadays, the airbag is an inherent safety system in almost all road vehicles, protecting passengers not only in frontal and side impacts, but special airbag systems mitigate injury to other parts of the human body (knee, chest, etc.) that are also considered vulnerable and likely to be injured [2].

Current trends in the automotive industry bring new challenges for active and passive safety technology. Non-traditional seating configurations in autonomous vehicles and complex crash scenarios including multi-directional impacts are to be considered [3–5] in future automatic vehicles. The expected future scenarios will cover complex and highly unpredictable loading from various directions [6]. This study is testing a new restrain system that can find its benefit in these non-standard seating configurations, where standard airbags can lose their performance. However, nanobag technology needs to be tested and certified firstly in the standard seating position. Moreover, the main aim here is to assess the performance of the nanobag compared to the standard airbag, and it is certified for a standard seating configuration only. Thus, only the standard seating configuration and frontal impact are considered in this study.

The aim of this study is to assess a brand new concept of the interior safety system for front and back seats made of elastic ultralight materials [7,8]. The assessment concerns a virtual numerical simulation using validated models of both the occupant and the restrain system. The new supplemental restraint system called the nanobag concerns a foil folded in front of the passenger to serve as an airbag. The system is built in the way that it can be easily adapted for side impact. The main advantages of this new technology are in minimizing the volume of the folded airbag, decreasing the car weight, simplifying technology production and maintenance, the low cost of materials and the assembly and possible applicability to multidirectional accident scenarios with non-standard seating configurations, which is going to be a critical issue within new technologies of future mobility ecosystems.

For assessing the safety of future mobility, the traditional anthropometric testing devices (dummies) are not suitable due to their unidirectional bio-fidelity, which cannot address non-traditional seating [9]. The new state-of-the art ATDs (THOR) are still in the process of exploration for the automated vehicles crash scenario application [10]. Therefore, the paper utilised an existing validated human body model, Virthuman [11]).

2. Methods

The study adopts new safety system documentation for the nanobag [6] and the hybrid numerical virtual human body model Virthuman [11] in the standard frontal sled test scenario within the defined acceleration pulse simulating 30 km/h and 50 km/h collisions [11]. The computational approach using the validated numerical human model is used for assessing the performance of the new vehicle safety system in the frontal sled test with the identified material of the nanofoil. The nanobag concerns a thin foil (nanofoil) unrolled between side supports. The nanofoil is based on a linear low-density polyethylene (LLDPE), where the material properties were previously identified in both static and dynamic loading conditions [12]. The frontal scenario was chosen as the first step for assessing the performance of the nanobag system due to the ease of comparison to standard airbag performance. The entire numerical tests were performed under the ESI Virtual Performance Solution (VPS) package [13]. The injury risk of the most threatened body parts was monitored by the selected injury criteria [1].

2.1. Occupant Selection

The aim of the study was to compare the performance of both safety systems (the traditional airbag and the new nanobag) for a spectrum of the population by selecting the specific occupant anthropometry to be tested in the frontal sled test with the particular safety features. Authors chose the specific subjects based on the anthropometry of the Czech Republic population representing the average European population and selected the "local peaks" of the population only; see Figure 1.

Figure 1 shows the representation of the age groups in the Czech population. The peaks show the highest representation for 10, 28, 44, 54 and 62–66 years old (further referred to as YO) for both males (M) and females (F). As the comparison concerns frontal seat impact, the youngest group was selected to be in-line with the Czech Republic regulation for the front seat height limit, which is a passenger higher than 150 cm. Thus, the youngest age group was chosen in order to have the female higher than 150 cm (here 14–15 YO). Additionally, percentiles P50 and P95 for the males and P5 of the females from each age interval (in correspondence with the dummy size) were implemented. The particular intervals are defined from the Virthuman model and its internal scaling algorithm, where the age is defined in the intervals (not a single value) [14]. Thus, the specified age groups are selected based on Figure 1, but defined with respect to the Virthuman model scaling, where the ages are defined by the intervals. The list of the selected occupants are as follows, in Table 1:

Table 1. Selected occupant anthropometries of Virthuman model.

Age	Gender	P	h [cm]	m [kg]
14–15	M	50	170	57
	M	95	180	70
	F	5	152.6	41.4
25–30	M	50	178	76
	M	95	187	94
	F	5	158	52.5
35–45	M	50	174	79
	M	95	185.5	96.3
	F	5	154.3	52.5
45–55	M	50	172.3	78.5
	M	95	184.4	96
	F	5	154.2	55
55–65	M	50	171.9	83
	M	95	180.2	95
	F	5	153.5	60

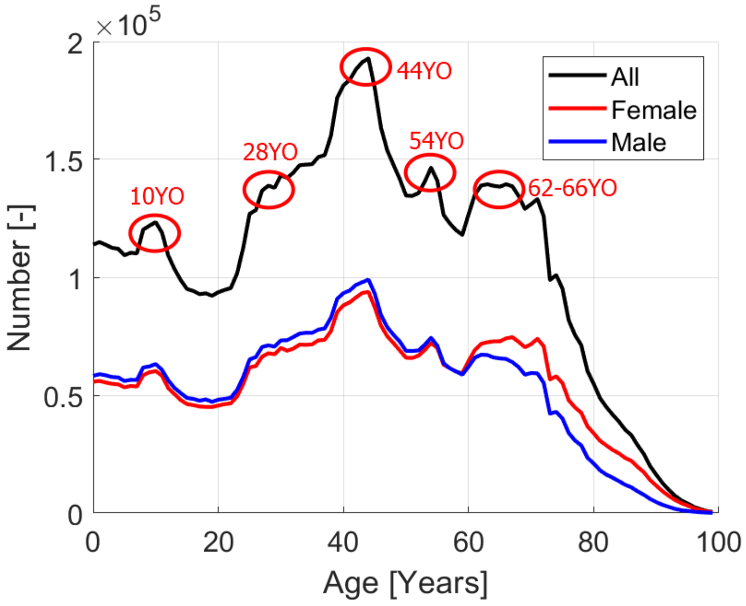

Figure 1. Population of the Czech Republic in 2019 (source: Czech Statistical Office).

2.2. Human Body Model

The study implements Virthuman as a hybrid model combining the advantages of the deformable elements based on finite element methods (FEM) coupled to the multibody structure (MBS) [11]. The deformable elements, representing the external shape of the human body, are connected via non-linear springs and dampers to the rigid segments. Such segments form an open tree structure based on the multibody principle. The particular rigid segments are connected via kinematic joints representing the real human joints (shoulder, elbow, knee, etc.) or breakable joints for the description of the bone fracture.

The Virthuman model is a fully scalable human body model, taking into account the gender, age, height (h) and weight (m) of the particular subject [14], where the wide set of a human anthropometric database [15] is the basis of the automatic scaling algorithm implemented in the model.

The Virthuman model was validated against a large set of validation tests. The full-body tests for various traffic scenarios [16–18] and body sizes [19,20] as well as detailed tests for the particular human body segments [11] were performed to ensure the biofidelity of the Virthuman model. This model is MBS-based using the deformable elements (virtual springs, dampers and kinematic joints with internal stiffness or breakable joints) to consider the deformability of the human body. It does not include internal structures and internal organs. However, the deformability and injury risk that could be assessed are taken into account through injury criteria coupled with the injury risk curves. The criteria are calculated based on the mechanical quantities, such as accelerations, velocities, forces, torques, etc.

2.3. Safety System

This paper implemented two supplemental restraint system (SRS) into the frontal sled test scenario—namely the standard airbag and a new system called the nanobag, together with the standard three points seat belt.

2.4. Airbag

The previously utilized model of the standard airbag (referred to as AB in figures and tables) was used for the simulations [11]. The undeployed airbag model is fixed to the steering wheel, and the deploying process runs within the simulation. The airbag is activated at the begging of the simulation for both simulations. The airbag starts the deploying process within the simulation, defined via the characteristics of the airbag in the VPS software. The airbag is modelled as a single chamber with all its features, such as inflating or leakage.

2.5. Nanobag System

The nanobag (later referred to as NB in figures and tables) system consists of two thin, layered curtains folded in front of the occupant. Such technology consists of an elastic wall, brackets, a gas generator and a controlling system; see Figure 2. They are arranged under the roof and deployed under sensor activation (similar to the standard airbag). The simplified geometry of the nanobag system was built based on the documentation provided by [6]. The study implements the previously identified linear low density polyethylene LLDPE nanofoil material [12]. Hynčík [12] performed the numerical optimization of material parameters to fit the performed experimental tests. Static and dynamical analysis were considered to model and validate the material behaviour for such loading. The nanobag is considered as a several layers of such LLDPE foil. The number of layers is one of the main parameters of the safety assessment of this technology, and it is to be tested.

Figure 2. Nanobag system.

For the assessment of the safety performance, the nanobag support frame is considered a rigid body, and the nanobag is considered to be deployed at the beginning of the simulation. The process of the deployment (unfolding) of the nanobag was not considered in this study. The inclination of the nanobag support to the cushion seat is 25° for the inner layer and 30° for the outer layer. The position of the seat and the nanobag was equal for all the configurations. In order to respect the adjusting of the seat and to model the experimental test correctly, the footrest was adjusted closely to the feet (the feet are in the close contact with the footrest); see Figure 3. The nanobag rigid frame is considered to be fixed to the car roof (into the reinforcement). However, since this system is still under development and not has been tested and certified, the particular design and method of fixing to the frame is not considered in this study.

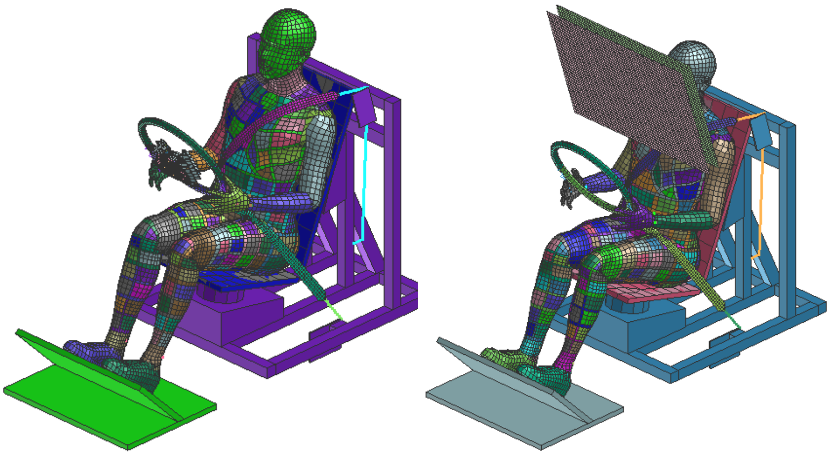

Figure 3. The sled test initial configurations. The airbag (**left**) and the nanobag (**right**).

2.6. Seat Belts

The model is seated as a driver and fastened with a seatbelt using a semi-automatic tool build implemented in the VPS software with the default material properties of the seat belt. For simplicity, the seat is considered rigid. In order to represent a more realistic case, the hands were considered to be in contact with the steering wheel [21]. The seat belt consists of the membrane elements (in the part of contact with the body) and bar elements (in the connection to a retractor, slipring and buckle, respectively). The material characteristics of these structures are defined (and previously validated in VPS software).

2.7. Sled Test Scenario

The standard frontal sled test scenario was used here [22]. The configuration based on the previous tests [11] consists of the seat fixed to the rigid frame, 3-point seat belt system and the particular elements of the passive safety (airbag or nanobag). The steering wheel was also included (to fix the airbag), and it is being modelled as rigid. The motion of the sled device was defined by the acceleration pulses corresponding to the velocities 30 km/h and 50 km/h [11] defined on the COG of a rigid seat. The sled tests were performed for two velocities using two safety systems (airbag and nanobag). The test matrix can be summarized as follows:

- Two velocities (30 km/h and 50 km/h);
- 15 occupant anthropometries (according to Table 1);
- Two safety approaches (airbag and nanobag),

where the nanobag was tested for 4, 6, 8 and 10 layers of LLDPE forming the nanobag, i.e., 2 × 15 × 5 = 150 configurations in total. Figure 3 shows the particular initial configurations for the airbag and the nanobag in case of the P50 male, age range 25–30 YO, height equal to 178 cm and weight equal to 78 kg.

3. Results and Discussion

This study virtually assessed new safety technology, the nanobag, with respect to the airbag. This feature consists of the rigid frame and thin elastic foil. Such technology can help in the safety of the future cars (where the non-standard seating configurations are being considered—i.e., autonomous car). The identified material model of the LLDPE foil was used to develop the nanobag safety system, and its safety performance was assessed and compared to the traditional airbag by the numerical simulations using a previously validated biomechanical virtual human body model.

Since the most vulnerable human parts in the case of frontal crashes are the head and the neck, respectively, their injury indicators (criteria) are considered the main assessment criteria for the nanobag safety system. The head injury risk is evaluated with the head injury criteria (HIC) [1] and brain criteria (BrIC and UBrIC) for soft tissue injury criteria [23–25], and neck injury is tested via neck injury criteria (Nij) [1,26]. The head acceleration curves are filtered with the CFC 1000 filter, and HIC is calculated from such filtered curves. In order to assess the performance of the nanobag with respect to the traditional airbag, the additional probability of AIS injury for head and brain injury were also considered [1]. The UBrIC criterion for predicting brain injury (soft tissue) is based on the response of the second-order mechanical system, and relates rotational head kinematics to strain-based brain injury. It was developed based on the maximum principal strain (MPS) or cumulative strain damage measure (CSDM), and it can be evaluated with respect to these matrices. The Nij criterion considers the axial force and bending moment generated on the neck spine and plots them into corridors. These corridors are changing with the anthropometry of a particular passenger.

Consequently, the HIC and maximum Nij criteria result in a single scalar value that can be formulated with the injury risk. These values can be recalculated by utilizing the S-Shape curve to obtain the probability of a particular injury risk in terms of abbreviated injury scale (AIS) value. The contact force between the occupant and a particular SRS is also monitored, and the maximum values are presented.

3.1. 30 km/h Results

Head acceleration results in the time dependence curve of its COG versus time. The plot on Figure 4 shows the limits (maximum and minimum values) of all the configurations as well as their mean values. This plot shows that all the cases have a similar curve shape, and there is not a one curve, which would behave in very different manner.

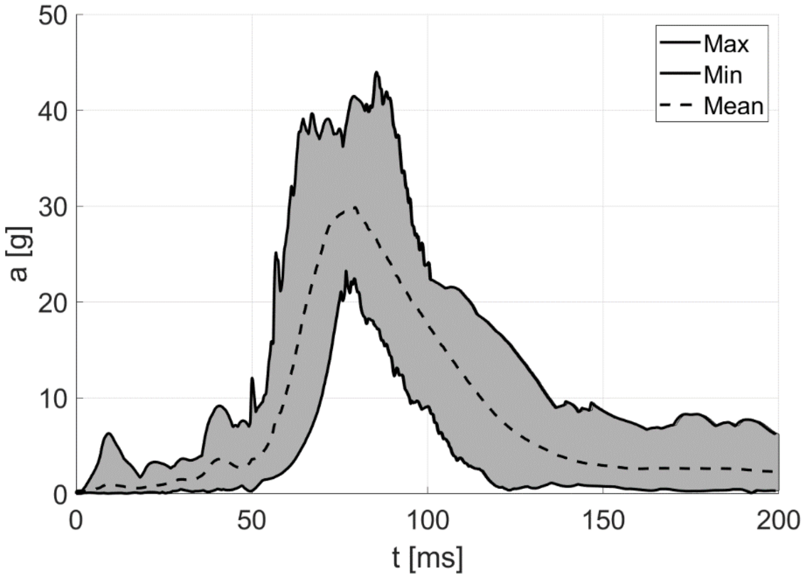

Figure 4. Head COG acceleration for 30 km/h pulse.

In order to assess the effect of the airbag and nanobag for various anthropometry, respectively, the plot of body mass index (BMI) vs. head injury criterion (HIC) are depicted. The BMI pairs the height and weight of the subject, and both are considered to be assessed for the safety effect; see Figure 5. All the curves report increasing the HIC value for higher a BMI for both safety systems. The approximation curve is the lowest in the case of the airbag, followed by the 4-layer nanobag. With increasing numbers of layers, the HIC values tend to increase (more layers, stiffer obstacle and higher head acceleration). However, all values are still within the acceptable region of head injury risk of <1000 [27]. The best protection is predicted for a standard airbag for a BMI up to 29. After this limit, the HIC predicts lower values for the nanobag with 4 layers.

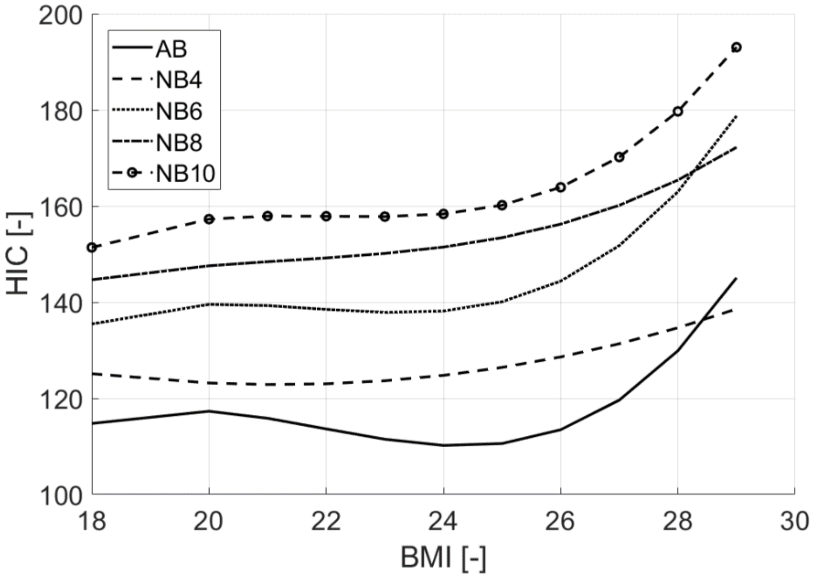

Figure 5. BMI vs. HIC plots for 30 km/h pulse.

Neck injury risk is tested by means of the Nij criterion, which plots the axial compression force depending on the bending moment into the corridor (function of the antopometry). If the curves are inside the corridor, the risk of neck injury is within the safety limits, and no serious injury should appear. The Nij criterion curves lay inside the defined corridors in all tested scenarios for the acceleration pulse of 30 km/h.

The full results are displayed in Table 2, where the HIC value, the Nij max value, the probability of AIS injury 2 for the head and 2–5 for the neck, BrIC, UBrIC criteria and the maximum contact force F_c between the passenger and the SRS (airbag and nanobag), respectively, are displayed. The last three lines (79–81) in the Table 2 show the maximum, minimum and averages of the particular values.

Particular subjects (VH) are represented as males (Ma) and females (Fa) of a given age (a) and percentile (p). Airbag (AB) and nanobag NBn of n layers are compared.

Table 2. Results of 30 km/h impact pulse.

VH	m [kg]	h [cm]	BMI	SRS	HIC	Nij	Head	Neck				BrIC	UBrIC		Fc [kN]
							AIS2+	AIS2+	AIS3+	AIS4+	AIS5+		MPS	CSDM	
M14 p50	57	170	20	AB	126	0.13	1.69	13.08	4.91	7.36	2.52	0.57	0.19	0.28	1.37
	57	170	20	NB4	113	0.071	1.22	12.24	4.36	6.86	2.34	0.50	0.17	0.24	0.46
	57	170	20	NB6	125	0.061	1.67	12.12	4.28	6.79	2.31	0.49	0.17	0.24	0.64
	57	170	20	NB8	135	0.061	2.06	12.12	4.28	6.79	2.31	0.48	0.16	0.23	0.73
	57	170	20	NB10	145	0.051	2.55	11.99	4.20	6.71	2.28	0.47	0.16	0.22	0.79
M14 p95	70	180	22	AB	95	0.099	0.69	12.62	4.60	7.08	2.42	0.64	0.23	0.32	1.41
	70	180	22	NB4	110	0.057	1.11	12.06	4.25	6.75	2.30	0.50	0.17	0.24	0.49
	70	180	22	NB6	128	0.05	1.78	11.98	4.19	6.70	2.28	0.53	0.18	0.26	0.64
	70	180	22	NB8	135	0.045	2.10	11.91	4.15	6.66	2.27	0.51	0.18	0.25	0.76
	70	180	22	NB10	143	0.039	2.46	11.84	4.11	6.62	2.25	0.50	0.17	0.24	0.83
F14 p05	41	153	18	AB	108	0.23	1.06	14.45	5.88	8.18	2.82	0.50	0.17	0.24	0.90
	41	153	18	NB4	126	0.13	1.69	13.05	4.89	7.34	2.51	0.49	0.16	0.23	0.39
	41	153	18	NB6	138	0.11	2.20	12.79	4.72	7.18	2.45	0.48	0.16	0.23	0.48
	41	153	18	NB8	145	0.097	2.56	12.59	4.58	7.06	2.41	0.47	0.15	0.22	0.54
	41	153	18	NB10	153	0.086	2.92	12.44	4.49	6.98	2.38	0.46	0.15	0.22	0.63
M28 p50	76	178	24	AB	91	0.14	0.59	13.22	5.01	7.44	2.55	0.63	0.22	0.31	0.10
	76	178	24	NB4	100	0.09	0.81	12.49	4.52	7.00	2.39	0.51	0.17	0.24	0.45
	76	178	24	NB6	108	0.077	1.06	12.33	4.42	6.91	2.36	0.50	0.17	0.24	0.62
	76	178	24	NB8	116	0.069	1.33	12.22	4.35	6.84	2.33	0.49	0.16	0.24	0.74
	76	178	24	NB10	124	0.066	1.62	12.18	4.32	6.82	2.32	0.49	0.16	0.23	0.81
M28 p95	94	187	27	AB	95	0.11	0.68	12.82	4.73	7.20	2.46	0.73	0.26	0.36	2.16
	94	187	27	NB4	112	0.069	1.20	12.23	4.35	6.85	2.33	0.51	0.17	0.25	0.54
	94	187	27	NB6	127	0.055	1.75	12.04	4.23	6.74	2.29	0.52	0.18	0.25	0.71
	94	187	27	NB8	141	0.049	2.37	11.97	4.19	6.70	2.28	0.52	0.18	0.25	0.86
	94	187	27	NB10	153	0.045	2.93	11.92	4.16	6.67	2.27	0.50	0.17	0.25	1.00
F28 p05	53	158	21	AB	125	0.21	1.67	14.17	5.68	8.02	2.75	0.47	0.16	0.22	1.17
	53	158	21	NB4	137	0.13	2.18	12.96	4.83	7.29	2.49	0.48	0.16	0.23	0.47
	53	158	21	NB6	152	0.095	2.90	12.56	4.56	7.05	2.40	0.46	0.15	0.22	0.67
	53	158	21	NB8	164	0.077	3.53	12.32	4.41	6.90	2.35	0.45	0.15	0.21	0.80
	53	158	21	NB10	173	0.072	4.05	12.26	4.37	6.87	2.34	0.43	0.14	0.21	0.88
M44 p50	79	174	26	AB	117	0.16	1.36	13.38	5.12	7.54	2.58	0.72	0.26	0.36	1.64
	79	174	26	NB4	125	0.087	1.66	12.46	4.50	6.99	2.38	0.57	0.20	0.28	0.47
	79	174	26	NB6	140	0.068	2.33	12.21	4.34	6.84	2.33	0.62	0.22	0.31	0.64
	79	174	26	NB8	151	0.058	2.86	12.08	4.26	6.76	2.30	0.63	0.23	0.31	0.84
	79	174	26	NB10	162	0.049	3.44	11.97	4.19	6.70	2.28	0.64	0.23	0.32	0.94
M44 p95	96	186	28	AB	144	0.14	2.48	13.18	4.98	7.42	2.54	0.71	0.24	0.34	2.16
	96	186	28	NB4	114	0.087	1.24	12.45	4.49	6.98	2.38	0.65	0.23	0.32	0.51
	96	186	28	NB6	132	0.078	1.96	12.34	4.42	6.91	2.36	0.56	0.19	0.27	0.68
	96	186	28	NB8	141	0.063	2.36	12.15	4.30	6.80	2.32	0.55	0.19	0.27	0.83
	96	186	28	NB10	145	0.059	2.55	12.10	4.27	6.77	2.31	0.71	0.26	0.36	0.97
F44 p05	53	154	22	AB	116	0.24	1.34	14.54	5.94	8.24	2.83	0.42	0.14	0.20	1.45
	53	154	22	NB4	137	0.12	2.19	12.90	4.79	7.25	2.48	0.48	0.16	0.23	0.50
	53	154	22	NB6	152	0.089	2.89	12.48	4.51	7.00	2.39	0.46	0.15	0.22	0.64
	53	154	22	NB8	162	0.087	3.45	12.46	4.50	6.98	2.38	0.44	0.15	0.21	0.73
	53	154	22	NB10	172	0.086	3.97	12.44	4.49	6.98	2.38	0.44	0.14	0.21	0.84
M54 p50	79	172	27	AB	119	0.15	1.41	13.28	5.05	7.48	2.56	0.75	0.27	0.38	1.77
	79	172	27	NB4	144	0.083	2.47	12.40	4.46	6.95	2.37	0.67	0.24	0.34	0.53
	79	172	27	NB6	150	0.075	2.81	12.30	4.40	6.89	2.35	0.67	0.24	0.33	0.71
	79	172	27	NB8	172	0.051	3.97	11.99	4.20	6.71	2.28	0.79	0.29	0.40	0.87
	79	172	27	NB10	184	0.05	4.73	11.98	4.19	6.70	2.28	0.82	0.31	0.42	1.02
M54 p95	96	184	28	AB	164	0.17	3.52	13.56	5.24	7.65	2.62	0.61	0.21	0.30	2.30
	96	184	28	NB4	147	0.073	2.66	12.28	4.38	6.88	2.34	0.57	0.20	0.28	0.53
	96	184	28	NB6	214	0.073	6.73	12.27	4.38	6.87	2.34	0.51	0.17	0.25	0.77
	96	184	28	NB8	180	0.058	4.46	12.09	4.26	6.77	2.30	0.60	0.21	0.30	0.87
	96	184	28	NB10	193	0.056	5.34	12.06	4.25	6.75	2.30	0.57	0.20	0.29	0.99
F54 p05	55	154	23	AB	122	0.24	1.56	14.66	6.03	8.31	2.86	0.42	0.14	0.20	1.59
	55	154	23	NB4	124	0.13	1.61	13.04	4.89	7.34	2.51	0.56	0.19	0.27	0.47
	55	154	23	NB6	147	0.1	2.65	12.62	4.61	7.08	2.42	0.52	0.18	0.25	0.67
	55	154	23	NB8	159	0.086	3.28	12.44	4.49	6.98	2.38	0.52	0.18	0.25	0.77
	55	154	23	NB10	166	0.08	3.68	12.36	4.44	6.93	2.36	0.44	0.14	0.21	0.86
M64 p50	83	172	28	AB	124	0.17	1.62	13.64	5.29	7.69	2.64	0.87	0.32	0.44	1.77
	83	172	28	NB4	150	0.099	2.78	12.61	4.60	7.08	2.42	0.63	0.22	0.31	0.54
	83	172	28	NB6	170	0.077	3.87	12.33	4.42	6.91	2.36	0.72	0.26	0.36	0.74
	83	172	28	NB8	185	0.063	4.81	12.15	4.30	6.80	2.32	0.77	0.29	0.39	0.90
	83	172	28	NB10	199	0.063	5.71	12.15	4.30	6.80	2.32	0.83	0.31	0.42	0.98

Table 2. *Cont.*

VH	m [kg]	h [cm]	BMI	SRS	HIC	Nij	Head	Neck				BrIC	UBrIC		Fc [kN]
							AIS2+	AIS2+	AIS3+	AIS4+	AIS5+		MPS	CSDM	
M64 p95	95	180	29	AB	126	0.15	1.68	13.26	5.03	7.47	2.55	0.90	0.33	0.45	2.11
	95	180	29	NB4	136	0.087	2.10	12.46	4.50	6.98	2.38	0.83	0.31	0.42	0.53
	95	180	29	NB6	170	0.066	3.88	12.18	4.32	6.82	2.32	0.80	0.30	0.41	0.71
	95	180	29	NB8	168	0.053	3.78	12.02	4.22	6.73	2.29	0.69	0.25	0.35	0.85
	95	180	29	NB10	193	0.055	5.33	12.04	4.23	6.74	2.29	0.70	0.26	0.35	1.00
F64 p05	60	154	25	AB	120	0.24	1.48	14.58	5.98	8.26	2.84	0.44	0.15	0.21	1.74
	60	154	25	NB4	150	0.16	2.80	13.41	5.14	7.56	2.59	0.54	0.18	0.25	0.47
	60	154	25	NB6	167	0.14	3.74	13.12	4.94	7.38	2.53	0.51	0.17	0.24	0.61
	60	154	25	NB8	179	0.12	4.44	12.92	4.80	7.26	2.48	0.49	0.16	0.23	0.71
	60	154	25	NB10	187	0.11	4.89	12.75	4.69	7.16	2.45	0.48	0.16	0.23	0.86
M28 p50	76	178	24	–	84	0.12	0.45	12.90	4.79	7.25	2.48	0.54	0.18	0.26	
Max					214.00	0.24	6.73	14.66	6.03	8.31	2.86	0.90	0.33	0.45	2.30
Min					91.00	0.04	0.59	11.84	4.11	6.62	2.25	0.42	0.14	0.20	0.10
Ø					144.15	0.10	2.65	12.60	4.60	7.07	2.41	0.58	0.20	0.28	0.88

The maximum value of the HIC is 214 (M, P95, 54 YO, 184 cm, 96 kg for a 6-layer nanobag), and its minimum is 91 (M, P50, 28 YO, 178 cm, 76 kg, airbag). The results of the crash scenario with no safety features (seat belts only) for the average occupant (M P50, 28 YO, 178 cm, 76 kg) are also provided in Table 2 (line 78) to get a referenced value for no SRS configuration. The maximum probability of AIS 2+ for the head and neck are 6.7% and 14.7%, respectively. The criteria for soft tissue brain injury (BrIC and UBrIC) do not have specific thresholds to distinguish the particular injury risk. However, they can be used to assess the performance of the nanobag, comparing to a traditional airbag. BrIC results with a minimum value of 0.4 (F P05, 44 YO, 154 cm, 53 kg—airbag) and with a maximum of 0.9 (M P95, 64 YO, 180 cm, 95 kg—airbag). Generally, the BrIC gives slightly higher values for the particular anthropometry in configuration with the airbag, but the range of these values is not very large. Criterion UBrIC has its minimum MPS value 0.14 (F P05, 28 YO, 158 cm, 53 kg—nanobag 10 layers; F P05, 44 YO, 154 cm, 53 kg—airbag and nanobag 10 layers; F P05, 54 YO, 154 cm, 55 kg—airbag) and the minimum CSDM value 0.2 (F P05, 44 YO, 154 cm, 53 kg—airbag, F P05, 54 YO, 154 cm, 55 kg—airbag), while the maximum MPS value is 0.33 (M P95, 64 YO, 180 cm, 95 kg—airbag), and the maximum in CSDM is 0.45 (M P95, 64 YO, 180 cm, 95 kg—airbag). The UBrIC criterion results in very similar values for the specific anthropometry; however, the maximal values for MPS and CSDM are predicted for the airbag. The minimum contact force is 0.1 kN (M P50, 28 YO, 178 cm, 76 kg—airbag) and the maximum value 2.3 kN (M P95, 54 YO, 184 cm, 96 kg—airbag). The minimum value is for the average male (the size of P50 dummy) with the airbag SRS. Such results confirmed that the passive safety technologies (seat belts and airbag) are optimized for this anthropometry. The Table 3 summarizes the minimum, maximum and average values for the particular criteria, together with the anthropometry and SRS.

The results suggest that head and neck injury risks for all safety measures are in the acceptable range and predicts a similar safety performance of the nanobag and airbag in this specific crash configuration. The majority of the max values occurs for the airbag. However, the airbag SRS also offers a majority of the minimal values.

Table 3. Summary of the extreme values of the particular criteria for 30 km/h.

Criteria	Min			Max			Average
	Value	Anthropometry	SRS	Value	Anthropometry	SRS	
HIC	91	M P50, 28 YO, 178 cm, 76 kg	AB	214	M P95, 54 YO, 184 cm, 96 kg	NB6	144
Nij	0.039	M P95, 14 YO, 180 cm, 70 kg	NB10	0.24	F P05, 64 YO, 150 cm, 60 kg	AB	0.1
BrIC	0.4	F P05, 44 YO, 154 cm, 53 kg	AB	0.9	M P95, 64 YO, 180 cm, 95 kg	AB	0.58
UBrIC—MPS	0.14	F P05, 28 YO, 158 cm, 53 kg F P05, 44 YO, 154 cm, 53 kg F P05, 54 YO, 154 cm, 55 kg	NB10 AB & NB10 AB	0.33	M P95, 64 YO, 180 cm, 95 kg	AB	0.2
UBrIC—CSDM	0.2	F P05, 44 YO, 154 cm, 53 kg	AB	0.45	M P95, 64 YO, 180 cm, 95 kg	AB	0.28
Fc [kN]	0.1	M P50, 28 YO, 178 cm, 76 kg	AB	2.3	M P95, 54 YO, 184 cm, 96 kg	AB	0.88

3.2. 50 km/h Results

The head acceleration curves (corridors of max and min values and average curve) are plotted at the Figure 6. There is a significant peak in the acceleration at about the time of 700 ms, with the peak value being about 135 g. These are curves of Male, P95 percentile, 54 YO, 184 cm, 96 kg. Such values are higher than the rest of the curves; however, the HIC criterion are still lower than critical threshold of 1000 (here the max value is 702 for the 10 layers nanobag). The peak is caused by the internal structure of the Virthuman, where the neck vertebrae reaches their defined physiological limit and stops the head's forward motion.

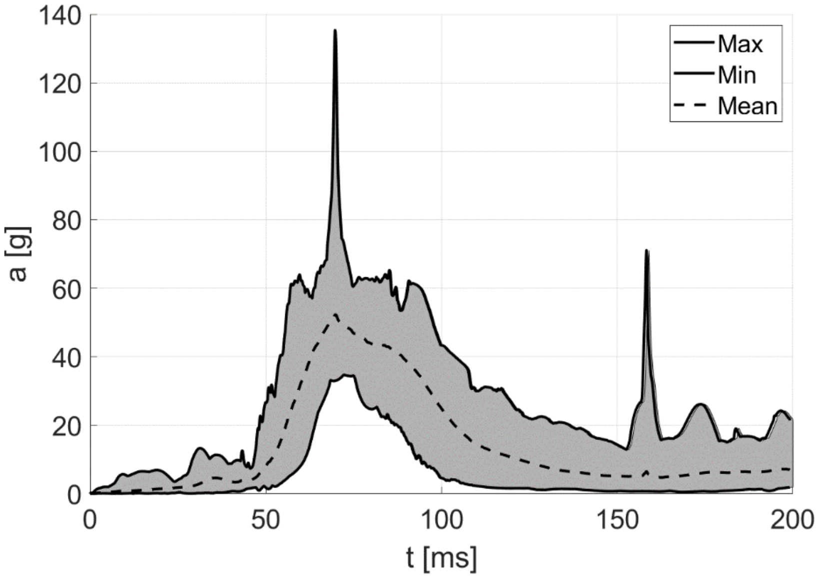

Figure 6. Head COG acceleration for 50 km/h pulse.

The curves of BMI vs. HIC have a similar trend to the 30 km/h pulse. However, there is an interesting effect of the higher impact velocity. The approximation curve (mean value) does not significantly increase with the increasing number of LLDPE layers; see Figure 7. The best protection of the head is achieved by the application of the four-layer nanobag. These results suggest that in a higher impact velocity, the difference between the standard airbag and nanobag is lower than in a slow velocity impact.

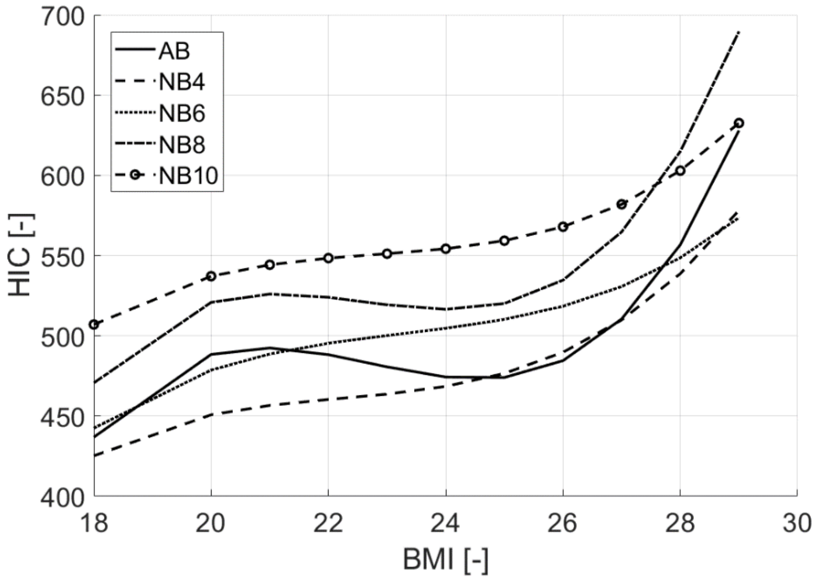

Figure 7. BMI vs. HIC plots for 50 km/h pulse.

The Nij curves are significantly higher than in case of 30 km/h; however, they still lay inside the corridors. There is only one configuration where the curves cross the corridors (M, P95, 54 YO, 184 cm, 95 kg); see Figure 8, where also the results of Male, P50, 28 YO, 178 cm, 76 kg (standard dummy size) are plotted as a reference.

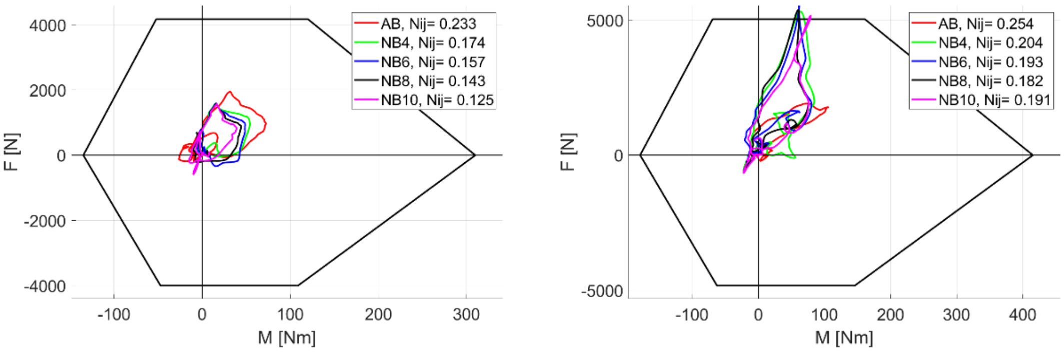

Figure 8. Nij criterion for average Male, P50, 28 YO, 178 cm, 76 kg (**left**) and Male, P95, 54 YO, 184 cm, 95 kg (**right**).

The full results table are displayed in Table 4, where the HIC value, the Nij max value, the probability of AIS injury 2 for the head and 2–5 for the neck, BrIC, UBrIC criteria and the maximum contact force Fc between passenger and SRS (airbag and nanobag), respectively, are displayed. The last three lines (79–81) in the Table 4 show the maximum, minimum and average of the particular values.

Table 4. Results of 50 km/h impact pulse.

VH	m [kg]	h [cm]	BMI	SRS	HIC	Nij	Head	Neck				BrIC	UBrIC		Fc [kN]
							AIS2+	AIS2+	AIS3+	AIS4+	AIS5+		MPS	CSDM	
M14 p50	57	170	20	AB	493	0.21	26.59	14.13	5.65	7.99	2.75	0.72	0.24	0.35	1.00
	57	170	20	NB4	409	0.12	21.26	12.87	4.77	7.23	2.47	0.60	0.20	0.29	0.67
	57	170	20	NB6	428	0.11	22.57	12.70	4.66	7.13	2.44	0.58	0.19	0.28	0.95
	57	170	20	NB8	456	0.09	24.36	12.52	4.54	7.02	2.40	0.60	0.20	0.29	1.16
	57	170	20	NB10	476	0.08	25.59	12.34	4.42	6.92	2.36	0.61	0.21	0.30	1.36
M14 p95	70	180	22	AB	499	0.16	26.90	13.40	5.13	7.55	2.59	0.96	0.35	0.48	2.49
	70	180	22	NB4	460	0.12	24.58	12.84	4.75	7.21	2.46	0.62	0.20	0.30	0.67
	70	180	22	NB6	495	0.10	26.67	12.59	4.59	7.07	2.41	0.58	0.19	0.28	0.89
	70	180	22	NB8	541	0.08	29.14	12.39	4.46	6.95	2.37	0.71	0.25	0.35	1.13
	70	180	22	NB10	575	0.07	30.78	12.29	4.39	6.89	2.35	0.79	0.29	0.40	1.32
F14 p05	41	153	18	AB	423	0.33	22.24	16.02	7.09	9.15	3.17	0.57	0.19	0.28	1.99
	41	153	18	NB4	419	0.20	21.96	14.07	5.60	7.95	2.73	0.61	0.20	0.29	0.56
	41	153	18	NB6	440	0.16	23.34	13.48	5.18	7.60	2.60	0.57	0.19	0.27	0.79
	41	153	18	NB8	476	0.12	25.59	12.86	4.76	7.22	2.47	0.54	0.18	0.26	0.96
	41	153	18	NB10	508	0.08	27.43	12.39	4.46	6.95	2.37	0.52	0.17	0.25	1.15
M28 p50	76	178	24	AB	452	0.23	24.10	14.49	5.91	8.21	2.82	1.02	0.37	0.51	0.12
	76	178	24	NB4	496	0.17	26.77	13.64	5.30	7.69	2.64	0.63	0.21	0.31	0.79
	76	178	24	NB6	519	0.16	28.02	13.40	5.13	7.55	2.58	0.59	0.20	0.29	1.02
	76	178	24	NB8	541	0.14	29.18	13.20	4.99	7.43	2.54	0.58	0.20	0.28	1.27
	76	178	24	NB10	562	0.13	30.19	12.97	4.83	7.29	2.49	0.62	0.22	0.31	1.51
M28 p95	94	187	27	AB	510	0.19	27.51	13.92	5.50	7.87	2.70	0.91	0.33	0.45	2.41
	94	187	27	NB4	541	0.18	29.14	13.74	5.37	7.75	2.66	0.84	0.28	0.40	1.00
	94	187	27	NB6	505	0.16	27.24	13.42	5.14	7.56	2.59	0.93	0.32	0.46	0.99
	94	187	27	NB8	499	0.14	26.91	13.10	4.92	7.37	2.52	0.64	0.22	0.32	1.44
	94	187	27	NB10	517	0.13	27.91	12.98	4.85	7.30	2.50	0.72	0.25	0.36	1.70
F28 p05	53	158	21	AB	561	0.44	30.15	17.77	8.57	10.24	3.57	0.81	0.26	0.42	2.42
	53	158	21	NB4	571	0.27	30.59	15.07	6.35	8.56	2.95	0.71	0.23	0.35	0.63
	53	158	21	NB6	600	0.22	31.89	14.31	5.78	8.10	2.79	0.67	0.22	0.34	0.93
	53	158	21	NB8	620	0.18	32.69	13.67	5.32	7.71	2.64	0.65	0.21	0.33	1.17
	53	158	21	NB10	643	0.16	33.58	13.42	5.14	7.56	2.59	0.64	0.21	0.32	1.38
M44 p50	79	174	26	AB	595	0.24	31.70	14.54	5.95	8.24	2.84	0.93	0.33	0.47	2.79
	79	174	26	NB4	475	0.15	25.53	13.36	5.10	7.53	2.58	0.65	0.22	0.32	0.70
	79	174	26	NB6	506	0.13	27.33	13.09	4.92	7.36	2.52	0.62	0.21	0.30	1.00
	79	174	26	NB8	545	0.11	29.36	12.74	4.68	7.15	2.44	0.67	0.24	0.33	1.29
	79	174	26	NB10	577	0.09	30.88	12.45	4.49	6.98	2.38	0.75	0.27	0.37	1.57
M44 p95	96	186	28	AB	567	0.24	30.43	14.58	5.98	8.27	2.84	0.89	0.31	0.44	3.34
	96	186	28	NB4	624	0.17	32.87	13.64	5.30	7.70	2.64	0.80	0.26	0.39	0.82
	96	186	28	NB6	500	0.14	26.98	13.11	4.93	7.38	2.52	0.64	0.21	0.31	1.09
	96	186	28	NB8	619	0.17	32.68	13.52	5.21	7.62	2.61	0.77	0.26	0.37	1.30
	96	186	28	NB10	636	0.16	33.32	13.46	5.17	7.58	2.60	0.76	0.26	0.37	1.55
F44 p05	53	154	22	AB	453	0.39	24.14	16.95	7.86	9.72	3.38	0.63	0.22	0.31	2.73
	53	154	22	NB4	448	0.26	23.85	14.82	6.16	8.41	2.90	0.64	0.21	0.31	0.63
	53	154	22	NB6	476	0.20	25.61	14.04	5.58	7.94	2.73	0.61	0.20	0.29	0.85
	53	154	22	NB8	513	0.16	27.70	13.46	5.17	7.58	2.60	0.58	0.19	0.28	1.09
	53	154	22	NB10	542	0.14	29.22	13.10	4.93	7.37	2.52	0.57	0.19	0.28	1.27
M54 p50	79	172	27	AB	531	0.23	28.66	14.49	5.91	8.21	2.82	0.79	0.28	0.40	3.35
	79	172	27	NB4	476	0.16	25.58	13.39	5.12	7.54	2.58	0.68	0.23	0.33	0.70
	79	172	27	NB6	516	0.14	27.86	13.15	4.96	7.40	2.53	0.62	0.21	0.30	1.00
	79	172	27	NB8	545	0.12	29.39	12.85	4.76	7.22	2.47	0.71	0.25	0.35	1.29
	79	172	27	NB10	571	0.10	30.61	12.59	4.58	7.06	2.41	0.82	0.30	0.41	1.53
M54 p95	96	184	28	AB	563	0.25	30.22	14.80	6.14	8.40	2.89	0.86	0.31	0.43	3.62
	96	184	28	NB4	519	0.20	28.05	14.06	5.59	7.95	2.73	0.85	0.28	0.41	0.68
	96	184	28	NB6	676	0.19	34.71	13.90	5.48	7.85	2.70	0.88	0.29	0.42	0.98
	96	184	28	NB8	704	0.18	35.55	13.75	5.37	7.76	2.66	0.85	0.28	0.40	1.00
	96	184	28	NB10	703	0.19	35.53	13.87	5.46	7.83	2.69	0.83	0.28	0.40	1.14
F54 p05	55	154	23	AB	444	0.38	23.60	16.80	7.74	9.63	3.35	0.56	0.19	0.27	2.81
	55	154	23	NB4	377	0.24	19.01	14.53	5.94	8.23	2.83	0.64	0.21	0.31	0.61
	55	154	23	NB6	450	0.20	23.97	14.05	5.59	7.94	2.73	0.57	0.19	0.27	0.89
	55	154	23	NB8	456	0.15	24.38	13.29	5.05	7.48	2.56	0.58	0.20	0.28	1.09
	55	154	23	NB10	487	0.13	26.26	12.98	4.84	7.30	2.49	0.63	0.22	0.31	1.30
M64 p50	83	172	28	AB	497	0.25	26.79	14.81	6.15	8.40	2.89	1.09	0.40	0.55	2.59
	83	172	28	NB4	538	0.18	29.04	13.69	5.33	7.72	2.65	0.58	0.19	0.29	0.83
	83	172	28	NB6	592	0.16	31.53	13.47	5.18	7.60	2.60	0.65	0.21	0.32	0.94
	83	172	28	NB8	635	0.16	33.27	13.41	5.14	7.56	2.59	0.75	0.24	0.39	1.21
	83	172	28	NB10	624	0.13	32.87	13.01	4.86	7.32	2.50	0.70	0.25	0.35	1.44
M64 p95	95	180	29	AB	629	0.22	33.06	14.30	5.77	8.09	2.78	1.04	0.38	0.53	3.69
	95	180	29	NB4	538	0.14	29.04	13.13	4.94	7.39	2.53	0.73	0.24	0.36	0.88
	95	180	29	NB6	515	0.11	27.80	12.78	4.71	7.18	2.45	0.82	0.29	0.41	1.10
	95	180	29	NB8	648	0.13	33.77	12.96	4.83	7.29	2.49	0.64	0.21	0.32	1.50
	95	180	29	NB10	563	0.10	30.23	12.59	4.59	7.07	2.41	0.93	0.34	0.47	1.67

Table 4. *Cont.*

VH	m [kg]	h [cm]	BMI	SRS	HIC	Nij	Head	Neck				BrIC	UBrIC		Fc [kN]
							AIS2+	AIS2+	AIS3+	AIS4+	AIS5+		MPS	CSDM	
F64 p05	60	154	25	AB	405	0.36	20.98	16.49	7.48	9.44	3.28	0.50	0.17	0.24	2.53
	60	154	25	NB4	474	0.24	25.43	14.54	5.94	8.24	2.83	0.68	0.22	0.33	0.63
	60	154	25	NB6	499	0.19	26.94	13.90	5.48	7.85	2.69	0.64	0.21	0.30	0.88
	60	154	25	NB8	524	0.17	28.29	13.54	5.23	7.64	2.62	0.63	0.21	0.31	1.16
	60	154	25	NB10	539	0.16	29.05	13.44	5.16	7.58	2.60	0.64	0.21	0.32	1.37
M28 p50	76	178	24	–	539	0.17	29.07	13.65	5.30	7.70	2.64	0.74	0.25	0.35	
Max					702	0.44	35.50	17.77	8.57	10.24	3.57	1.09	0.40	0.55	3.69
Min					377	0.07	19.02	12.29	4.39	6.89	2.35	0.50	0.17	0.24	0.12
Ø					454	0.09	24.19	12.52	4.54	7.02	2.40	0.60	0.20	0.29	1.16

Particular subjects (VH) are represented as males (M) and females (F) of a given percentile (P). Airbag (AB) and nanobag NBn of n layers are compared.

The maximum value of the HIC is 702 (M, P95, 54 YO, 184 cm, 96 kg; 10 layers nanobag); its minium is 377 (M, P05, 54 YO, 154 cm, 55 kg, nanobag 4) and the average value is 454 (safety value of HIC). The maximal probability of AIS 2+ for head and neck are 35.5% and 19%, respectively. These results suggest the safety region of injury risk for all safety features. The results also indicate a significant increase of head injury risk with a higher impact velocity (AIS2+ for head: 6.73% and 35.5% for 30 km/h and 50 km/h pulse, respective), while the neck injury risk increases in-significantly (AIS2+ for neck: 14.66% and 17.7% for 30 km/h and 50 km/h pulse, respective). The BrIC criterium results with the minimum value 0.5 (F P05, 64 YO, 154 cm, 60 kg—airbag) and with the maximum 1.09 (M P50, 64 YO, 180 cm, 95 kg—airbag). Generally, the BrIC gives similar values for each particular anthropometry in all configurations. Criterion UBrIC has its minimum MPS value at 0.17 (F P05, 14 YO, 153 cm, 41 kg—nanobag 10 layers; F P05, 64 YO, 154 cm, 60 kg—airbag) and the minimum CSDM value of 0.24 (F P05, 64 YO, 154 cm, 60 kg—airbag), while the maximum MPS value is 0.4 (M P50, 64 YO, 172 cm, 83 kg—airbag) and the maximum in CSDM is 0.55 (M P50, 64 YO, 172 cm, 83 kg—airbag). The UBrIC criterion results in very similar values for the specific anthropometry; however, the maximal values for MPS and CSDM are predicted for the airbag. The minimum contact force is 0.12 kN (M P50, 28 YO, 178 cm, 76 kg—airbag) and maximum value 3.69 kN (M P95, 64 YO, 180 cm, 95 kg—airbag). The minimum value is predicted for the average male (the size of P50 dummy) with the airbag SRS. Such results confirmed that the passive safety measures (seat belts and airbag) are optimized for this anthropometry. Similarly, to the 30 km/h pulse, the results of the crash scenario with no safety features (seat belts only) for the average occupant (M, P50, 28 YO, 178 cm, 76 kg) are also provided. Table 5 summarizes the minimum, maximum and average values for all particular criteria, together with the anthropometry and SRS.

The results of 50 km/h impacting velocities also predicted the assessment of the nanobag with the safety region of the head and neck injury risk. Moreover, it also gave similar safety measures to the nanobag and airbag in this specific crash configuration. Most of the extremes values were also predicted for the airbag (maximum and minimum) in the higher velocity impact.

Table 5. Summary of the extreme values of the particular criteria for 50 km/h.

Criteria	Min			Max			Average
	Value	Anthropometry	SRS	Value	Anthropometry	SRS	
HIC	377	F P05, 54 YO, 154 cm, 55 kg	NB4	702	M P95, 54 YO, 184 cm, 96 kg	NB10	454
Nij	0.07	M P95, 14 YO, 180 cm, 70 kg	NB10	0.44	F P05, 28 YO, 158 cm, 53 kg	AB	0.09
BrIC	0.5	F P05, 64 YO, 154 cm, 60 kg	AB	1.09	M P50, 64 YO, 172 cm, 83 kg	AB	0.6
UBrIC—MPS	0.17	F P05, 14 YO, 153 cm, 41 kg F P05, 64 YO, 154 cm, 60 kg	NB10 AB	0.4	M P50, 64 YO, 172 cm, 83 kg	AB	0.2
UBrIC—CSDM	0.24	F P05, 64 YO, 154 cm, 60 kg	AB	0.55	M P50, 64 YO, 172 cm, 83 kg	AB	0.29
Fc [kN]	0.12	M P50, 28 YO, 178 cm, 76 kg	AB	3.69	M P95, 64 YO, 180 cm, 95 kg	AB	1.16

3.3. Summary of Results

The results of a frontal sled test exhibited a similar performance for the standard airbag and for the nanobag. In the impacting velocity of 30 km/h, all the HIC values lied within the minor injury risk (max. value was 214—nanobag). The maximal HIC of all the airbag scenarios was 164—which was in the same anthropometry as the total max value of 214 (M, P95, 54 years, 184 cm, 96 kg—NB6). The highest probability of head injury of AIS2+ was 6.7%. The highest neck injury risks were 14.6% (AIS2+), 6.0 (AIS3+), 8.3 (AIS4+) and 2.9 (AIS5+). AIS 2+ injury was classified as a moderate injury, and in case of the neck it was considered a minor laceration of vertebrae or dislocation without fracture.

The scenario with the higher impact velocity (50 km/h) resulted in a higher injury risk for the head and neck, respectively. The maximal HIC value was 702 (acceptable injury) (M, P95, 54 years, 184 cm, 96 kg—NB10), while the average was 520 (minor injury—good condition of survivability for human) [27]. The maximal HIC of all the airbag scenarios was 595 (M, P50, 44 years, 174 cm, 79 kg). The highest probability of head injury of AIS2+ was 35.5%. The highest neck injury risks were 17.7% (AIS2+), 8.6 (AIS3+), 10.2 (AIS4+) and 3.6 (AIS5+). All the values of injury risk lied within the safety region. The results suggest that increasing of the impact velocity affects more the head then the neck injury risk: head AIS2+: 6.7 (30 km/h) and 35.5 (50 km/h); and neck AIS2+: 14.7 (30 km/h) and 17.7 (50 km/h). The brain soft tissue injury criteria (BrIC and UBrIC) and maximum contact force had similar results for all particular scenarios (both impacting velocities and all configurations).

4. Conclusions

This paper tested the safety assessment of a new safety system called nanobag. Such a system consists of thin polymer foil protecting the head in the similar way to a traditional airbag. It is a brand new system, and it is not certified yet. This paper compares its protective effect in the frontal test and compares it to standard airbag performance. The benefits of the nanobag solution lie in the minimization of the volume of the folded nanobag, the minimization of the weight, the simplicity of the technology production and the low cost of material inputs, including the assembly and maintenance. The system can be easily adapted for nonstandard seating positions (tightly connected with the autonomous vehicles), where the side, oblique or rear direction of the impact are to be occurred. The performance of the standard airbag is assumed to lose its benefit in such configurations. The numerical simulations with the application of human body models as a surrogate for the occupant could lead to faster progress in the field of safety measure optimization for a diverse society. The nanobag safety system shows comparable performance to the traditional airbag solution in frontal direction impacts. For the tested populations (five age groups and 5th female, 50th percentile male and 94th percentile male) the assessment of the nanobag is comparable to the airbag. Most of the monitored criterion gave the maximum values (weak protection) for the airbag, but the airbag also predicts the minimal values in the same criterion (for different anthropometries). Such results show a similar protective effect for both safety systems (traditional airbag and new nanobag) for a frontal impact. The maximal HIC criterion results are below the critical safety limit of 1000 (214 for 30 km/h and 702 for 50 km/h), which is considered a safety region. However, the key point of the calculated results are comparable to the safety assessment of the nanobag system compared to the traditional airbag in the two velocities for frontal crashes.

It gives another possible safety solution for car developers and enables them to build future cars safer. The suggested technology does not try to replace the airbag; it only suggests a new technical solution, which, of course, could have some pros and cons, especially that a prototype of the mechanical system based on a nanobag must be tested in a real full-scale setup to be certified. Moreover, the technology of adjusting the system to real vehicles is also not fully developed. However, the safety effect is expected to be beneficial and comparable to the traditional airbag. Together with other safety technologies, the annanobag can find some benefits for future cars.

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