Effect Analysis of Different Use Ways of a Q10 Child Seat

Junjie Li, Chen Zang

CATARC (Tianjin) Automotive Engineering Research Institute Co., Ltd, Tianjin 300300, China

Abstract: In this paper, the injury situation of Q10 child dummy was optimized and analyzed by analyzing the impact of different ways of using a certain child seat ,and analyzing the crash test data of a real car based on LS-DYNA crash simulation analysis software after the vehicle benchmarking, by elaborating on the protection of child occupants in different ways of using this type of child seat, so as to provide a reference for the development of child restraint system of new cars. The results show that: Regardless of whether this type of child seat has an optional seat back, adding seat belt Secure Guard and not using ISOFIX fixing, the dummies' injuries show a decreasing trend. This study provides reference for the selection and use of this type of child seat in dynamic test.

Keywords: Child Occupant Protection; Injury of Q10 dummy; Child Seat.

1. Preface

Ordinary consumers are aware of the product of child seats, but a large number of people do not know how to use it correctly. According to a report of China Consumer Network[1], the misuse rate of child seats in Australia, where the usage rate is as high as 95%, is up to 79%; and that in the United States is 72.6%.

Zhang Jinhuan et al.[2] analyzed the impact of misoperation of child seat support legs on dummy injuries in a study, and concluded that the impact of misuse of support legs on safety performance includes: the maximum displacement of the dummy's head will increase by 14.3%, the maximum Head Injury Criterion (HIC) value of the head will increase by 37.2%, the maximum 3ms acceleration of the chest will increase by 37.3%, and the maximum 3ms acceleration of the chest in the Z-direction will increase by 15.4%. Facing such a high proportion of misuse and the serious consequences it brings, it is worth parents with children and automakers to ponder deeply. Automakers need to clearly introduce the proper use of child seats compatible with their vehicle models in the vehicle owner's manual, which is a key consideration for child protection development engineers during the automotive development process. Correct use of child seats can effectively protect child occupants from injury or reduce the severity of injury in traffic accidents[3]. This underscores the importance of child restraint systems for child protection, and it is essential to choose and use child seats correctly in vehicles.

In recent years, the evaluation of child protection has been strengthened at the level of NCAP (New Car Assessment Programme). Taking China NCAP[4] and Euro NCAP[5] management regulations as examples, restrictions have been imposed on the types of child seats used in Q10. However, there are few direct quantitative studies on how to match the protective performance of child restraint systems under different management regulations and how to correctly use optional child seat accessories. Different usage methods of child seats can lead to different protective effects on children. Therefore, to fill the research gap and solve practical engineering application problems, this paper, based on the benchmarking of the Frontal 50% Overlap Moveable Progressive Deformable Barrier Crash Test (MPDB) data from a real vehicle, analyzes the injury patterns of Q10 dummies in child restraint system simulations by investigating different usage methods of a particular type of child seat. It derives the variation patterns associated with different usage methods of this type of child seat, providing data references for child restraint system and vehicle engineers, as well as a basis for accurately providing child seat usage information in vehicle owner's manuals, ultimately enhancing the safety of children in vehicles.

2. Evaluation Basis for Injury Assessment of Child Q10 Dummy

Based on the scoring systems of C-NCAP 2021 and Euro-NCAP 2023, this paper analyzes the changes in injury levels of the Q10 child dummy by referring to the performance limits for critical injury metrics in MPDB (Mobile Progressive Deformable Barrier) tests. By integrating the evaluation areas specified in the regulatory guidelines, the 3-ms acceleration of the Q10 child dummy's head, the axial tension FZ of the neck, the 3-ms acceleration of the chest, and the upper and lower compression of the chest are selected as the evaluation areas for analyzing the Q10 child dummy in this paper.

If the Q10 child's head experiences a secondary collision with components such as the front seat or B-pillar during forward movement, the head injury assessment is conducted using two metrics: the Head Injury Criteria 15 (HIC15) and the cumulative 3-ms resultant acceleration of the head. The final head injury assessment is determined by taking the more severe outcome of the two metrics. For neck evaluation, it is generated through the extension tension Fz index of the Q10 dummy's neck, with the extension bending moment My serving as a reference for refining the neck evaluation. Chest evaluation encompasses two indicators: the cumulative 3-ms resultant acceleration of the dummy's chest and the chest compression deformation. In Euro-NCAP, threshold values are set for head and chest injuries. If any of the evaluation metrics exceed these thresholds, the entire Q10 dummy's score will be adjusted to zero.

The Q10 child dummy in this paper is evaluated based on the above three areas, and the injury metrics collected for each area are shown in Table 1 below.

Table 1. Injury Indicators of Q10 Child Dummy

Part	Evaluation Item	Unit
Head	HIC15(Contact)	-
	a3ms	g
Neck	Fz	Kn
	My	Nm
Chest	a3ms	g
	Chest_Def_Up	mm
	Chest_Def_Low	mm

During the testing of the Q10 child dummy, phenomena such as shoulder slipping, Belt-neck interaction, and submarining may occasionally occur. The Euro-NCAP regulatory guidelines have set penalty points for these phenomena, which account for a relatively high proportion of the overall score and therefore require special attention.

In the case of the dummy's forward movement, penalty points for shoulder slipping are assessed under two scenarios. The first scenario is when the shoulder belt slips from the shoulder, meaning the belt slides down the upper arm below the shoulder joint. In this case, the dummy will be awarded an overall score of zero. The second scenario is when the shoulder belt moves into the gap between the shoulders, resulting in a penalty of 4 points. An example image illustrating the shoulder slipping phenomenon is shown in Figure 1.

The first scenario: Shoulder slipping The Second scenario: Shoulder slipping

Figure 1. Case display of shoulder slipping

Child dummy submarining refers to the situation where during the entire collision process, the pelvis of the child dummy slides below the position where the seatbelt can effectively restrain it, or the lap belt fails to effectively prevent the dummy from moving upwards during rebound, no longer restraining the pelvis of the child dummy. In this case, the dummy will be penalized with 8 points. However, current regulatory guidelines do not have specific quantitative indicators for assessing child submarining. The test evaluator must rely on high-speed video footage, static photos taken before and after the test, and dummy injury curve data to determine whether submarining has occurred. An example image illustrating the submarining phenomenon is shown in Figure 2

Figure 2. Case display of submarining

Regarding the phenomenon of Belt-neck interaction on the Q10 child dummy, the ENCAP regulatory guidelines (January 2024, Version 8.1) do not explicitly describe penalty measures for it. However, this does not imply that future updated versions of ENCAP will not address this issue. Currently, the phenomenon of Belt-neck interaction, along with the neck load injury on the dummy, is reflected in the final, officially published report. In contrast, the 2024 version of C-NCAP imposes a penalty of 1 point for the occurrence of Belt-neck interaction on the Q10 dummy.

Overall, from a development perspective, the phenomenon of Belt-neck interaction is highly detrimental to child injury, and therefore, it is crucial to avoid it during the forward development process. An illustrative image corresponding to the phenomenon of Belt-neck interaction is shown in Figure 3.

Figure 3. Case display of Belt-neck interaction

3. Optimization Analysis of Child Q10 Dummy Injury

3.1. Establishment of simulation model

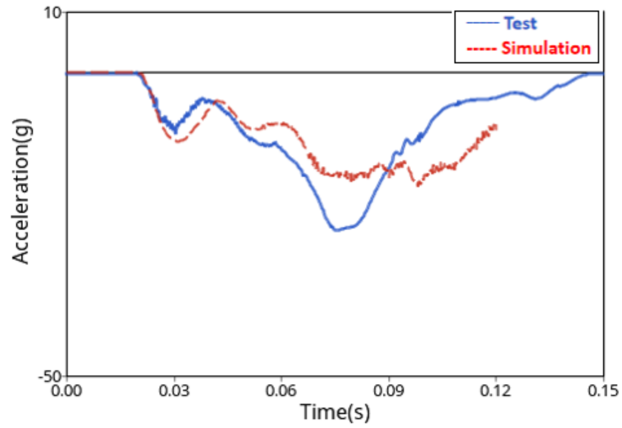
Based on the actual vehicle collision data of a certain car and the CAD data of its model, a simulation model of the Q10 child restraint system was established, as shown in Figure 4.

Figure 4. Simulation Model of the Q10 Child Dummy under MPDB Conditions

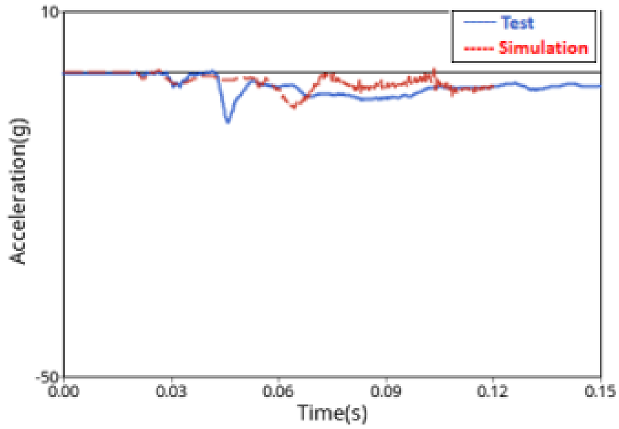
3.2. Simulation Model Benchmarking

Based on the results of actual vehicle collision tests, the

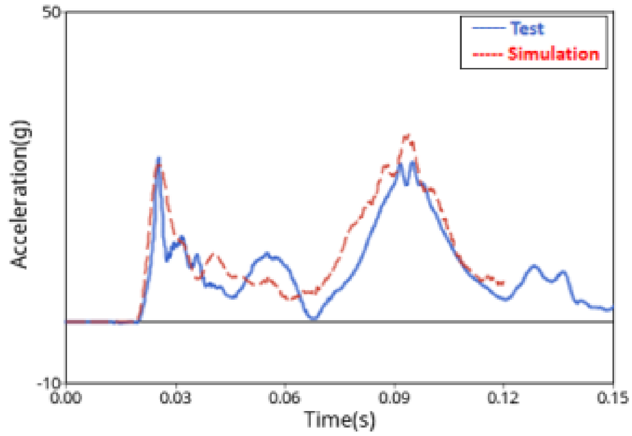
Q10 child dummy restraint system model was benchmarked against the physical Q10 child seat in use under MPDB conditions. The benchmarking results for the head injury curve, neck injury curve, chest injury curve, and pelvis acceleration curve are shown in Figures 5 to 8.



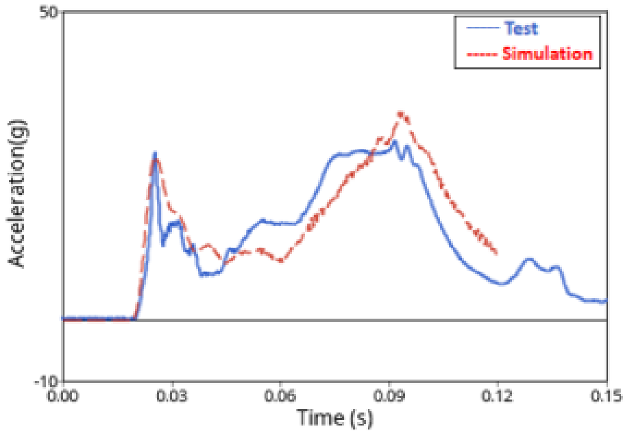
Head Acceleration X



Head Acceleration Y

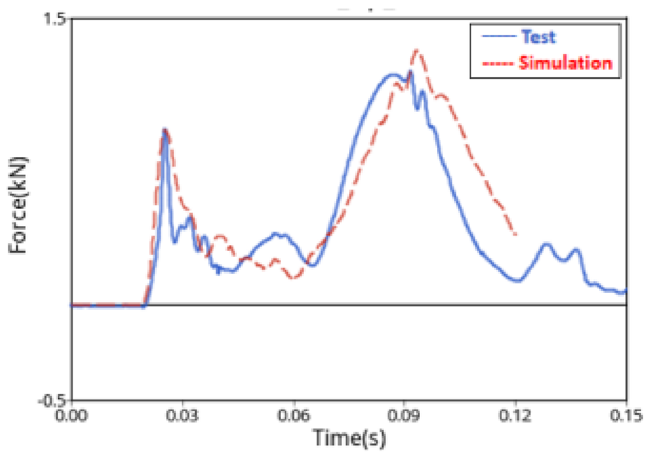


Head Acceleration Z

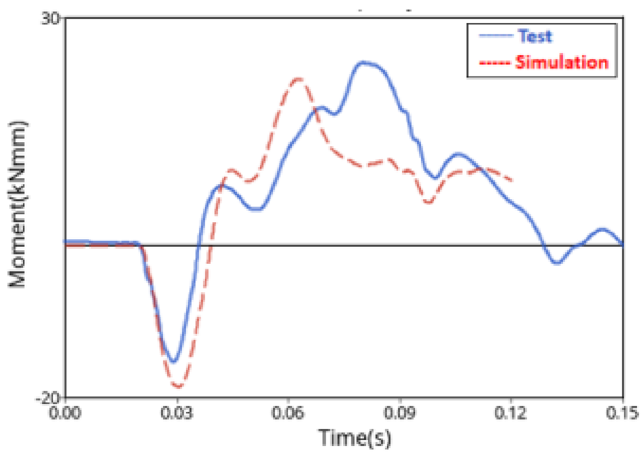


Head Acceleration Res.

Figure 5. Benchmarking Results of the Head Injury Curve for the Q10 Child Dummy

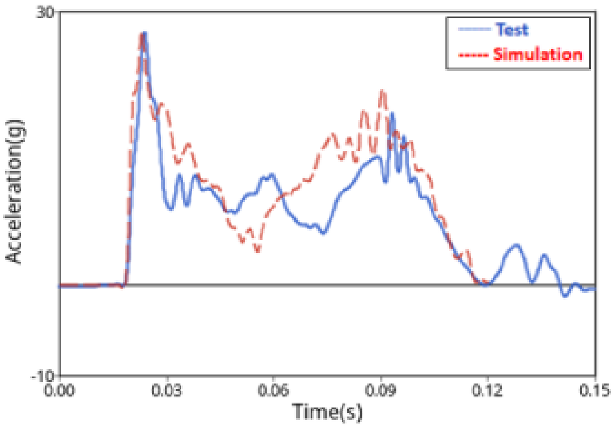


Neck Force Fz

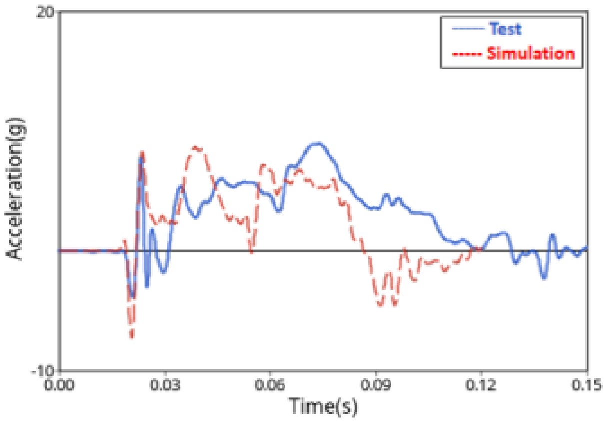


Neck Moment My

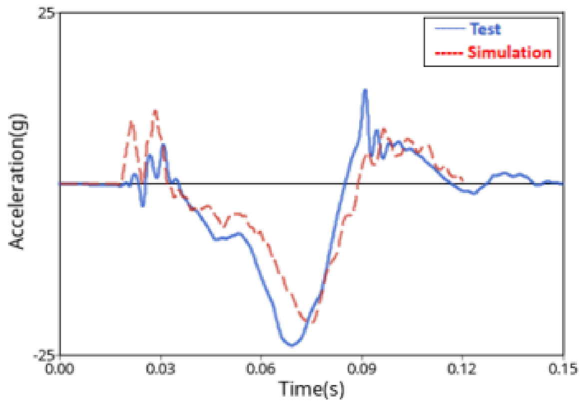
Figure 6. Benchmarking Results of the Neck Injury Curve for the Q10 Child Dummy



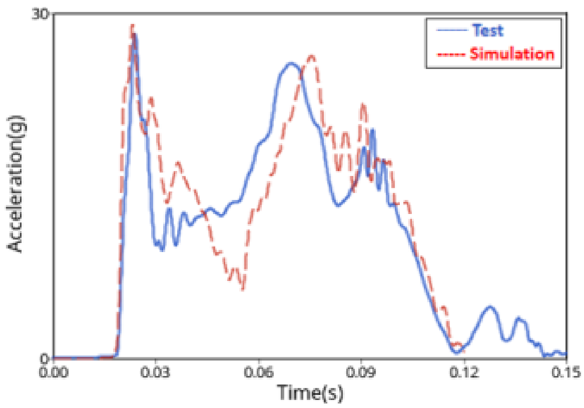
Chest Acceleration X



Chest Acceleration Y

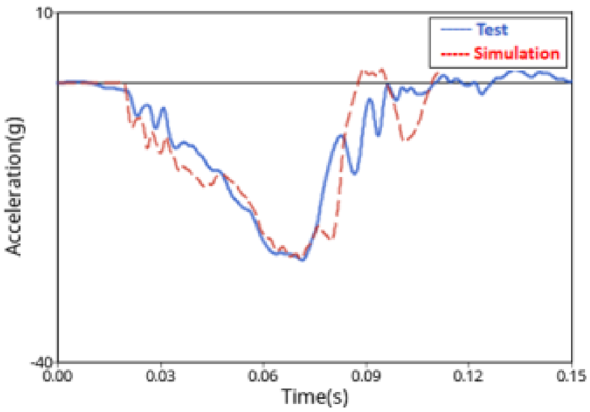


Chest Acceleration Z

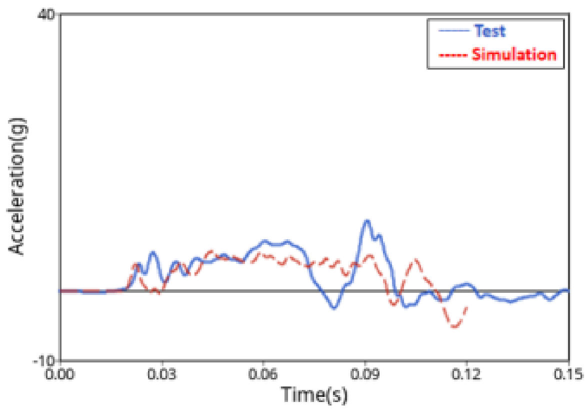


Chest Acceleration Res.

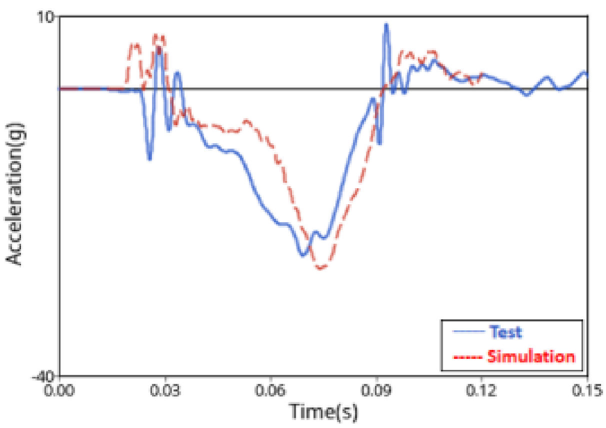
Figure 7. Benchmarking Results of the Chest Injury Curve for the Q10 Child Dummy



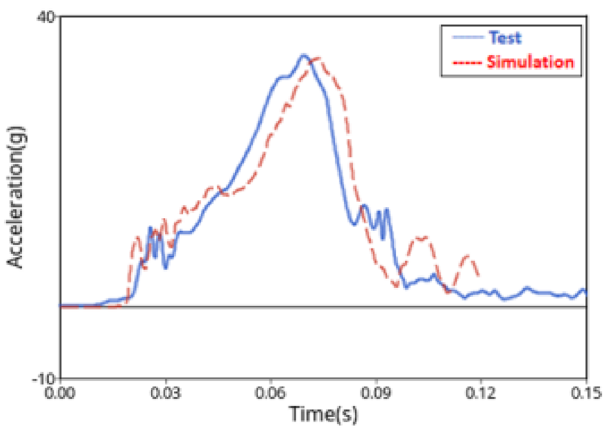
Pelvis Acceleration X



Pelvis Acceleration Y



Pelvis Acceleration Z



Pelvis Acceleration Z

Figure 8. Benchmarking Results of the Pelvis Injury Curve for the Q10 Child Dummy

From the above curves, it can be seen that the peak values and waveform timings of the benchmarked acceleration curves in the X, Y, and Z directions of the head, the axial tension Fz of the neck, the extension moment My of the neck, the acceleration curves in the X, Y, and Z directions of the chest, and the acceleration curves in the X, Y, and Z directions of the pelvis are basically consistent with the experimental data. The simulation model shows good consistency with the actual vehicle test, and this simulation model can be used as a base model to study the influence of different usage methods of a certain child seat on the injury of the Q10 child dummy.

4. Analysis of the Effectiveness of Different Usage Methods for a Certain Child Seat

4.1. Introducing Variables and Setting Up Scenarios

The target child seat analyzed in this paper allows for optional installation of a child seat backrest, belt anchor hooks, and the choice of using ISOFIX fixation based on actual usage requirements. There are differences in the selection of Q10 child restraint systems between C-NCAP and E-NCAP regulations. The 2021 version of C-NCAP describes it as follows: During the collision test, a three-point seat belt is used to restrain the Q10 dummy, and the model of the child restraint system is determined according to the following priority:

a) If the vehicle is equipped with a built-in child restraint system in the right-hand second-row position, and its applicable weight range covers the Q10 dummy, then the built-in child restraint system shall be used preferentially for the collision test;

b) Enterprise-recommended child restraint system model, but with the following requirements: the vehicle manual (or instructions) must specify or recommend this child restraint system; the child restraint system must have a CCC certification certificate; and there must be formal sales channels available in China for purchasing the system (no restrictions on online or offline purchases). For imported vehicles, the above requirements for child restraint systems do not apply, and the enterprise shall provide the child restraint system product for the collision test, but the product should have obtained relevant certification from abroad. The child restraint system is provided by the enterprise.

c) "The enterprise selects the child restraint system from the 'List of Child Restraint System Products for Collision Tests' designated by the C-NCAP Administration Center. The child restraint system is provided by the testing laboratory."

d) "The testing laboratory selects the child restraint system from the 'List of Child Restraint System Products for Collision Tests' designated by the C-NCAP Administration Center. The child restraint system is provided by the testing laboratory."

e) Based on the requirements of the C-NCAP regulations, there are no specific usage requirements imposed on the Q10 child seat. However, E-NCAP does stipulate that the Q10 child seat must use a booster seat type. The booster seat falls under the category of partial restraint[6], which is a sturdy and specialized cushion used to elevate the height of the child occupant in the seat so that the adult seat belt can be used directly. The E-NCAP regulations describe it as follows:

The Q10 dummy should only be placed on a booster seat. This booster seat should be the one recommended by the vehicle manufacturer in the vehicle's user manual. If the vehicle manufacturer recommends a child seat with a removable backrest in the user manual, then a child seat without a backrest should be used. If the vehicle manufacturer has no recommendation or recommends a child seat with a non-removable seat backrest, then an appropriate booster seat should be selected from the TB012 list. When the Q10 dummy is seated on the booster seat, its head should not exceed a vertical height of 840mm above the Cr point (seat R-point). The booster seat will undergo dynamic testing, and booster seats approved under ECE R129 do not need to meet this requirement.

Given the differences in NCAP regulations, researching different usage methods of the same child seat and analyzing the dummy injury response patterns can provide data references for targeted optimization of dummy injury mitigation.

The optional usage states of the target child seat are shown in Figure 9.

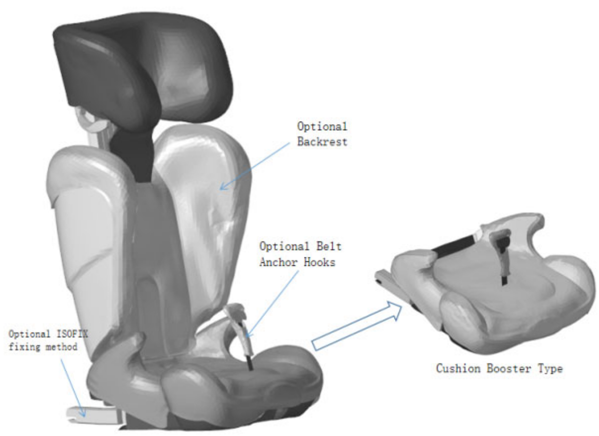


Figure 9. Demonstration of Usage State Variables for the Target Child Seat

Based on the optional variables for this child seat, the target scenarios are set as shown in Table 2 below.

Table 2. Variable-based Scenario Settings

Scheme Number	Scheme Description
Scheme 1	with backrest, no anchor hook, with ISOFIX connection
Scheme 2	with backrest, no anchor hook, no ISOFIX connection
Scheme 3	no backrest, no anchor hook, with ISOFIX connection
Scheme 4	no backrest, no anchor hook,no ISOFIX connection
Scheme 5	with backrest, with anchor hook, with ISOFIX connection
Scheme 6	with backrest, with anchor hook, no ISOFIX connection
Scheme 7	no backrest, with anchor hook, with ISOFIX connection
Scheme 8	no backrest, with anchor hook, no ISOFIX connection

4.2. Analysis and Summary of Simulation Results

Based on the set scenarios, the simulation models were adjusted accordingly. After simulation calculations, the injury situations of key body parts of the Q10 dummy are presented in Tables 3 and 4.

Table 3. Injury Situations of Key Body Parts of Q10 Dummy (Scheme 1-4)

Part	Evaluation Item	Unit	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Head	HIC15(Contact)	-	No	No	No	No
	a3ms	g	32.02	30.06	27.22	28.84
Neck	Fz	Kn	1.333	1.329	1.062	1.236
	My	Nm	18.56	18.49	17.60	16.99
Chest	a3ms	g	25.57	28.95	36.16	36.09
	Chest_Def_Up	mm	20.46	23.36	32.63	30.65
	Chest_Def_Low	mm	15.15	15.66	23.14	20.68

Table 3. Injury Situations of Key Body Parts of Q10 Dummy (Scheme 1-4)

Part	Evaluation Item	Unit	Scheme 5	Scheme 6	Scheme 7	Scheme 8
Head	HIC15(Contact)	-	No	No	No	No
	a3ms	g	34.43	26.96	30.52	26.93
Neck	Fz	Kn	1.259	1.282	1.050	1.231
	My	Nm	18.65	18.21	16.65	15.79
Chest	a3ms	g	26.55	28.41	26.14	26.47
	Chest_Def_Up	mm	20.62	22.68	28.46	27.09
	Chest_Def_Low	mm	17.06	17.07	22.05	19.22

Based on the above table showing the injury situations of the Q10 dummy, and combining with the variables, the following patterns can be summarized:

4.2.1. Effectiveness of Using Child Seats with or without Backrests

By classifying the scenarios based on the presence or absence of a child seat backrest, i.e., comparing Scenario 1 with Scenario 3, Scenario 2 with Scenario 4, Scenario 5 with Scenario 7, and Scenario 6 with Scenario 8, and using the presence of a child seat backrest as a single-factor variable for analysis, the following conclusions can be drawn by analyzing the changes in injury values:

Replacing the child seat backrest with a booster seat: The head and neck injuries show a decreasing trend, while the chest injuries show an increasing trend. The trend of injury changes is illustrated in Figures 10 and 11.

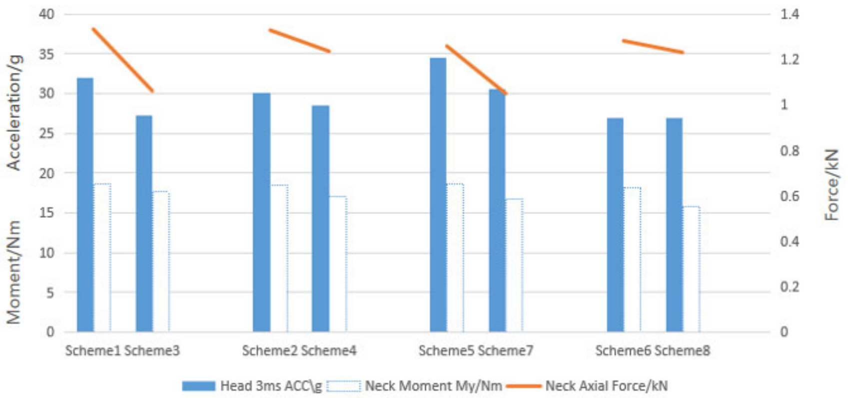


Figure 10. Trend of Head and Neck Injury Changes for the Q10 Dummy in the Implemented Scenarios

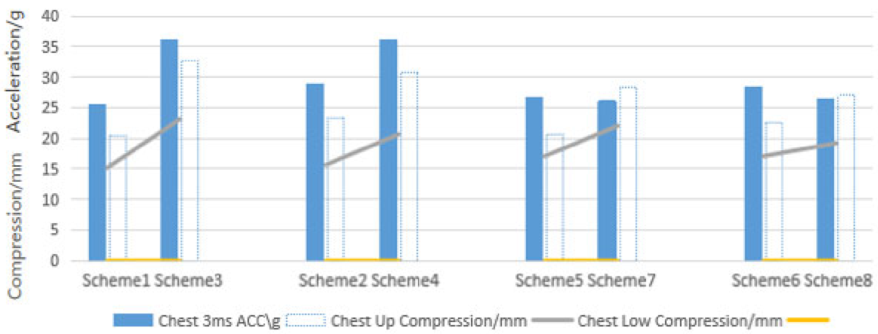


Figure 11. Trend of Chest Injury Changes for the Q10 Dummy in the Implemented Scenarios

4.2.2. Effectiveness of Using Belt Anchorage Hooks

By classifying the scenarios based on the presence or absence of belt anchorage hooks, i.e., comparing Scenario 1 with Scenario 5, Scenario 2 with Scenario 6, Scenario 3 with Scenario 7, and Scenario 4 with Scenario 8, and using the belt anchorage hooks as a single-factor variable for analysis, the following conclusions can be drawn regarding the changes in injury values:

The variation pattern of head injuries is influenced by the ISOFIX attachment method. When ISOFIX is used, the addition of anchorage hooks results in an increasing trend of head injuries, as shown in Figure 12. In contrast, when ISOFIX is not used, the head injuries show a decreasing trend, as depicted in Figure 13.

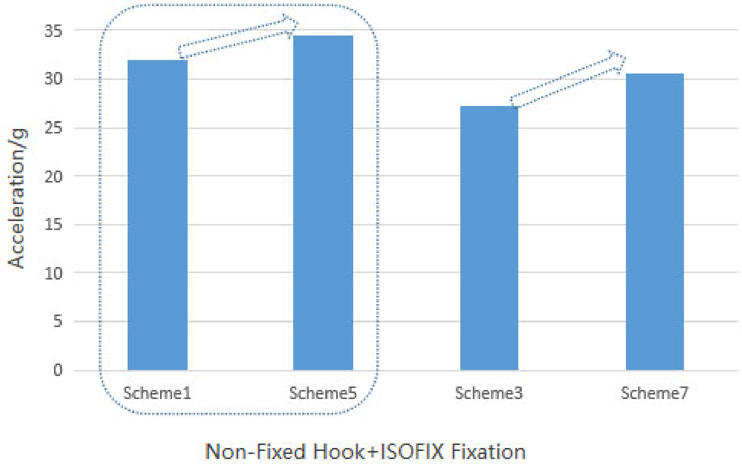


Figure 12. Trend of Head Injury Changes for the Q10 Dummy in the Implemented Scenarios

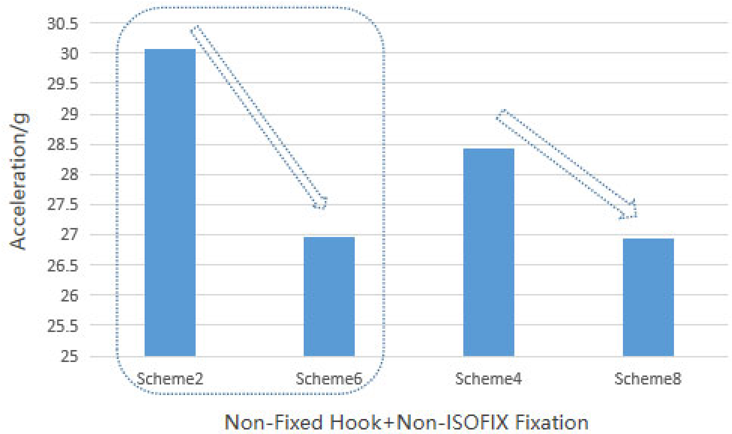


Figure 13. Trend of Head Injury Changes for the Q10 Dummy in the Implemented Scenarios

Changes in Neck Injuries: The presence or absence of a backrest affects the neck injury trends. When a backrest is present, there is a decreasing trend in neck injuries; whereas, when a backrest is absent, there is no significant change. Overall, there is a general decreasing trend in neck injuries, as illustrated in Figure 14.

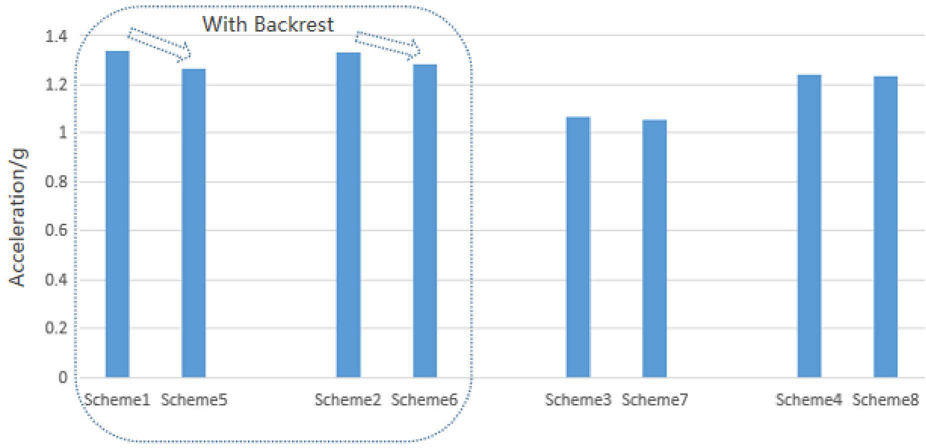


Figure 14. Trend of Neck Injury Changes for the Q10 Dummy in the Implemented Scenarios

Changes in Chest Injuries: In the presence of a backrest, the use of anchorage hooks exacerbates the magnitude of chest compression. However, in the absence of a backrest, adding anchorage hooks can mitigate the chest injury by reducing both chest acceleration and chest compression. The variation in injury patterns is depicted in Figure 15.

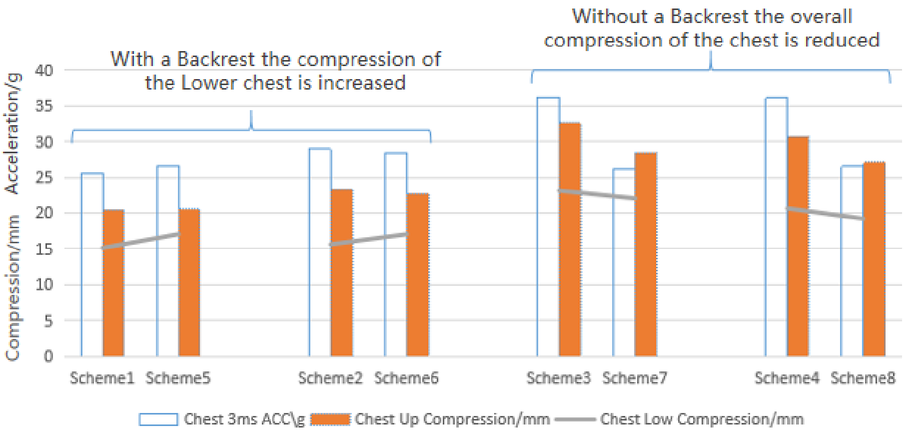


Figure 15. Trend of Chest Injury Changes for the Q10 Dummy in the Implemented Scenarios

4.2.3. Effectiveness of Using ISOFIX Anchorage Connection

By classifying the scenarios based on whether ISOFIX hooks are used, i.e., comparing Scenario 1 with Scenario 2, Scenario 3 with Scenario 4, Scenario 5 with Scenario 6, and Scenario 7 with Scenario 8, and using the ISOFIX anchorage method as a single-factor variable for analysis, the following conclusions can be drawn regarding the changes in head injury values:

Overall, there is a decreasing trend in head injuries. The variation in injury patterns is depicted in Figure 16 below.

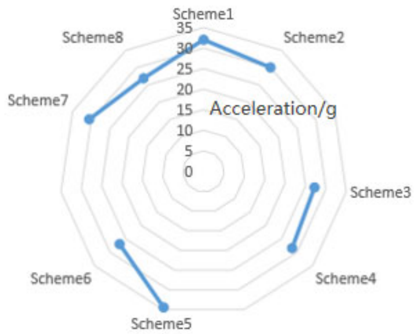


Figure 16. Trend of Head Injury Changes for the Q10 Dummy in the Implemented Scenarios

The changes in neck and chest injuries are influenced by the presence or absence of a child seat backrest. When a backrest is present, there is no significant change in neck injuries, but the chest acceleration and upper chest compression injuries show an increasing trend. In scenarios without a backrest, there is an increasing trend in neck injuries, while both upper and lower chest compression injuries show a decreasing trend. The variation in injury patterns is depicted in Figure 17 below.

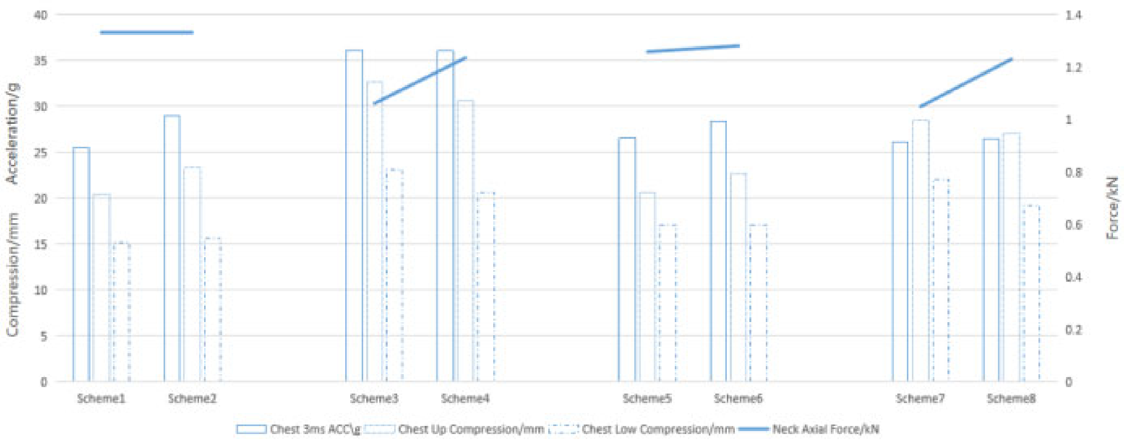


Figure 17. Trend of Neck and Chest Injury Changes for the Q10 Dummy in the Implemented Scenarios

5. Conclusion

This paper conducts a univariate analysis of various usage modes of a commonly used child seat in C-NCAP and E-NCAP by utilizing a finite element Q10 child restraint system model of a specific vehicle. Based on the trends in injury changes to critical areas of the Q10 child dummy, the following conclusions are drawn:

For E-NCAP scenarios where only booster seats can be used, due to the absence of the child seat backrest, there is a potential risk of increased chest injuries. According to the previous analysis, measures such as adding belt anchorage hooks without ISOFIX fixation can be taken to mitigate the risk of increased chest injuries.

For C-NCAP scenarios, in addition to adopting the same usage mode as E-NCAP, child seats with backrests can also be used. However, when a child seat with a backrest is chosen, the risk of head and neck injuries may increase compared to using a booster seat. Based on the previous analysis, adding belt anchorage hooks without ISOFIX connection can be considered to reduce the risk of head and neck injuries. It is important to note that when conducting dynamic tests with child seats equipped with backrests, if significant risks are observed in the chest acceleration and compression of the Q10 dummy, targeted optimizations can be performed. According to the data analysis presented earlier, removing belt anchorage hooks and adding ISOFIX connections can be a one-to-one optimization strategy.

References

[1] China Consumer Network. Misoperation! Child Safety Seats Become Potential Hazards[EB/OL].(2018-05-31)[20230920]. https://mp.weixin.qq.com/s?__biz=MzAxOTgzNjUzNQ==&mid=2247483943&idx=3&sn=306b991c7c891be1bef7c5ae7eae9568&chksm=9bc1b93facb63029c22862160b736a9b74b1f66408772df13f782874c9bdfa608ead5f438e25&scene=27

[2] Zang jinhuan, Li Hao, Zhou Yong, etc.Influence of support leg misuse on the safety performance of child restraint system ISOFIX [J]. Automotive Safety and Energy, 2015,Vol.6 No.4:360-364

[3] BENEDETTI M,KLINICH K D,MANARY M A,et al. Factors affecting child injury risk in motor-vehicle crashes [C]. SAE Pa-per 2019-22-0008.

[4] China Automotive Technology & Research Center Co., Ltd. C-NCAP Management Regulations (2021 Revised Edition) [S]. Tianjin: China Automotive Technology & Research Center Co., Ltd., 2023

[5] European New Car Assessment Programme. Euro NCAP Management Regulations (Released in January 2023, Version 8.0) [S]. Germany: European New Car Assessment Programme

[6] Hao Donghui, Qiang Yi, Ji Ang, et al. Analysis and Research on the Classification and Quality Status of Child Seats [J]. Machinery Industry Standards and Quality, October 2021, Issue 581: 26-31.