◎ 논 문

CRS 하네스 벨트 사용에 따른 어린이 인체 모형 상해 연구 및 실차 레벨 충돌 평가

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Injury Study of Older Children Anthropomorphic Test Device with CRS Harness Belt and Vehicle Level Crash Test

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Key Words : Q6, Q10, Adult restraint system(성인구속장치), CRS(어린이구속장치), Harness belt(시트삽입형벨트), Child injury(유아 상해), Child passenger(유아 승객)

ABSTRACT

For years, Q1.5 (anthropomorphic test device for 1.5 years old infant) and Q3 (anthropomorphic test device for 3 years old infant) dummy protection has been improved considerably by the effort of EuroNCAP. ISOFIX strength of vehicle structure has increased and many child occupant protection tests have made child restraint system (hereafter CRS) optimized for child safety. However, from 2016, EuroNCAP changed the dummy which is used for the child occupant protection from Q1.5/Q3 to Q6/Q10 and these were also adopted in KNCAP from 2017. Therefore, a new method is required to secure the safety for older children

In this research, child dummies were tested by using adult safety systems, and the different results from each adult restraint system were compared. Finally, dummies were tested with the CRS harness belt commonly used for infants, which has yielded significant result.

In this research, mid-sized sedan and small SUV were used for the test. The researchers of this paper performed sled tests to correlate between the different adult safety belt system and child injury. Following the sled test, an actual vehicle test was conducted to gather the injury data of Q-dummy with the CRS harness belts.

This paper will show the advantages of applying a pre-tensioner in the second row for child protection and the necessity of CRS which has its own harness belts to improve safety for older children.

1. Introduction

Many test results of child occupant protection (COP) in EuroNCAP have shown that children between ages of 1.5 and 3 are sufficiently protected recently.

However, there is lack of safety system development for older children occupant protection. Moreover, EuroNCAP announced the dummy for offset frontal test and side moving deformable

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barrier (MDB) would change from group I to group III from January 2016. Thus, the proper methods for group III should be introduced with the different restraint systems.

In this research, several sled tests were conducted to analyze the injury of older children using Q6/Q10 with booster seats and adult belts. The tests revealed the effectiveness of the load limiter (hereafter LL) and pre-tensioner belt (hereafter PT). But even though PT belt was used, the dummy behavior was not stable during the impact, and submarining reaction was found in the abdomen of Q10 dummy.

Mid-sized sedan crash test was also conducted for Q6 dummy behaviors with CRS harness belt (the belt mounted in CRS), and the result showed improvement of injury in the region of head, neck and chest. The CRS used for this test does not support babies over 29.5kg, but Q10 dummy was set for the crash test of mid-size sedan with CRS harness belt as a principle evaluation of child behavior only for the purpose of research. Notwithstanding the fact that the test with Q10 has low possibility to be applied for the actual environment, Q10 dummy showed the more improved behavior, which will be explained later in this paper.

This paper will present the different results when the load limiter and PT belt(see chapter 2) were applied and the behavior and injury changes in case that the belts mounted in CRS was used in priority (see chapter 3).

2. Child Injury with a Booster and an Adult Belt

To examine safety performance of existing booster seats, sled tests were conducted with boosters and three kinds of adult belts: emergency locking retractor (ELR), load limiter (LL) and pre-tensioner (PT) belts. The sled pulse was obtained from mid-sized sedan 64kph offset front crash test. The result of the base test with ELR was compared with the results from the tests with LL and PT belts. In every test, Q6 dummy was set in the back of front passenger seat and Q10 dummy was seated in the back of the driver. Because the impact deformation pulses of the driver side are generally more severe than the opposite side, Q10 dummy was placed behind the driver to investigate whether the structure bonded ISOFIX can endure from its deformation.

Fig. 1 A sled test with boosters and adult belts

Britax Romer Kidfix booster seats were used for this sled test, and it was mounted with ISOFIX. The specification of the booster seats are below

Table 1 Booster seat, cushion only for Q10

Model	Britax Kidfix
Group	2/3 4 ~ 12 years 15 ~ 36kg
Installation	ISOFIX
Restraint	Adult belts

In sled structure from mid-sized sedan, dummies were placed in the 2nd row seat with ELR, LL, and PT respectively. The major behaviors of Q dummy were belt slippage into the neck and submarining in common. Belt webbing was slipped from its original position into the neck of both dummies, which made the rotation movement of dummies. It is shown in Fig. 2 and 3. Especially, submarining was observed from Q10 dummy. No head excursion exceeding 550mm happened in all tests. Injury result is as follows.

Table 2 Q6 Child injury with boosters and adult belts

Adult restraints	HIC15	Head 3ms	Neck Fz	Chest 3ms	Head excursion
Pre-tensioner	377.14	56.50g	1.61kN	45.92g	465mm
Load limiter	742.86	75.30g	2.25kN	50.98g	537mm
ELR	1200.97	104.32g	3.16kN	57.92g	516mm

Table 3 Q10 Child injury with boosters and adult belts

Adult restraints	HIC15	Head 3ms	Neck Fz	Chest 3ms	Head excursion
Pre-tensioner	263.09	66.53g	0.89kN	51.90g	363mm
Load limiter	1080.22	85.00g	1.81kN	64.00g	441mm
ELR#	419.21	63.39g	2.02kN	51.04g	405mm

Fig. 2 Belt slippage into the neck, load limiter (stills from videos at 83ms)

Fig. 3 Belt slippage into the neck and submarining, load limiter (stills from Videos at 110ms)

Fig. 4 Submarining of Q10, load limiter (stills from videos at 110ms)

The result from the test showed that PT belt helped reduce the injury of both of the dummies in the area of head, neck and chest. Compared to ELR and LL, PT belts could make the best performance for the child safety. As presented in Table 3, the injury of Q10 in test with LL and ELR belts had the different tendency from that of Q6. This was due to the sliding behavior of the dummy (Fig. 6) after abdomen penetration of lap belt, and this behavior caused less severe injury of head and chest in LL test of Q10.

Fig. 5 Submarining of Q10, load limiter (post test)

Fig. 6 Dummy sliding motion of Q10, emergency locking retractor (stills from videos at 120ms)

3. Child Injury with CRS Harness Belts

In this section, the injury result from vehicle level test conducted with CRS harness belts will be introduced. The result from section 2 will be used for the safety comparison between the boosters with adult belt and ones with their own harness belts. Whereas the adult belt tests were conducted with sled test, CRS harness belt data was collected from vehicle level test for better applying to the field circumstance.

The test car was the same model as the one used for sled test in section 2: a mid-sized sedan. The structure deceleration of an actual vehicle is more severe than sled pulse, thus the result from the vehicle level test should be considered as more intensive. Nevertheless, better safety performance was observed in the vehicle level test with CRS harness belts than sled test with adult belt. This will be presented in section 3.2.

The researchers of this paper selected CRS which met the criteria that had its own harness belt and was possible for Q6/10 to be placed. The selected CRS was Clek foonf and it was available in North America CRS market. According to its specification, placement of Q6 was allowed in the field condition, but Q10 test was done for only research purpose since the permissible passenger weight of CRS is under 29.5kg.

Fig. 7 Tested child restraint system Clek Foonf

Table 4 Child restraint system specification from its web site

Model	Clek Foonf
Group	2+ years 9 ~ 29.5kg
Installation	ISOFIX +Top tether
Restraint	Harness belt

Table 5 Test condition

Type	4 door sedan
Model	Midsized sedan
Impact speed	64kph
Impact mode	40% Offset frontal
Vehicle weight	1,474kg

3.1. Structure Resistance by Dummy Movement

The inspection of structure resistance by movement of dummies reached the conclusion that there is no potential danger which can happen due to the fracture of vehicle body. The mounting point between the vehicle structure and CRS is represented Fig. 8 and 9 below.

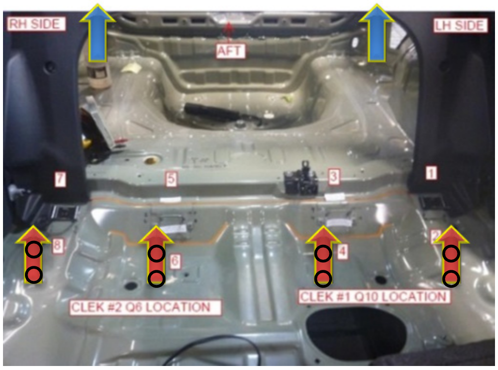

Fig. 8 Child restraint system mounting points(solid=ISOFIX, dot=Top Tether)

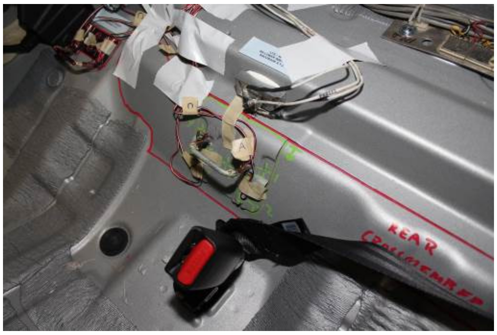

Fig. 9 Structure bonded ISOFIX after the test (no fracture)

The maximum load generated from ISOFIX due to CRS dynamic behaviors was 7,470N, and it occurred on inboard ISOFIX of Q10. The vehicle structure resistance was considered to be enough for the total weight of Q10 dummy and CRS, which was 52.5kg.

3.2. Dummy Injuries

The injury results will be confined to the area of head, neck and chest, which are considered as the most important areas in terms of frequency of severe injuries. In addition, the video analysis of dummy movements was conducted to verify the penetration of the seatbelt in the region of neck and abdomen. The result of CRS harness belt test were compared with the test using booster seat and adult PT belt where the result showed the highest performance in terms of injury. The results of Q6, Q10 injury are shown in Table 6 and 7 respectively, and the behaviors are in Fig. 10.

Table 6 Injuries of Q6

	CRS Harness Belt	PT Belt
HIC15	279.03	377.14
Head acceleration 3ms	51.60g	56.50g
Neck Tension	1.47kN	1.61kN
Chest acceleration 3ms	36.83g	45.92g
Neck penetration	X	O
Abdomen penetration	X	O

Table 7 Injuries of Q10

	CRS Harness Belt	PT Belt
HIC15	229.12	263.09
Head acceleration 3ms	47.68g	66.53g
Neck Tension	1.77kN	0.89kN
Chest acceleration 3ms	41.49g	51.90g
Neck penetration	X	O
Abdomen penetration	X	O

As shown in Fig. 10, the test with harness belt showed more stable behaviors than one with PT belt. In particular, as pelvis and both sides of shoulder were constrained by 4 point belt, there were no neck and abdomen penetration in the test with CRS harness belt, which is contrary to the test result with adult PT belt.

The results from the test with harness belt indicated better performance generally in all body regions regardless of dummy type. 26% and 13% of HIC was improved as compared with the PT belt results in Q6 and Q10 respectively, and 20% of the chest deceleration in both Q6 and Q10. 9% of Q6 neck tension was improved but neck tension of Q10 was increased as much as 99%. The results are illustrated in Fig. 11.

Fig. 10 Behaviors of Q6 and Q10 with pre-tensioner/load limiter and harness belt (stills from videos at the time of maximum excursion of dummy)

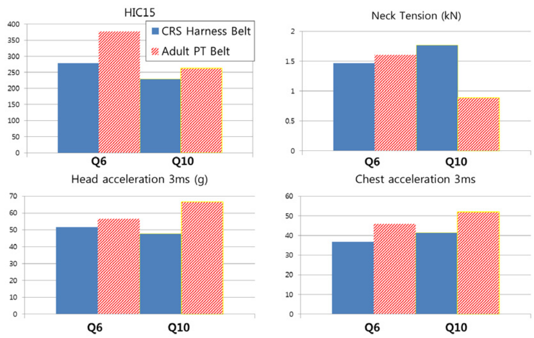

Fig. 11 Injury comparison of Q6/Q10

As mentioned above, whereas all of the injury results with harness belt were better than ones with PT belt except Q10 neck injury, the neck tension force data shows the tendency of decrease in the Q10 injury. This result is caused from the submarine behavior of Q10 dummy tested with PT belt. Once a dummy slips down from its original position, the restraint of dummy becomes unstable and the tensional axial force of neck becomes distributed to other axis. As a result, lateral axis force of neck increases and twisting force happens during the dummy excursion, hence the longitudinal force Fz decreased as much as distributed load. The lateral neck force of Q10 is shown in Fig. 12. While lateral neck force of dummy restrained with PT belt plotted with blue line increases, the force of dummy restrained with harness belt doesn't increase as much as PT belt. This means that neck load is concentrated into longitudinal force, which increases neck tension injury. Notwithstanding the fact that the neck force of Q10 increased in case of harness belt numerically, it cannot be said that the PT belt is safer than harness belt because the dummy restrained with PT belt showed more severe behaviors such as dummy slip and belt penetration.

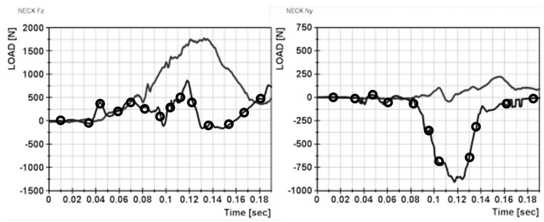

Fig. 12 Fz and Fy force of Q10 (solid line: harness belt/dotted line: PT)

4. Child Injury with a Booster and an Adult Belt

In this section, improvement cases of Q6 dummy in vehicle level will be introduced by using harness belt. The two tests were conducted with mid-sized sedan in condition of 64kph offset frontal impact. The CRSs used for each test were Britax Kidfix and DAIICHI D-guard respectively. In the first test, Q6 was restrained with booster (Britax Kidfix) and adult belt. In the second test, harness belt CRS (DAICHI) were used. Injury details are shown in Table 10 and Fig. 12. When adult belt was applied to Q6, neck penetration occurred, which led neck shear force to rise to 1.1kN. However, when harness belt was applied, head and chest acceleration was improved by 40% and 45% respectively. Neck tensional force was raised to

1.51kN as neck penetration eliminated.

The same condition test was done with small SUV. It showed the similar result of chest injury to the result of the test with mid−sized sedan, but the head injury was increased in the test with harness belt due to vehicle seatback fracture which was proto type vehicle seat. In spite of seat fracture, the chest injury was improved and the result is shown in Table 11 and Fig. 16.

Table 8 Child restraint system specification from the web site

Model	Britax Kidfix	DAIICHI D−guard
Group	2/3 4 ~ 12 years 15 ~ 36kg	Group 2/3 1~10years 9 ~ 36kg
Installation	ISOFIX	ISOFIX
Restraint	Adult belts	6y harness belt 10y adult belts

Table 9 Test condition

Type	4 door sedan	5 Door SUV
Model	Mid−sized sedan	Small SUV
Impact speed	64kph	64kph
Impact mode	40% Offset frontal	40% Offset frontal
Vehicle weight	1,537kg	1,341kg

Table 10 Injuries of Q6, mid−sized sedan

	CRS Harness Belt	Adult Belt
HIC15	266.44	805.52
Head acceleration 3ms	51.88 g	86.63 g
Neck Tension	1.51 kN	0.70 kN
Chest acceleration 3ms	38.07 g	68.74 g
Neck penetration	X	O
Abdomen penetration	X	X
Head excursion	342	526

Fig. 13 Neck penetration of Q6 (after test)

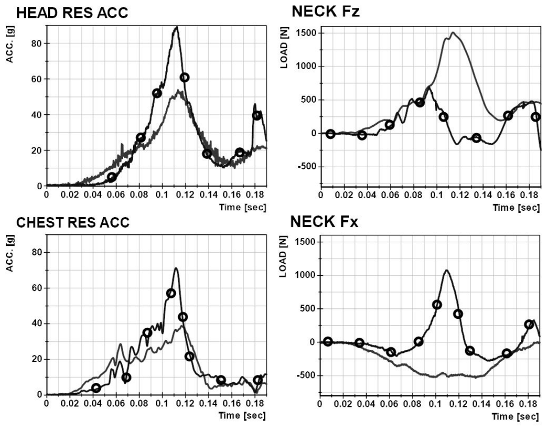

Fig. 14 Q6 head, neck and chest Injury plot, mid−sized sedan (solid line: harness, dotted line: adult belt)

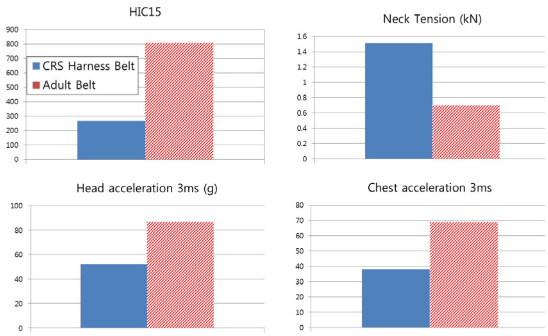

Fig. 15 Q6 Injury comparison depending on adult belt and harness, mid−sized sedan.

Table 11 Injuries of Q6, small SUV

	CRS Harness Belt	Adult Belt
Head acceleration 3ms	72.13 g	58.46 g
Neck Tension	1.05 kN	1.84 kN
Chest acceleration 3ms	46.71 g	58.46 g

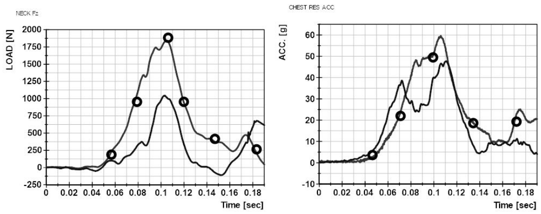

Fig. 16 Q6 Neck tension and chest acceleration, small SUV (solid line: Harness, dotted line: Adult belt)

5. Conclusion

This research was performed to find the new method for protection of children of Q6/Q10. This paper intended to discuss the adequacy of using adult belt with only a booster for older children despite the potential risk of unstable behaviors like neck belt penetration and submarining mentioned in this paper.

Most of the child protection countermeasures were concentrated on using existing adult belt for Q6/Q10, but more diversified countermeasures are necessary for child occupant protection. Therefore, the researchers of this paper will keep up studying on development of proper CRS and harness belt for Q6 and Q10. The new concept of CRS will be aimed at stable behaviors and low risk of injuries with interpolated harness belts.

1) The sled test of Q6/Q10 was conducted with adult belt of Emergency locking retractor (ELR), loadlimiter (LL) and pre-tentioner (PT) belt. The results of the test conducted with PT belt showed the best performance in safety, and the data was used for the comparison between child safety with adult belt and one with CRS harness belt.

PT belt showed the improvement compared to ELR seat belt, it is indicated in Table 2, 3.

2) CRS with harness belt test was conducted to compare with adult belt, which proved that belt penetration in neck and abdomen was eliminated when using harness belt and the injury was also improved in all body area: head, neck, and chest. Most of all, the behavior of dummies was significantly improved; no belt penetrations happened in neck and abdomen.

HIC was improved by 26% and 13% of Q6 and Q10 head respectively, by 20% of Q6 and Q10 chest deceleration and by 9% of Q6 neck. Q10 neck force injury rather deteriorated due to the difference of behavior but harness belt showed more stable behavior.

3) Improvement case of Q6 injury in vehicle level by using CRS harness belt was introduced. Before the CRS was applied for the vehicle test, the strength verification was conducted through sled tests. Test result from harness belt showed more stable behavior and improved injury level, because Q6 with harness belt was restrained more firmly. Head excursion of Q6 with harness belt was reduced by 184mm shown in Table 10.

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