VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

CHILD DUMMY FINITE ELEMENT MODELS DEVELOPMENT: A REVIEW

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ABSTRACT
Advancement in computer aided engineering has made it possible to apply finite element (FE) analysis in crash simulations. Biofidelic dummy FE models are necessary for the application of FE methods in both design and evaluation of cars. Anthropomorphic test device (ATD) and human models are numerical tools designed to imitate real human being response and measure moments, forces and accelerations experienced by human body during crash, which will give data to quantify the severity of injury that the body sustained. While adult FE models have been extensively studied, children models need more vigorous research works to enhance their biofidelity. This paper provides a review on the child FE models with the aim of highlighting the development made so far and work needed to be carried out to enhance the biofidelity of the models. The review is divided in to six parts: child human models, ATD child models, head models, neck models, anthropometry, and model validation.

Keywords: anthropometry, ATD, child dummy, fininte element modelling, human model, validation.

INTRODUCTION
As the usage of cars in the road transportation increased, involvement of children in road traffic accident has also increased drastically. Road traffic accidents have become a major public health concern worldwide: Motor vehicle crashes are the leading cause of death for persons aged 5–35 years in the United States (West *et al.* 2011). This problem is expected to be high in developing countries where there are weak safety regulations and poor infrastructures.

Finite element (FE) modelling has become the most efficient method of developing human and anthropomorphic test device models because of its repeatability and low cost compared to the physical crash dummies. Today, physical child crash dummies have been transformed to FE models as during vehicle design large number of simulations are performed and using FE models provides huge cost savings and reduce the need for prototyping. Human child model is expected to have more human like response than child crash dummy models if well validated. The fact that geometry of the body parts is obtained from computer tomography (CT) of subjects made development of child human models difficult because of ethical reasons.

This review will focus on child models because it needs more attention than their adult counterparts. The study will cover the available child human models, ATD FE models and also highlights the dummy body segments that are given more priority in research because of their vulnerability in accident events: the head and neck. Discussions on anthropometry and model validation will also follow. Recommendation will be stated on the areas that need more studies.

CHILD HUMAN MODELS
Child human FE models are developed from computer tomography (CT) scan of the whole human body that give actual shape and geometry of soft and hard tissues. Human body models could be used to evaluate injuries in different impact locations if well validated but ATD models are developed for frontal and side impacts only. Six year old child human model developed by Okamoto *et al.* (2003) using MRI scans of whole body is an example. Only lower limb for this model was validated for pedestrian analysis purposes. There are currently few child FE human models. The only ones available in the open literature were based on scaling adult human models. Model based scaling technique was applied to develop three year old (3YO) child FE dummy model from AM50 adult human model by Mizuno *et al.* (2005). Anthropometric data of body segment were based on United States children and bone properties were obtained from literature. The model was validated using Hybrid III (HIII) 3YO calibration test for neck flexion, thorax impact response and torso flexion. Test for lap belt loading was also conducted. Response of FE model was reported to be closer to HIII 3YO and for ECE R44 sled test conducted using two different types of CRS, whole spine flex for child FE model, while for HIII 3YO only cervical spine and lumbar spine flex.

Later, Mizuno *et al.* (2009) incorporated a pelvis to the previously developed dummy model to evaluate stress distribution. The response of the modified model was compared with HIII 3YO in sled test in which child FE model was found to be useful in predicting the child behaviour in impact than HIII 3YO. Zhang *et al.* (2009), implements a cadaver biomechanical response of the neck under tensile and bending loading to a 3YO child model

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from Mizuno *et al.* (2009) in which altering mechanical behaviour of the child neck, made neck forces and moments to be within corridor of pediatric cadaver tests. Figure-1 shows 3YO child human model developed by Mizuno. Section of the model shows the soft and hard tissues. It was developed using LS DYNA code and the material properties of all body segments were obtained from the literature and by scaling adult properties.

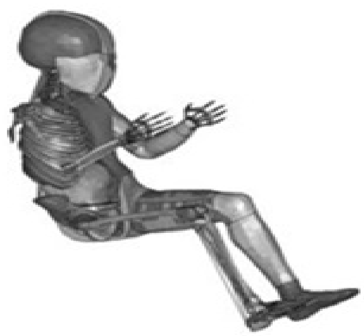

Figure-1. 3YO child human FE model (Mizuno *et al.* 2005).

Koizumi *et al.* (2005) also developed 3YO child dummy by scaling MADYMO adult FE human model to CANDAT database anthropometry. The model mesh was scaled using Kring's technique and the joint characteristics were scaled down using MDYMO/SCALER module. Scaled adult material properties from literature were then applied to the child model. This model response correlates well with dummy corridor for frontal and lateral impact. Differences in head trajectory and acceleration were noticed between child and dummy model in crash simulation. The dummy model was later validated by simulating thoracic pendulum impact tests, abdominal pendulum impact tests, abdominal lap-belt tests and neck loading tests. These tests were also conducted on HIII 3YO dummy FE model, to investigate differences between human and dummy models in which it was concluded that child human models possesses better biofidelity than HIII 3YO dummy model. An improved second generation dummy was developed using HUMOS-2 model, and enhanced biofidelity was noticed on thoracic response of the new dummy on single pendulum test (Koizumi *et al.* 2007). So far there is no complete child human FE model in the public literature other than the ones mentioned here.

Though complete dummy human models have been developed but their biofidelity is still based on certification corridors which make it similar to ATDs in terms of their ability to measure human response on crash. Models should be developed from CT scans of the child because it was shown by Roth et al (Roth *et al.* 2007) that scaling adult geometry to child anthropometry is not appropriate. It is important to note that in Mizuno and Kozoimi child models, scaled adult bone material properties were used due to lack of child human body segments material data. This can affect its biofidelity as it might not necessarily represent actual child bone properties. Meanwhile, research on child human model should be geared towards validating the models with cadaver response for all dummy segments with the ultimate goal of developing dummy that will represent the kinematic response of real human beings.

ATD CHILD MODELS

Following the advancement in computing technologies today, all physical crash dummies are developed in finite element and multibody models that could be used repeatedly without damage and at low cost compared to physical ones. They are used for automotive safety systems evaluation. Child ATD models includes: Hybrid III 3YO, Q3 and Q3s, Hybrid III 6YO and Q6 in PAM-Crash and Ls Dyna codes (Gras and Brolin 2012). These models in addition to P3 and P6 are also available in MADYMO (TNO Automotive 2013).

There are also Hybrid III 10YO and Q10 in LS Dyna codes and P10 in MADYMO. These dummies represent their physical counterparts and hence, they were validated against ATD certification tests. Figure-2 shows 3YO HIII dummy model restrained in five point harness in child restrain seat (CRS).

Figure-2. Three year old HIII dummy restrained in a child seat (Altenhof and Turchi 2004).

Because the certification corridors were based on physical dummies, the biomechanical response used, sometimes found to be different from real cadaver test data. An example is hybrid III 3YO dummy in which because of geometry and mechanical limits of engineering materials, dummy body segments contact itself and result in dramatic rise in moments in neck extension (Saul *et al.* 1998). Zhang *et al.* (2009) show that Hybrid III 3YO ATD neck is far from cadaver response in a sled test with peak acceleration of 17g. Recent studies by Loyd (2011) compared head response of ATD heads with age matched cadaver heads in which, it was concluded that peak resultant acceleration of Hybrid III 10 year old and Q dummies aged from 0 to 6 years old head was stiffer than the age matched cadaver head response in five impact locations. It was suggested that a factor should be applied to scale the ATD head response up/down to cadaver response. ATD requires modifications to improve their

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biofidelity. Changes in the dummy design are less difficult with FE models than physical crash dummies. Table-1 shows multipliers to be used in scaling 12 month CRABI head peak acceleration and head injury criteria (HIC) values to match age matched human cadaver response.

Table-1. 12-month CRABI corrector multiplier values for head acceleration and HIC that can be used to scale the 12-month CRABI response to match the human response (Loyd 2011).

Impact location	Drop Height	Acceleration	HIC
Forehead	15cm	1.33	-
Forehead	30cm	-	0.59
Occiput	15cm	1.87	2.0
Occiput	30cm	1.87	2.0
Vertex	15cm	0.77	0.46
Vertex	30cm	0.77	0.57
Lateral	15cm	0.81	0.72
Lateral	30cm	0.81	0.72

However, currently there are few child ATD models that can measure side impacts. While Q3s a modified Q3 Omni-directional dummy was designed for side impact assessment (Carlson *et al.* 2007), hybrid III child dummy models currently available are generally designed and validated for frontal impact only (LSTC 2013; FTSS 2009). There is of course a need to modify the design of other child FE dummy series to measure side impact parameters.

Multibody (MB) child models used for pedestrian injury evaluation has been developed by Liu and Yang (2002). They have good computational time and are preferred for pre-crash and emergency manoeuvres simulations (Gras and Brolin 2012). Unlike FE models which allow good contact in simulations for studying child's interaction with CRS, MB models have very complex contact definition. ATD dummies are validated based on the applications it is intended to. For example, Hu *et al.* (2012) modify 6YO HIII dummy model abdomen design to simulate and predict abdomen submarining. The model could be used in restraint system design optimization for young school-aged children. To the best of author's knowledge, no child human or ATD model is currently validated for all body segments or all impact directions.

HEAD MODELS

Child human head models were developed recently by many researchers. Meyer *et al.* (2014) developed 3YO child head based on CT scanning geometries. The model was used to reproduce skull fracture and head injury using 13 domestic accident reconstruction and mechanical parameters that correlate with observed injuries. In 2009, Roth *et al.* (2009) proposed a 3 year old child head with geometry obtained from CT scan of a 3 year old 50th percentile dimensions, with material properties obtained from the literature. The model was used to study neurological injuries for children, predictive properties was evaluated through accident reconstruction. It was found that shearing parameters was the best candidate as injury predictor in terms of von Mises stress for neurological injuries. Latter, in 2010, he developed a newborn child head model applying literature material properties. The model was validated against experimental data by simulating paediatric skull fracture from real world head trauma (Sebastien Roth, Raul, and Willinger 2010).

Head and neck are the FE dummy body segments that can be developed and validated separately from the full dummy. Other body parts such as thorax, pelvis lower and upper extremities are modelled as an integral part of the complete dummy. Hence, validating the response of these parts is considered as improving dummy biofidelity. Head is considered as the most injured body part for children in vehicle crash and fall accidents (Meyer *et al.* 2014).

Table-2. Injuries pattern of AIS2+ for children body segments with impact direction.

	Frontal crashes		Near side crashes		Far side crashes		Rear crashes	
	Children 0-7 years in CRS	Children 8-15 years in seat belts	Children 0-7 years in CRS	Children 8-15 years in seat belts	Children 0-7 years in CRS	Children 8-15 years in seat belts	Children 0-7 years in CRS	Children 8-15 years in seat belts
Overall AIS2+ injury risk (per 1000 children in crashes)	3.0	12.7	6.7	29.3	3.6	14.6	2.9	8.8
Head (%)	55.7	49.3	60.5	69.6	46.8	59.3	73.0	82.1
Face(%)	8.2	10.4	1.2	4.6	3.2	6.7	5.8	1.0
Chest(%)	4.4	9.0	4.9	4.6	4.8	5.9	3.6	1.8
Abdomen(%)	4.4	8.3	1.2	6.3	3.2	6.7	8.8	6.3
Neck/spine(%)	2.2	1.5	2.5	1.5	1.6	2.2	0.0	1.0
Upper extremity(%)	7.1	14.4	8.6	8.9	27.4	14.4	2.9	3.8
Lower extremity (%)	18.0	7.0	21.0	4.6	12.9	4.8	5.8	4.0

Source: (Arbogast and Durbin 2013)

VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
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The neck and chest are also frequently injured parts of the body that cause severe injury to the child or even lead to death in the motor vehicle and domestic accidents. Table 2 indicates that head injured frequently in all impact direction, followed by lower extremities for 0-7 YO children. The data is obtained from Partners for Child Passenger Safety (PCPS). It can be seen that head has the highest percentage of injury in all crash direction for children of 0 to 15 years old restrain in CRS or seat belt.

Some head models have been applied for height fall investigations (Li, Luo, and Zhang 2013; Miyazaki *et al.* 2009). While child human head models estimate the stress and strains of brain and skull on impacts, ATD models predict the linear accelerations and HIC. ATD head models of children are developed as part of whole body dummy models while child head models in the literature were considered as a separate entity used in the investigations of brain and intracranial pressures for the determination of injury thresholds. Studies on ATD child dummy models have not been given attention in the literature. Loyd (2011) compares ATD heads with age match cadaver with the aim of assessing their biofidelity. Child cadaver data for 23-months to 8- years-old and 10-years to 15-years-old children were not included in the study because of its un-availability.

It is important to note that child head human models developed in the literature were not coupled to the complete dummy for crash analysis, thus there is a need for work in that respect. It is also suggested that, investigations in the head parts material properties be carried out in order to develop more biofidelic models.

NECK MODELS

Spinal related injuries are frequently caused by motor vehicle crashes (Nightingale *et al.* 2013). Biofidelic neck models are necessary for designing protection devices.

Head is normally coupled to the neck for validation process using pendulum or sled test configuration. For ethical reasons no data exist in the literature for dynamic validation of paediatrics neck model (Meyer and Willinger 2009). Child neck biomechanical requirements are mainly based on Irwin *et al.* (2002). Child volunteer is rarely available. Dupuis *et al.*(2005) used scanner images of the subject to construct the neck finite element model of 3 year old child by segmenting the tissues and bones. The intervertebral discs were modelled using non-linear spring elements. The model was validated for kinematic response by the Q3 dummy response in frontal, rearward and lateral impact data because of lack of available cadaver data. Also the effect of neck response on head excursion has been studied.

Dibb (2011) developed six and ten year old child head and neck models from a validated adult frame work. The model was validated against pediatric volunteer data for low speed frontal impact. ATD models of these ages were found to be stiffer than developed model; hence biofidelity corridor has been established to guide future ATD designs. Recently Dong *et al.* (2013) developed a child ligamentous cervical spine FE model to predict soft tissue failures in tension for 10-year-old ligamentous cervical spine FE model. The geometry of the model was obtained from medical scans and meshed using a multi-block approach with material properties from the literature and the validation was carried out based on Child tensile force–deformation data in three segments, Occipital- C2 (C0–C2), C4–C5 and C6–C7. The cervical spine model was also validated in tension, flexion and extension against the child experimental data. The model can be applied in child FE human models to improve their biofidelity in measuring neck injuries.

ANTHROPOMETRY

Accurate anthropometric data is essential for child dummy models to mimic the exact response of the child it represents. However, child crash dummy body segment sizes are based on the anthropometric data representing United States children (Snyder *et al.* 1977; Schneider *et al.* 1983; Weber 2000). ATD and human child models are developed by scaling adult geometry. Scaling adult size to child is not appropriate, as it was shown by Roth and Willinger (2008) that the difference between real brain geometry and scaled brain geometry for a three-year-old child in terms of area was about 4% and 18% for saggital and coronal planes as shown in Figure-3.

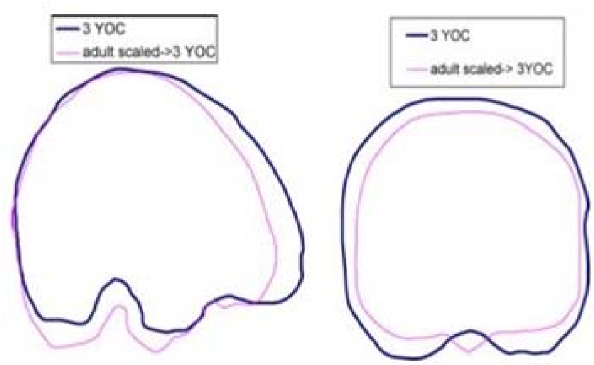

Figure-3. Geometry differences between brain's CT scan of 3YO and brain's CT scan of 3YO scaled from an adult in saggital and coronal planes (Roth and Willinger (2008).

The data used in child dummy development were collected long time ago, for example Mizuno *et al.* (2005) used anthropometric dimensions of master body developed by Young *et al.*(1976) to develop a three year old child dummy that is expected to measure injuries of current children around the world. That data might not necessarily represent current child size and weight. It is well known that anthropometric data vary significantly from country to country and race to race (Stephen 2005). Three-year-old child in US might not have the same size with African child of the same age, considering the nutrition and health issues, thus child dummy anthropometry should represent child of other parts of the world especially developing countries.

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Various studies have been carried out on scaling adult crash dummy models to other populations. Kim and Son (2003), presented a side impact dummies of 5th, 50th, 95th percentile by scaling the geometries, inertia and joint characteristics of EuroSID-1 to Korean anthropometry and evaluated the lateral response requirements for head, thorax and pelvis of the Koreans. Youn *et al.* (2009) scaled a 50th percentile Hybrid III dummy to Korean elderly people anthropometry with the aim of investigating thorax injury of the population. Happee *et al.* (1998) developed a scaled dummy model by scaling adult hybrid III to various range of occupant sizes in which frontal impact simulations gives different results for occupant of different sizes and injury parameters were found to be higher than that of standard dummy. There is yet a dummy model representing African child.

Anthropometry is influenced by population, gender, diversity and regions. Advanced countries such as US, Canada, Germany, Japan and Korea have crash dummy representing their anthropometry. Vigorous research has to be conducted to generate extensive anthropometric data of the various populations in the world for the development of crash dummy models that will represent the actual vehicle occupants. Vehicle users of various sizes who might be at high risk of injury especially in the developing countries need to be accounted for in the regulatory crash testing of vehicles. There was an attempt recently to develop child FE models. Mohamad *et al.* (2011) developed a six month old child FE model using Malaysian anthropometric data. The model was used to evaluate HIC for frontal and rear crash simulations which were found to be within threshold values. Rafukka *et al.* (2015) applied 3YO Nigerian child anthropometry to develop an ATD head model and it was validated based on the specification of 49CFR Part 572 Sub Part P for three-year-olds.

MODEL VALIDATION

Dummy models response ought to be validated against human subject it represents. Due to impossibility of subjecting living human beings to injuries or death, the response at least should mimic that of cadaver of the same age. Child cadaver experimental data is difficult to obtain because of ethical reasons, unlike their adult counterparts. Experimental test on child is nearly impossible because of ethical reasons (Roth *et al.* 2009) . For example there was no study to date that has provided data on the validation of the human 3-year-old child head hence, the only alternative is to use real accident trauma (Meyer *et al.* 2014).

Child models depend on the scaled adult data for their validation. The dummy certification corridors scaled from adult are applied in most of the dummy part validation. FE models however have to satisfy the physical dummy certification. Modification and validation of ATD dummy segments have been proposed in the literature. Tot *et al.* (2008) compares head and neck of hybrid III 3YO dummy FE model with pediatric cadaver data, under flexion-extension bending and axial loading condition. A big difference was noticed in rotational and linear stiffness between HIII 3YO dummy and cadaver. Cadaver response was then implemented in to Hybrid III 3YO FE model by changing the material model of neck cable from material type 1 to type 67 (MAT_Nonlinear_Elastic _Discrete_Beam) of Ls Dyna. The elastic bulk modulus, short and long-term shear modulus were modified from their original values. Zhang *et al.* (2009) implemented cadaver biomechanical response to the pediatric neck under tensile and bending loading by altering the material properties of ligaments, intervertebral disks and facet joints. Sherwood *et al.* (2003) also show in 49 km sled test that the Hybrid III 6YO dummy neck flex more than 12-year-old cadaver tested in a similar impact environment causing full-face contact with the dummy's chest. Cadaver shows both neck and thoracic flexion while, for the dummy only the neck flex as seen in Figure-4. It was concluded that stiff thoracic spine of the dummy results in high neck forces and moments which does not represent real injury.

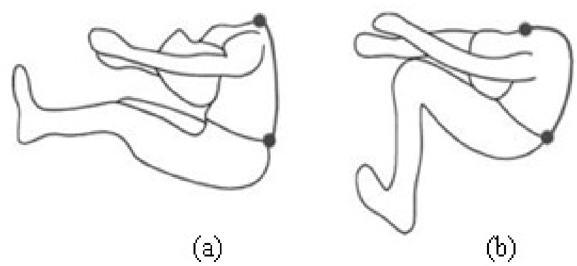

Figure-4. Schematic diagram of HIII 6YO dummy (a) and cadaver (b) in three point belt. The T1 to midlumbar is highlighted (Sherwood *et al.* 2003).

For neck response validation only a few volunteer test is available in the literature. The only one is conducted at Children Hospital of Philadelphia (CHOP) in which twenty pediatric children males aged 6 to 14 years were subjected to low speed 3g frontal impact (Arbogast *et al.* 2009). Also an investigation recently provide insight into the biofidelity of the pediatric ATD upper neck loads in low-speed crash environments. Comparison between upper neck loads of the Hybrid III and Q-series 6 and 10-year-old ATDs with size-matched male pediatric volunteers in low-speed frontal sled tests show that the ATDs underestimated axial force and bending moment compared to the human volunteers (Seacrist *et al.* 2013).

Post-mortem human subjects (PMHS) gives biomechanical response for the validation of dummy models, but for children, cadaver is specifically difficult to obtain. Only few pediatric PMHS are available in the literature that provide biomechanical response data.

Both human and ATD child dummy models depends on certification corridors in their validation. Accident reconstruction has been applied in the determination of injury criteria. Research should therefore be focused on obtaining children cadaver response data for all body segments as well as complete body kinematics to ease validation of child physical and FE dummies for better biofidelity. Lower extremities, pelvis and abdomen were not well validated for child human and crash dummy models. Thorax is however validated against scaled adult data.

CONCLUSIONS

In this review, child finite element models have been studied. Various child human and ATD models have been reviewed together with discussions on the anthropometric data and validation issues. Based on this it is therefore recommended that exact geometry and material properties be applied to the child human models and validations should be done against cadaver data as opposed to ATD certification corridors. Research on ATD models should focus on designing for side impacts, and ATD response should be validated against cadaver of the same age in order to further improve its biofidelity. Child head models developed need to be incorporated to full dummy for crash analysis. Only few neck models are available in the literature and cadaver data for neck validation is very scarce. Anthropometric data for child dummy represents children of some parts of the world at the expense of others. It is strongly recommended that dummies should be designed using anthropometric data of developing countries. Research work is needed to provide more cadaver data for dummy response validation.

ACKNOWLEDGEMENTS

The authors wish to thank Universiti Putra Malaysia for the facilities and Bayero University Kano, Nigeria for the financial support of the first author. In addition, this work was also supported by Fundamental Research Grant Scheme with Reference Number: FRGS/2/2013/TK01/UPM/01/1, vot 5524355, Ministry of Education (MOE), Malaysia, and was carried out in Universiti Putra Malaysia (UPM). The authors therefore would like to record their thanks to the MOE and UPM for the supports.

REFERENCES

[1] Altenhof, William, and Rita Turchi. 2004. "A Numerical Investigation into HIC and N Ij of Children for Forward and Rearward Facing Configurations in a Child Restraint System." In 8th International LS-DYNA Users Conference, 69–86.

[2] Arbogast, Kristy B., and Dennis R. Durbin. 2013. Pediatric Injury Biomechanics; Archive & Textbook. Edited by Jeff R. Crandall, Barry S. Myers, David F. Meaney, and Salena Z. Schmidtke. New York Heidelberg Dordrecht London: Springer Science+Business Media New York. doi:DOI 10.1007/978-1-4614-4154-0.

[3] Arbogast, Kristy B and Balasubramanian, Sriram and Seacrist, Thomas and Maltese, Matthew R and Garcia-Espana, J Felipe and Hopely, Terrence and Constans, Eric and L{'o}pez-Vald{'e}s, Francisco J and Kent, Richard W and Tanji, Hiromasa and others. 2009. "Comparison of Kinematic Responses of the Head and Spine for Children and Adults in Low-Speed Frontal Sled Tests." Stapp Car Crash Journal 53: 329–72.

[4] Carlson, Michael, Mark Burleigh, Andy Barnes, Kees Waagmeester, and Michiel van Ratingen. 2007. "Q3s 3 Year Old Side Impact Dummy Development." In 20th ESV Conference, Lyon, 18–21.

[5] Dibb, A T. 2011. "Pediatric Head and Neck Dynamic Response : A Computational Study." Duke University.

[6] Dong, Liqiang, Guangyao Li, Haojie Mao, Stanley Marek, and King H. Yang. 2013. "Development and Validation of a 10-Year-Old Child Ligamentous Cervical Spine Finite Element Model." Annals of Biomedical Engineering 41 (12): 2538–52. doi:10.1007/s10439-013-0858-7.

[7] Dupuis, Raphaël, Frank Meyer, and R Willinger. 2005. "Three Years Old Child Neck Finite Element Modelisation." Enhanced Safety Vehicle, 1–9. http://link.springer.com/chapter/10.1007/1-4020-3796-1_10.

[8] FTSS. 2009. "FTSS LS-DYNA Model of the Hybrid III 3-Year Old Child Dummy User Manual."

[9] Gras, Laure-lise, and Karin Brolin. 2012. "Active Child Models for Traffic Safety Research." Interim Report -1, Chalmers University, Sweden.

[10] Happee, R, R Van Haaster, L Michaelsen, and R Hoffmann. 1998. "Optimization of Vehicle Passive Safety for Occupants with Varying Anthropometry." Methods, no. 98: 1919–24.

[11] Hu, Jingwen, Kathleen D. Klinich, Matthew P. Reed, Michael Kokkolaras, and Jonathan D. Rupp. 2012. "Development and Validation of a Modified Hybrid-III Six-Year-Old Dummy Model for Simulating Submarining in Motor-Vehicle Crashes." Medical Engineering and Physics 34 (5). Institute of Physics and Engineering in Medicine: 541–51. doi:10.1016/j.medengphy.2011.08.013.

[12] Irwin, Annette L and Mertz, Harold J and Elhagediab, Ali M and Moss, Steve. 2002. "Guidelines for Assessing the Biofidelity of Side Impact Dummies of Various Sizes and Ages." Stapp Car Crash Journal 46: 297–319.

[13] Kim, Seong-jin, and Kwon Son. 2003. "Construction and Evaluation of Scaled Korean Side Impact Dummies" 17 (12): 1894–1903.

[14] Koizumi, T, N Tsujiuchi, and Y Uchida. 2005. “Impact Injury Rating of Child FE Human Model for 3-Year-Old.” In IMAC-XXIII: Conference and Exposition on Structural Dynamics.

[15] Koizumi, Takayuki, Nobutaka Tsujiuchi, Nobuhiro Taki, Patrick a Forbes, and Ronald De Lange. 2007. “Development and Impact Analysis of 3-Year-Old Child FE Human Model.” In Conference Proceedings of the Society for Experimental Mechanics Series, 25th Conference and Exposition on Structural Dynamics 2007, IMAC-XXV, Orlando, FL, USA, 1–3.

[16] Li, Zhigang, Xiao Luo, and Jinhuan Zhang. 2013. “Development/global Validation of a 6-Month-Old Pediatric Head Finite Element Model and Application in Investigation of Drop-Induced Infant Head Injury.” Computer Methods and Programs in Biomedicine 112 (3). Elsevier Ireland Ltd: 309–19. doi:10.1016/j.cmpb.2013.05.008.

[17] Liu, X. J., and J. K. Yang. 2002. “Development of Child Pedestrian Mathematical Models and Evaluation with Accident Reconstruction.” Traffic Injury Prevention 3 (4): 321–29. doi:10.1080/15389580214626.

[18] Loyd, Andre Matthew. 2011. “Studies of the Human Head from Neonate to Adult: An Inertial, Geometrical and Structural Analysis with Comparisons to the ATD Head.” Duke University. http://dukespace.lib.duke.edu/dspace/handle/10161/4986\nhttp://dukespace.lib.duke.edu/dspace/bitstream/10161/4986/1/Loyd_duke_0066D_11141.pdf.

[19] LSTC. 2013. “LSTC Hybrid III 6 Year Old Finite Element Model Documentation.”

[20] Meyer, F., C. Deck, R. Willinger, and P. Meyer. 2014. “Development of a 3-Year-Old Child Head–neck Finite Element Model and Derivation of Novel Head Injury Criterion.” International Journal of Crashworthiness 19 (3): 233–43. doi:10.1080/13588265.2013.815018.

[21] Meyer, Franck and Willinger, Remy. 2009. “Three-Year-Old Child Head-Neck Finite Element Modelling: Simulation of the Interaction with Airbag in Frontal and Side Impact.” International Journal of Vehicle Safety 4 (4): 285–99.

[22] Miyazaki, Y, Y Murai, Y Nishida, M Mochimaru, and M Kouchi. 2009. “Head Injury Analysis in Case of Fall from Playground Equipment Using Child Fall Simulator.” The Impact of Technology on Sport 3: 417–21.

[23] Mizuno, Koji, Kazuya Iwata, Takashi Deguchi, Takashi Ikami, and Masami Kubota. 2005. “Development of a Three-Year-Old Child FE Model.” Traffic Injury Prevention 6 (May 2014): 361–71. doi:10.1080/15389580500255922.

[24] Mizuno, Koji, Kazuya Iwata, Tatsuya Namikiri, and Nobuhiko Tanaka. 2009. “Comparison of Human FE Model and Crash Dummy Responses in Various Child Restraint Systems.” International Journal of Crashworthiness 14 (2): 139–49. doi:10.1080/13588260802614332.

[25] Mohamad Sulaiman Ibrahim, Rakhmad Arief Siregar, Khairul Fuad, Abdul Hamid Adom and Shah Fenner Khan. 2011. “Development of 6YO Numerical Child Dummy Model for Crashworthiness Assessment.” Jurnal Mekanikal, no. 32: 12–25.

[26] Nightingale, Roger W, Jason F Luck, and Injury Incidence. 2013. “Pediatric Injury Biomechanics.pdf.” doi:10.1007/978-1-4614-4154-0.

[27] Okamoto, Masayoshi and Takahashi, Yukou and Mori, Fumie and Hitosugi, Masahito and Madeley, Jane and Ivarsson, Johan and Crandall, Jeff R. 2003. “Development of Finite Element Model for Child Pedestrian Protection.” In Experimental Safety Vehicles Conference, 1–9.

[28] Rafukka, I A, B B Sahari, A A Nuraini, and A Manohar. 2015. “Development of Three Year Old Nigerian Numerical Child Dummy Head and Validation in Frontal Impact.” In Proceedings of 25th TheIIER International Conference, Kuala Lumpur, Malaysia, 50–54.

[29] Roth, Sébastien, Jean Sébastien Raul, and Rémy Willinger. 2008. “Biofidelic Child Head FE Model to Simulate Real World Trauma.” Computer Methods and Programs in Biomedicine 90: 262–74. doi:10.1016/j.cmpb.2008.01.007.

[30] Roth, Sebastien, Jean-Sebastien Raul, and Remy Willinger. 2010. “Finite Element Modelling of Paediatric Head Impact: Global Validation against Experimental Data.” Computer Methods and Programs in Biomedicine 99 (1). Elsevier Ireland Ltd: 25–33. doi:10.1016/j.cmpb.2009.10.004.

[31] Roth, Sebastien, Jonathan Vappou, Jean-Sebastien Raul, and Rémy Willinger. 2009. “Child Head Injury Criteria Investigation through Numerical Simulation of Real World Trauma.” Computer Methods and Programs in Biomedicine 93: 32–45. doi:10.1016/j.cmpb.2008.08.001.

[32] Roth, S and Raul, Jean-Sebastien and Ruan, J and Willinger, Remy. 2007. “Limitation of Scaling

Methods in Child Head Finite Element Modelling.” International Journal of Vehicle Safety 2 (4): 404–21.

[33] Saul, Roger A, Howard B Pritz, Stanley H Backaitis, and Heather Hallenbeck. 1998. “Description and Performance of the Hybrid Iii Three Year Old, Six Year Old and Small Female Test Dummies in Restraint System and out-of-Position Air Bag Environments.” In Proceedings: International Technical Conference on the Enhanced Safety of Vehicles, 1513–31.

[34] Schneider, L W, D H Robbins, M a Pflug, and R G Snyder. 1983. “Anthropometry of Motor Vehicle Occupants, Vol 1, Procedures, Summary Findings and Appendices Final Report.” http://mreed.umtri.umich.edu/mreed/downloads.html\nhttp://mreed.umtri.umich.edu/mreed/downloads/anthro/amvo/AMVOvol1.pdf.

[35] Seacrist, Thomas, Emily a. Mathews, Sriram Balasubramanian, Matthew R. Maltese, and Kristy B. Arbogast. 2013. “Evaluation of the Hybrid III and Q-Series Pediatric ATD Upper Neck Loads as Compared to Pediatric Volunteers in Low-Speed Frontal Crashes.” Annals of Biomedical Engineering 41 (11): 2381–90. doi:10.1007/s10439-013-0841-3.

[36] Sherwood, C P, C G Shaw, L Van Rooij, R W Kent, J R Crandall, K M Orzechowski, M R Eichelberger, and D Kallieris. 2003. “Prediction of Cervical Spine Injury Risk for the 6-Year-Old Child in Frontal Crashes.” Traffic Injury Prevention 4 (3): 206–13. doi:10.1080/15389580309885.

[37] Snyder, Richard G, Lawrence W Schneider, Clyde L. Owings, Herbert M. Reynolds, Henry Golomb, and Anthony Schork. 1977. “Anthopometry of Infants, Children and Youth to Age 18 for Product Safety Design.” Measurement, no. Final Report.

[38] Stephen, P. 2005. “Anthropometry, Ergonomics and the Design of Work.” CRC Press, Guildford.

[39] TNO Automotive. 2013. “MADYMO Manual Version 7.5, Tass International, Delft, Netherlands.”

[40] Tot, M, T Kapoor, W Altenhof, W Marino, and A Howard. 2008. “Implementation of Child Biomechanical Neck Behaviour into the Hybrid III Crash Test Dummy.” SAE Technical Paper. http://papers.sae.org/2008-01-1120/.

[41] Weber, Kathleen. 2000. “Crash Protection for Child Passengers A Review of the Best Practice.” UMTRI Research Review 31 (3): 1–28.

[42] West, Bethany A and Naumann, Rebecca B and others. 2011. “Motor Vehicle--Related Deaths—United States, 2003--2007.” CDC Health Disparities and Inequalities Report—United States, 2011. Vol. 60.

[43] Youn, Younghan and Han, WH and Hong, SJ and Hong, CH and Yoon, KH. 2009. “A Study of Thoracic Injury Criteria for Elderly Korean Occupant.” In International Technical Conference on the Enhanced Safety of Vehicles 21st Proceedings.

[44] Young, Joseph W and Reynolds, Herbert M and McConville, John T and Snyder, Richard G and Chandler, Richard F. 1976. “Development and Evaluation of Masterbody Forms for 3-and 6-Year-Old-Child Dummies.” FFA-AM-76-9, UMTRI.

[45] Zhang, Wencheng, Tanya Kapoor, William Altenhof, Andrew Howard, and Koji Mizuno. 2009. “Implementation of Child Biomechanical Neck Behaviour into a Child FE Model.” SAE International Conference, April. doi:10.4271/2009-01-0472.