COUPLING DEVICE FOR CHILD RESTRAINT SYSTEM (CRS) FOR INFANTS AFFECTED WITH OSTEOGENESIS IMPERFECTA: DESIGN AND NUMERICAL ASSESSMENT

Miguel Ángel, Martínez Miranda, Christopher René, Torres-San Miguel, Juan Alejandro, Flores Campos

Instituto Politécnico Nacional, Escuela Superior de Ingeniería Mecánica y Eléctrica, Sección de Estudios de Posgrado e Investigación, Unidad Profesional “Adolfo López Mateos” Zacatenco Edificio 5, 2° Piso Col. Lindavista C.P. 07738, México.

México.

Luis, Martínez-Sáez

Universidad Politécnica de Madrid

Spain
19-0063

ABSTRACT

The second death reason in children since 5 until 14 years is related with injures produced during traffic incidents mainly due to vehicle’s passive safety systems, which are not designed to safeguard their lives. Thus, current traffic norms impose the usage of Child Restraint Systems (CRS).

Notwithstanding, CRS for children with different ailments as bone-degenerative ones do not exist. For instance, around half a million persons suffering Osteogenesis Imperfecta (OI) are estimated to exist. At the best knowledge of the authors, currently, there is no CRS specially development for children with OI.

This work in progress aims to provide a solution for car mobility of infants with OI based on a CRS designed to dissipate a part of kinetic energy during vehicular impacts.

The proposed mechanism consists on a Cartesian mechanism system with linear displacements in axis X, featuring springs and dampers, which is aimed to dissipate kinetic energy in order to reduce the decelerations reaches for the child during a frontal crash. The system is designed in CAD software and is then analyzed numerically, through a 2D dynamical Software simulation.

In order to obtain a cheap and adaptable CRS, it was established a methodology based on the research, recovery, and analysis of information. The mechanics has been development to the new European standard R129 (I-SIZE).

This appliance can dissipate kinetic energy in critical amounts, which could cause damage to OI minors. Numerical analyses show the appropriateness of the design for the purpose of safeguarding OI bones from fractures during front impacts.

Critical deceleration can be present during this kind of impacts. Nevertheless, numerical results validate them obtaining lower decelerations using the proposed system than using ones of the typical CRS.

Despite 2D dynamical recreation, manufacture of the prototype and its further test in a sled platform to confirm that the design accomplishes its goal for different age groups according to R129 is required. Further research on optimizing the CRS is required so to improve these features.

It is important to remark that even the new European standard R129 (introduced completely) in 2018, as well as traffic regulations around the world (up to the best the knowledge of the authors), do not require the usage of any specialized CRS for infants with OI or for any other bone-degenerative diseases. Thus, this research sets an important precedent for the development of this type of specific systems as well as for corresponding regulations to protect OI child population of high risk in vehicular accidents.

INTRODUCTION

Osteogenesis Imperfecta (OI), also known as brittle bone disease, is a genetic disorder. According to data from the European Federation of OI (OIFE), in the world, about 0.008% of the world population is affected by this disease [1]. Depending on the characteristics of the pathology and its severity, there are 4 types of OI [2]. The classification of this disorder directly concerns the type of gene in which the mutation occurred [3]. The elastic modulus of the bones of people who suffer from OI also depends on the classification of their disease.

The bone system of a healthy person has an elastic modulus of 90 ± 19 MPa, while an affected person with type III OI is 40 ± 10 MPa [4-5]. So is easier who they suffer fractures, mainly in the long bones, femurs, tibias, and ribs [6].

On the other hand, there are four anthropometric and mechanical parameters for the evaluation of the safety offered by a vehicle to an OI affected [7]. The first one is for people at higher risk of fractures, limiting their mobility, risk that decreases during puberty. The second type is the riskiest because the affected presents prematurity and low weight. The third one includes those affected with various and intense symptoms having progressive malformations. Finally, the fourth, very similar to type one, is differentiated by having moderate symptoms [8].

Previous research in the Department of Spanish Traffic (DSE), shows results of biomechanical response of sick with OI using three modified CRS and from different manufacturers. For the research, dummies of the series Q3, Q6 and Q10 were adapted to the anthropometric properties of affected with OI. The tests were development down the R129 standard in a Sled platform with a velocity of 50 km/h in a frontal crash. The results were favorable but, the protection offered by these systems was not adequate for the affected population [9].

The different fields of research related to OI have not been fully explored due to the low incidence of this genetic disorder. In the field of engineering, they have taken on the task of developing new technologies with the aim of increasing the quality of life of those affected. Nowadays, in the area of passive vehicle safety, most of them have only been designed CRS for people who do not suffer any kind of suffering. Therefore, people with OI travel in CRS that are not suitable for their anthropometric and biomechanical needs.

The design and function of the anchoring systems (ISOFIX, LACHT) and retention (safety belt and pretension systems) established in the CRS manufacturing, design and commercialization standards; they do not meet the needs of restraint and retention of OI affected. Although its function is to avoid the displacements of the CRS and the excursion of its occupant, in many cases the response of these systems is usually sub-damped or over-damped. In previous studies conducted in dummies of the Q3 series at a speed of 50km / h during a frontal impact, when a seatbelt stops a person's excursion, chest pressures of up to 4500 N are reached [10]. Exposing the physical integrity of a passenger to high risk and even more when he suffers from OI.

Emerging the need to design a retention device that allows the control of the displacements that a CRS experiment during at least one frontal collision, as they are the most frequent. Also, while the displacements happen, a damping system would work. By the performance of the damping system and with a suiting CRS as possible for the OI affected, the pressure exerted by the restraint systems will be less, decreasing the risks of fractures and injuries. The above because the excursion and displacements of affect's body will be less.

As already mentioned, the OI sick travel in CRS made by relatives of them, further reducing the safety and comfort of the passenger [11]. And, in addition, exposing them to a greater risk at the time of moving in vehicles and especially in case of a vehicular accident. If a device with the characteristics stablished before, the safety of the occupants would be increased.

Nowadays, in the category of "special needs", including R44 and R129 [12], there are no guidelines in which the needs of the population with OI are established. Therefore, the main objective of this research is to develop a device that be able to reduce the risk of injuries affected by OI in the event of a vehicular frontal impact accident. This research is organized as next; In the materials and methods section, the established guidelines for the design and evolution of the damping device for CRS are shown. The methodology is based on the search, collect and analysis of information. In order to identify the principal requirements then recognize the possible solutions and finally chose the best one according with the researcher's experience. Subsequently, the design was modelled. Detected the solution, the simulations were carried out to evaluate the system proposed. Within this same section, the conditions under which the system would work were established. In the results section, the graphs corresponding to the response of the damping mechanism, the sizing of the active components of the system and the response of the passenger's body. Finally, in the conclusions section, the achievements reached throughout the development of this research are presented. Also, compared with the peaks, the acceleration will be achieved through experimental and numerical analysis.

Versus the maximum peaks of accelerations with the use of the system develop. The experimental research with which the results are compared was worked out in a sled platform tested at $50\ km\ /\ h$ using a dummy of the Q3 series modified according to the anthropometric characteristics of a person suffering from OI [13].

The numerical research used in the comparation also developed for a vehicle frontal crash at 50 km/h with a dummy of series Q3.

MATERIALS AND METHOD

The methodology proposed is based on the collection, recovery, and analysis of information. Through which the design criteria will be obtained, for this it is necessary to have knowledge of certain characteristics of OI. For example, knowing the elastic modulus of the osseous system of an affected OI and the malformations it undergoes [14-15]. In addition, it is necessary to study the current international norms of vehicular mobility of infants, as well as the manufacture and commercialization of CRS according to the Economic Commission of the United Nations of Europe (CEPE) [16].

The protocol where anthropometric information provided by the "Volume II: Biomechanics Test" of the National Highway Traffic Safety Administration (NHTSA) [17] was retaken and analysed. Similarly, the report of "Anthropometry of babies, children and young people up to 18 years for the design of safety products", from the University of Michigan [18]. Which has been coupled to the needs of people with OI, by the Polytechnic University of Madrid [19]. It was also required to collect and analyse information about the nature of a frontal vehicular impact, according to the science of road accidents and general forensic studies [20]. And of the biomechanics of the behaviour of an occupant of SRI during a frontal crash [21].

After the search and analysis of the information within the literature of free access, and in accordance with the experience of the researchers, it has been possible to establish the main characteristics of the design proposed. As a first instance, the device must be designed according to the current standards. Therefore, it must have the ability to change the orientation of the anchor ISOFIX, according to the age of the child. The design should allow for adaptability and the assembly with any model of automobile.

The proposed solution should allow control of the displacements and accelerations experienced by the occupant of the CRS. By means of the reduction of the accelerations suffered by the occupant, the pressures that the safety belts would exert will be lower. Also decreasing the possibility of collision with objects that are in front of the passenger. To reduce the cost, the design of the solution has been adapted to work as universal support adaptable to any type of CRS manufactured according to current standards. The solution will be established in an adaptable clamping and anchoring device for CRS. The proposed methodology is summarized in Figure 1.

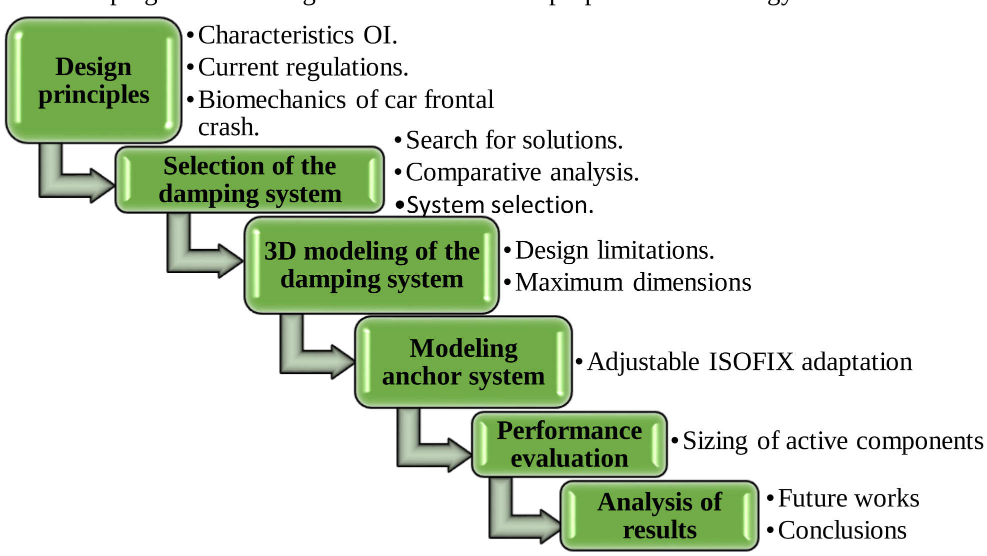


Figure 1: Design methodology of the damping adaptive device for CRS.

For the selection of the damping system, the analysis of the functions to be performed based on the inputs and outputs of the device is performed. The inputs are: the average accelerations ($G's[t]$) that a CRS experiences and the user when an accident occurs, as well as the force ($F[t]$) it receives and the mass (m) of both.

On the other hand, the displacement ($x[t]$), the velocity ($\dot{x}[t]$) and the accelerations ($\ddot{x}[t]$) of the CRS and the occupant are presented in the outputs.

It was determinate that the damping system should allow position, velocity and acceleration control ($x[t], \dot{x}[t], \ddot{x}[t]$) of the CRS and its occupant. In addition, based on the experience of the researchers, it was proposed to perform the analysis of two control systems, the first open loop and fully mechanical and the second a feedback electromechanical system. For the first case, a Cartesian mechanism was chosen that would have a set of springs and dampers as actuators. For the second option, a position control by reaction wheels with electric motors was selected. In Figure 2, you can see a block diagram of the first proposal.

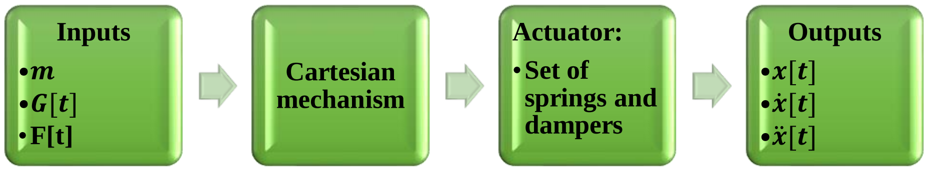


Figure 2: Diagram of inputs and outputs of Cartesian mechanism.

Figure 3 shows a block diagram of a position control system by reaction wheel type, where it should be noted that there are two additional inputs: electric power ($v[t]$) and the error input ($e(t)$).

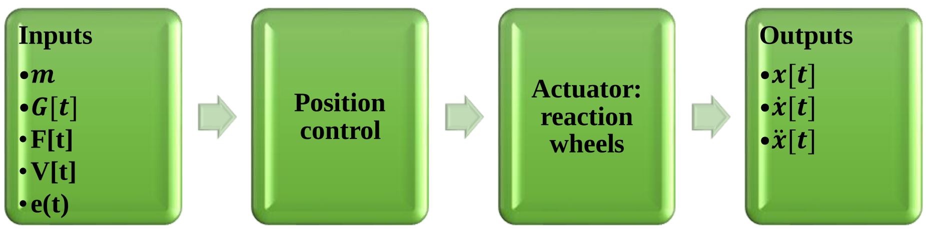


Figure 3: Block diagram of the inputs and outputs of a position control system by reaction wheels.

Determinate the possible solutions, they were thoroughly analysed, determining the advantages and disadvantages of each one based on the experience of the researchers. The main disadvantage of the Cartesian mechanism is that there is no feedback. Without feedback within the mechanism, no control strategy can be implemented, although it is possible to study its behaviour before certain inputs and thus size the system. In other hand the system has great advantages, the most important is that it does not require an external source of energy to function, also its easy implementation, and it is a robust system, characteristics that reduce the possibility of failures.

In contrast, the main advantage of the reaction wheel system is the existence of feedback. Establishing the possibility of use control strategies. But the main disadvantage of this system is that it requires an external power source of electrical energy ($V(t)$), Figure 3. Also, the implementation requires numerous electronic systems, increasing its cost and complexity.

After the above conditions, the set of reaction wheels is put at a disadvantage with respect to the first proposed. So, the Cartesian mechanism was selected with a set of springs and dampers as actuators. Although the response of the Cartesian system does not have feedback, the chances of failure are less, since it does not depend on an external source of energy. And the response speed of this system meets the established needs.

Modelling of adaptive support for CRS used by OI affected

Once the Cartesian mechanism was selected, it has been adapted a damping system. A proposal of the components and its dimensions has been presented. It was determined that it should be a system that allows linear displacements along the X axis.

Also, in order to dissipate the kinetic energy were add a pair of dampers and springs. The array of springs and dampers allows the displacements in a controlled oscillate way. In the end, two mass concentrators were attaching the system in order to make the behaviour of the system as a vibration absorber.

Cartesian mechanism, in Figure 4, you can see the diagram of the proposed mechanism. Which has a linear bearing (B1) arranged on the rails (X1, X2). It can also be observed that there are eight springs (RX1, RX2, RX3, RX4, RX5, RX6, RX7, and RX8) placed concentrically on the rails. The spring anchors, RX1, RX2, RX7, RX8, have a fixed point and a moving point. While the anchors of springs RX3, RX4, RX5, RX6 are all mobile and move according to the displacements of the concentrators of mass and the slide. Likewise, the dampers (A1, A2, A3, A4) can be observed, which have a fixed point and a moving point, anchored to the bearing (B1). It is important to mention that the mass concentrators (M1 and M2), are fundamental pieces when it comes to reducing the accelerations reached by the passenger when the crash happens.

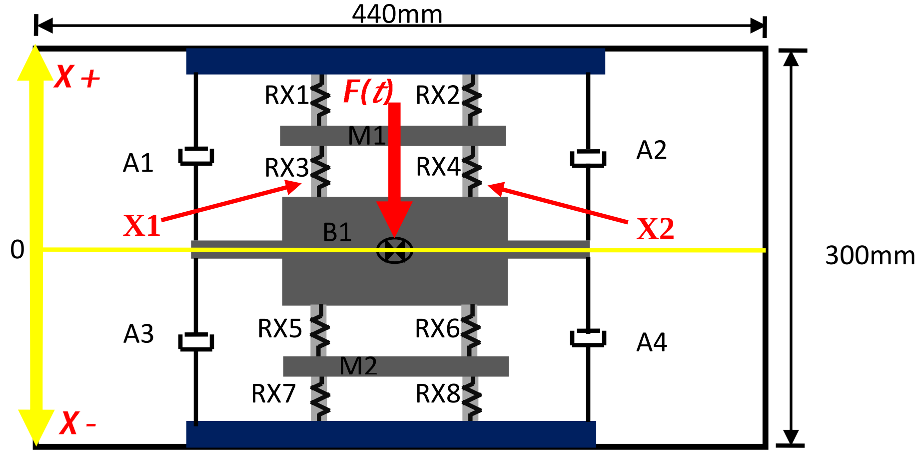


Figure 4: Diagram of the Cartesian mechanism.

Once the components of the Cartesian mechanism were established, as well as the arrangement and the maximum dimensions of the system, the three-dimensional model was generated. A computer program of Computer Aided Design (CAD), *SolidWorks ®* 2017 and high-performance computing equipment were used. In Figure 5, the proposed design of the Cartesian mechanism modelled in three dimensions can be observed.

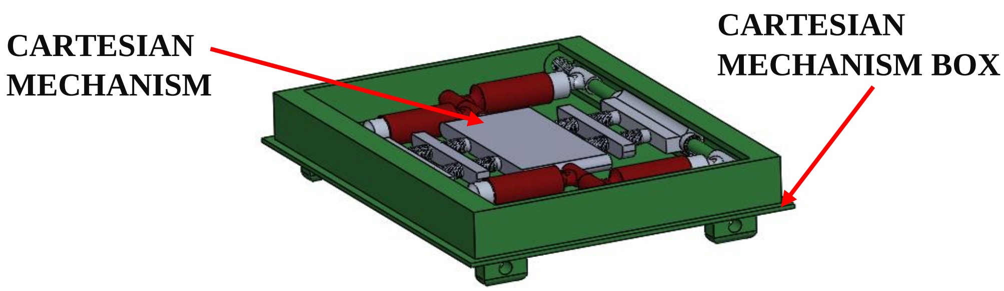


Figure 5: 3D model of the Cartesian mechanism.

With the Cartesian mechanism 3D model, the design of the support was carried out in conjunction with the anchoring system. As mentioned above, the adaptive support design was develop based on current standards. So, the system must have ISOFIX, according to the R129 standard. In the same way, it is necessary to establish a system in such a way that its orientation can be modified. Therefore, it has a set of insurance and rods that allow changing the orientation of the anchors, when necessary.

Anchoring of the adaptable support see Figure 6, the system consists of 3 rods, of which two are placed in the same direction and one in the opposite direction. The locks are designed in such a way that the rod presses into the lock. In addition, this one has an "L" shape, where the longest part is the one that penetrates the CRS, and the shortest one is with the locks.

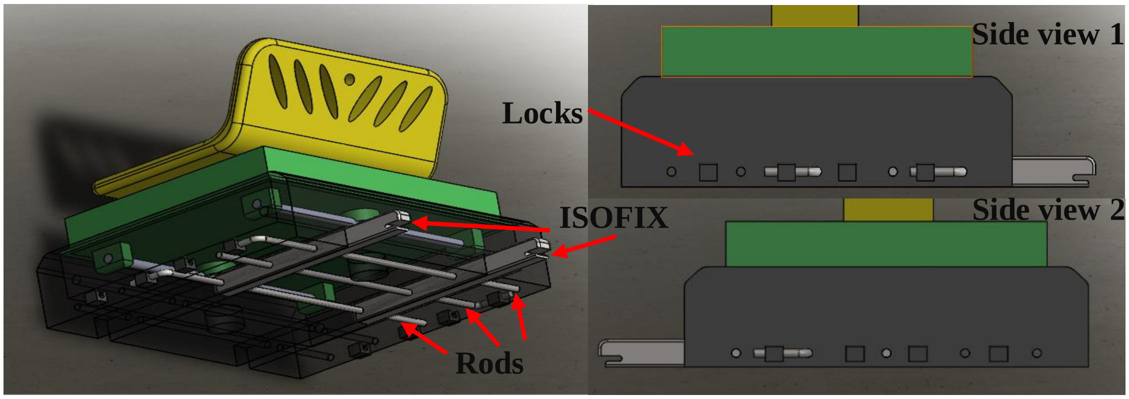


Figure 6: Anchoring of the adaptable support

As stipulated in the beginning, this research will develop an adaptive support for CRS, but not the retention system as such. Once the design of the anchoring system for the adaptable support has been established, it is only necessary to design a system that allows the correct CRS clamping.

CRS anchor, the main function is to keep the CRS fixed, in the adaptive support. See Figure 7, you can see the anchoring system of the CRS, which consists of a piece moulded to match the external part of the backrest and the base of a CRS. Also, in the lower part of the piece, there is the block that will be fixed to the slide B1, of the Cartesian mechanism; thus, joining the CRS with the adaptive support.

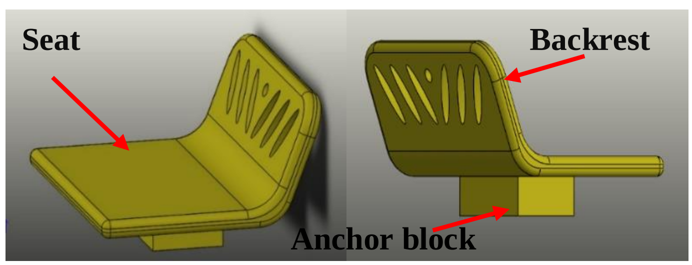


Figure 7: Anchoring system for the CRS.

The last design of the resulting adaptive support can be observed in Figure 8, where the car seat, the adaptive support and the CRS are presented.

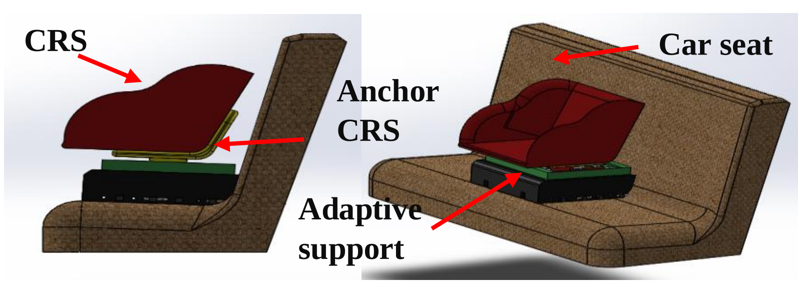


Figure 8: Final design of the adaptive shock absorber support with a CRS installed and arranged in an automotive seat.

Dynamic simulation in two dimensions

The modelling of the system was carried out, by means of a two-dimensional movement simulation computer program for dynamic designs. Through these simulations, it is possible to know the answer to external stimuli ($F(t)$). So, it was necessary to draw the Cartesian mechanism. The dimensions of the model made in the two-dimensional simulator should be the same as those of the CAD model in three dimensions.

In order to know the biomechanical response of the occupant, modelling of a dummy was made in 2D based on the anthropometric parameters of weight and length of the parts of the body of an affected one with OI obtained by means of statistical data collection [22]. It was also necessary to model a CRS, which was anchored using the ISOFIX system and where the dummy was placed. To simulate the retention of the safety belts, springs and dampers were placed strategically.

As well to study the biomechanical response of the occupant, a CRS was modelled that was placed on the designed damping device. As above, the dummy was set, and the damper spring systems were installed that emulate the behaviour of the safety belts. Once both models were finished, they were subjected to the accelerations that they would experience during a frontal impact.

To perform the dynamic simulations, it was necessary to know the impulses of force with which the operation of the system will be tested. It is required to know the average acceleration experienced by a child with an approximate weight of 15kg during a vehicular frontal collision at 50 km / h. The input pulses for the system will be collected from previous investigations developed under the guidelines of the R129 standard.

Cartesian Mechanism, the dynamic simulation of system behaviour, aims to know the linear displacements ($x(t)$), velocities ($\dot{x}(t)$) and accelerations ($\ddot{x}(t)$), in front a force ($F(t)$) perpendicular to the Y axis. As mentioned, the mechanism consists of a bearing (B1) anchored to the rails (X1 and X2), allowing the displacement along the length of the x axis. In addition, two mass concentrators (M1 and M2) are included, with an approximate weight of 2.5 Kg each, turn up Figure 1, you can see the diagram of the Cartesian mechanism, which must be modelled in the computation program for dynamic simulations in two dimensions, see Figure 9.

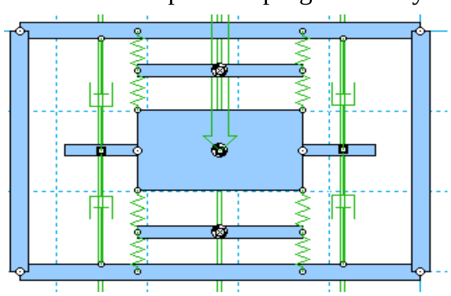


Figure 9: Dynamic simulation of behaviour on the X axis.

Development of the dummy and the CRS, for the modelling of the two-dimensional dummy, took advice previous researches, in which information was collected on the anthropometric parameters of weight and length of specific parts of the body of those affected. In Table 1, relevant information about the approximate weight and its distribution in the body of an affected by OI is observed [23].

Table 1:
Estimated mass distribution for an affected OI [23].

Part	Estimated mass (kg)
Head	3.94
Neck	0.25
Clavicle	0.29
Torso	5.59
Right arm	0.77
Left arm	0.77
Right Femur	1.22
Left Femur	1.19
Left tibia	0.84
Right tibia	0.90
Total mass	15.76

Known the approximate mass distribution of an affected OI, the weight parameters that would be used for modelling the dummy in 2D were established. Table 2 shows the amount of weight that was assigned to each part of the body of the proposed model. It is important to mention that the approximate weight of the clavicle and the arms were assigned to the torso, also being a model in two dimensions, the weight of both femurs and tibias was assigned to only one, see Figure 10.

Table 2:
Weights established for 2D dummy modelling

Part	Estimated mass(kg)
Head	3.94
Neck	0.25
Torso	7.42
Femur	2.41
Tibia	1.74
Total mass	15.76

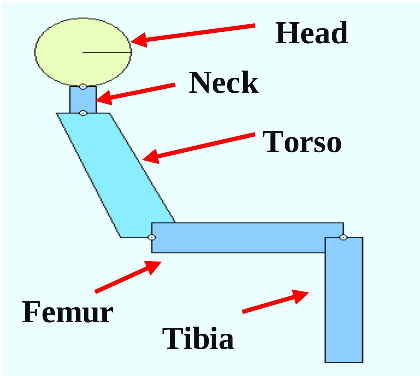
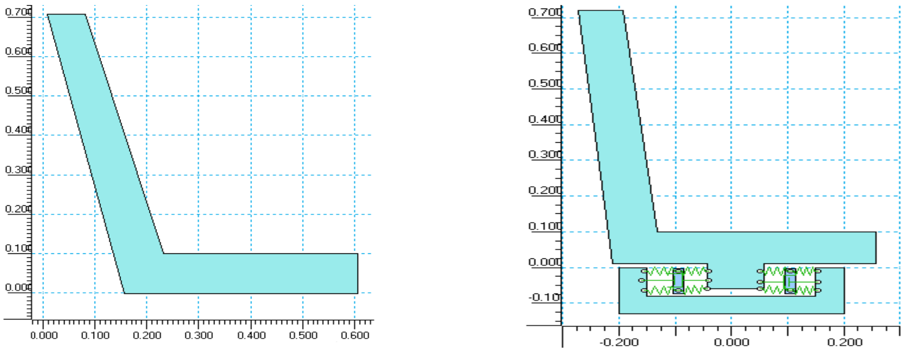


Figure 10: Dummy modelling for simulations

After the dummy modelling was completed, the design of two CRS was carried out, the first of them; using conventional anchoring systems (ISOFIX), see Figure 11 a). Then, the modelling of a CRS was performed, but using the buffer device proposed in this investigation, see Figure 11 b). And the dummy was placed on both CRS. With both models finalized, restrictions of linear displacement were established on the x axis, and the force ($F(t)$) was applied to which both bodies would be subjected (dummy and CRS); in the centre of mass, in case of vehicular frontal impact, see Figure 12. It is important to mention that the approximate weigh of each CRS established was about 5 Kg.



a) b)

Figure 11: a) Conventional CRS b) CRS modelled using the proposed damping device.

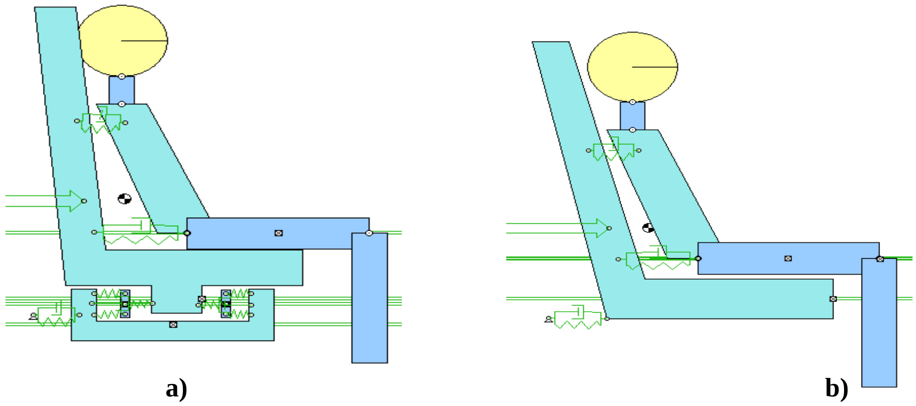


Figure 12: a) conventional CRS and dummy, b) CRS and dummy using the proposed damping device

<u>Pulses of forces used for the numerical simulation</u>, like the damping device is integrated by several springs and dampers with the function of control the displacements, velocities and accelerations ($x(t), \dot{x}(t)$ and $\ddot{x}(t)$, respectively) which experiences a CRS and its occupant during a frontal collision. The response of the active components of the system (springs and dampers) must be studied. This test is done by applying the force pulse ($F(t)$) that a CRS and its occupant would receive during the impact. It is important to mention that these pulses of force must be obtained through tests carried out under the guidelines established by the R 129 standard for frontal impact tests at $50\ km/h$. Finally, the mass of the occupant with whom the study was conducted should be approximately $15kg$, since according to statistics it is the average weight of an affected OI [24].

To test the operation of the system in the event of a frontal impact, the data obtained from previous research was retaken. The study was to determine the average accelerations experienced by the body of a child under 36 months of age (dummy series Q3), weighing approximately $15\ kg$, and his CRS (weight approximately $5\ kg$) during a frontal impact at $50\ km/h$ under the guidelines of standard R129 [25]. Obtaining the graph of Figure 15, from which it can be highlighted that the maximum peak of the average accelerations that are experienced ($\ddot{x}(t)$) is approximately $100\ G's$ at around $38ms$ the curve obtained in this study was made with the help of a program of computation of numerical simulations using a finite element.

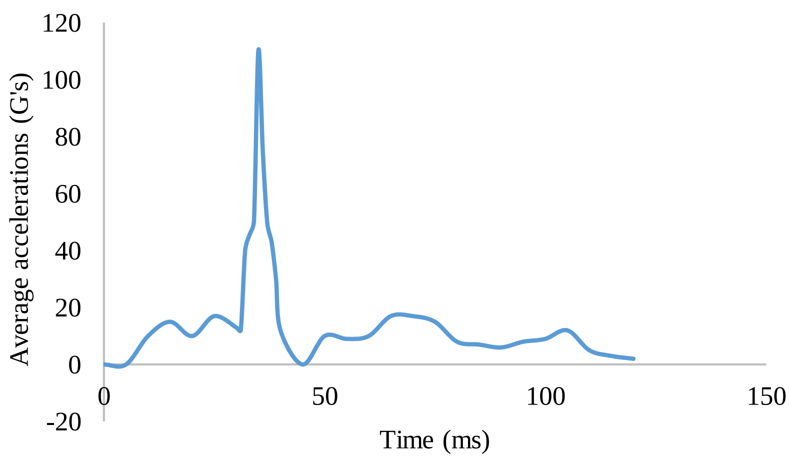


Figure 15: Average acceleration experienced by a minor during a frontal vehicular impact.

From the graph of Figure 11, it is also worth noting that the critical period in which the vehicle accident occurs is less than 120ms. In addition, it has a behaviour like that of a pulse function or Dirac Delta ($\delta(t)$). An algorithm was made to interpolate by the Lagrange method a polynomial as a function of time (Equation I) that describes the behaviour of the accelerations experienced by a CRS and its occupant from the acceleration curve of Figure 11.

$$\ddot{x}[t] = 7.807t - 1.885t^2 + 0.178t^3 - 0.007t^4 + 0.0001 - 0.000002t^6 + 1.582 \times 10^{-8}t^7 - 6.351 \times 10^{-11}t^8 + 1.067 \times 10^{-13}t^9 \quad \text{(Equation I)}$$

Figure 16 shows the graph of the polynomial as a function of time (Equation I), which describes the average accelerations $x\ddot{(t)}$ experienced by the minor, during 120ms.

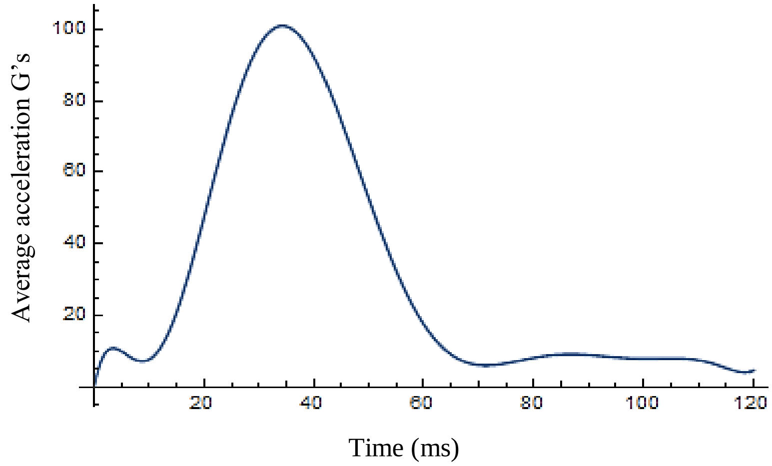


Figure 16: Graph corresponding to Equation I.

By Equation I, it is possible to obtain the force as a function of time$(F(t))$, which will experience the child and its CRS during vehicular impact. The above is possible by Equation II. Where m, is the mass of child (approximately15 kg) plus the mass of the SRI (approximately 5 kg), $\ddot{x}(t)$, is Equation I and $F(t)$, it will be the input force impulse used for the simulation dynamic. Applied for the first simulation in the centre of mass of the slide (B1) and in the second in de centre of mass of dummy an its CRS both during a time of$120ms$.

$$Fx(t) = m\,\ddot{x}(t) \quad \text{(Equation II)}$$

RESULTS

This stage of the research was divided into three parts, the first consisted of the sizing of the active components based on the experience of the researchers and the availability of the components in the current market. The second part was based on obtaining the displacement graphs $(x(t))$, and acceleration $(x\ddot{(t)})$ of the bearing B1 of the Cartesian mechanism, the total weight (CRS and child), was assigned to bearing B1. The final stage consists of the average acceleration graphs experienced by the occupant's body using the three established proposals

Sizing of springs and dampers of the Cartesian mechanism.

The function played by these devices is important, through them it is possible to reduce the accelerations that could damage to the OI affected during frontal impact vehicle. Decreasing the possibility of injury or reduce the severity of them. Therefore, the sizing of the dampers and springs must be done as best as possible. The coefficients depend to a great extent on the mass of the CRS and its occupant. As mentioned, this study was carried out considering that the mass of the minor is approximately 15 kg and that of the CRS around 5 kg.

Table 3, you can see the proposals for the springs and dampers constants of the mechanism. In the first proposal, value A, a very high value was established for the spring's coefficient, while the value of the dampers is small. For option B, the coefficients were proposed, according to the experience of the researchers. Finally, the values of option C were proposed based on a catalogue of compression springs [26] and a catalogue of dampers [27], both commercial.

Table 3:
Constants of springs and dampers belonging to the Cartesian mechanism

Device	ID	A	B	C	Length
Dampers ($N\frac{m}{s}$)	A1	1	15	12	15
	A2	1	15	12	15
	A3	1	6	12	15
	A4	1	6	12	15
Springs ($\frac{N}{m}$)	RX1	50	10	10	5
	RX2	50	10	5	5
	RX3	50	5	5	5
	RX4	50	5	5	5
	RX5	50	10	5	5
	RX6	50	10	5	5
	RX7	50	10	5	5
	RX8	50	10	5	5

Graphs of displacement $x(t)$ and acceleration $\ddot{x}(t)$.

Knowledge of behaviour of the Cartesian mechanism face the force input ($F(t)$) of Equation II, during a time of $120ms$ applied at the centre of mass of the bearing (B1) is important. The displacement graphs allow us to know if the bearing (B1) stops before reaching the limit switches of the mechanism. The accelerations allow the evaluation of the response of the damping device before previously established injury criteria. At last, the comparison between the maximum peaks of the accelerations experienced when a conventional CRS is used, versus the use of system proposed. See Figure 17, the graphs resulting from acceleration are showed and the displacements in Figure 18, when the values proposed in Option A, B and C of Table 3 are used.

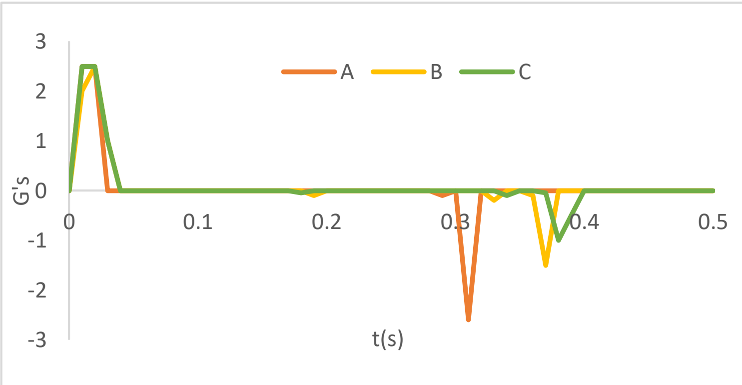


Figure 17: Response of the accelerations ($\ddot{x}(t)$) of the Cartesian mechanism face a force (F (t)) input.

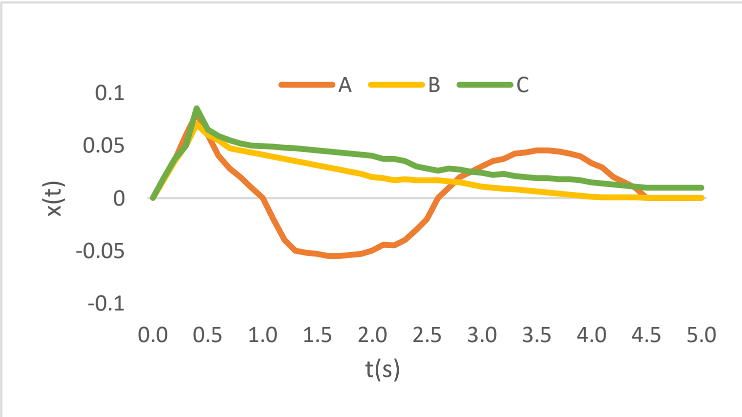
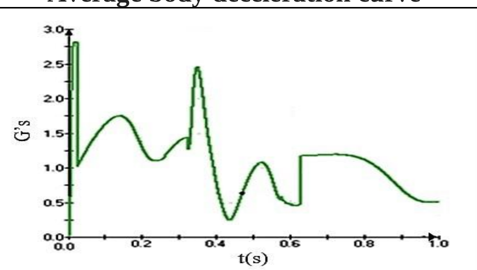
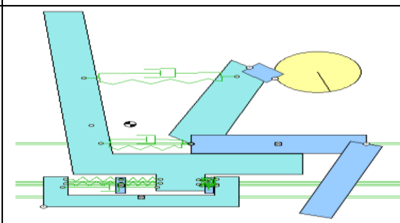
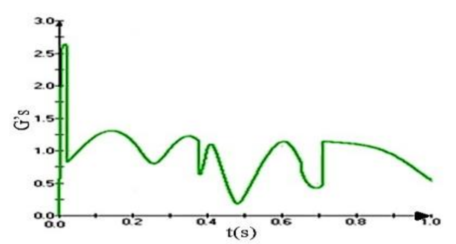
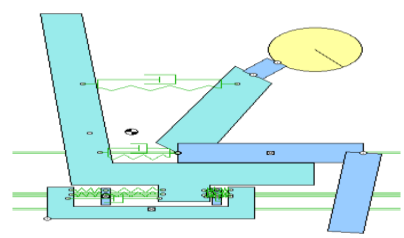
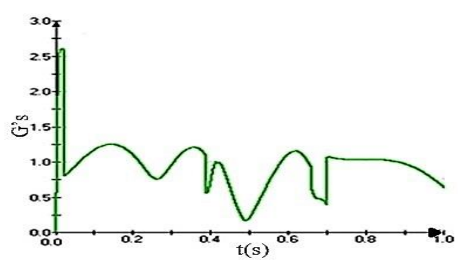
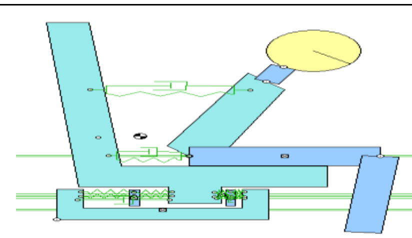


Figure 18: Response of the displacements ($x(t)$) of the Cartesian mechanism face a force (F (t)) input.

In Option A of Figure 17, the acceleration responses ($\ddot{x}(t)$) of the Cartesian mechanism are observed, where the maximum acceleration peak was of approximately $2.5G's$; also, at $0.3\ s$ an acceleration is experienced in the opposite direction that reaches around $2.5G's$. The acceleration curve, from Option B, the maximum acceleration peak reached a value of about $2.5G's$.. Also is the presence of an acceleration in the opposite direction, approximately $1.5G's$ at around the$0.38s$. Finally, in Option C, the maximum acceleration peak reached a value of around $2.5G's$. Similarly, the presence of an acceleration in opposite direction of approximately $0.5G's$ at of around the $0.38s$.
In Figure 18, the displacement curve of Option A is seen; where a maximum peak of $0.08m$, is recorded, decreasing with each cycle that occurs and presenting oscillations. As for the curve of Option B, a maximum displacement peak of approximately $0.08m$ is recorded, then it begins to decrease logarithmically, until reaching the position of origin after $5s$. Finally, for the curve of Option C, a maximum displacement peak of approximately $0.08m$ is obtained and then logarithmically decremented, until reaching the origin position after $5s$.

Average accelerations experienced by the occupant of the CRS using the damping device.
Knowledge of the average acceleration experienced by the occupant is important, in order to validate the functionality of the damper system. As higher the accelerations experienced by the user are, the excursion of the head, neck, and thorax (whiplash) will also be higher. With a high excursion of the body, the pressure exerted by the safety belts on the body of the infant to stop the excursion and displacements increases. On the other hand, the possibilities of collision with the possible objects that are in front of the passenger increase.
Next, in Table 5, the average deceleration curves experienced by the occupant's body are shown. Using the damping device with the different coefficients of the options in Table 3. And the excursion suffered by the passenger when the frontal impact occurs.

Table 5:
Average accelerations and excursions experienced by the body.

ID	Average body deceleration curve	Excursion.
A		
B		
C		

In the answer of the option, A, the maximum peak of the average decelerations experienced by the minor's body is approximately 2.8 G's. Subsequently, decelerations begin to decrease while oscillate, the second peak of approximately 2.5 G's is registered at 0.4 s. The behaviour in general of the decelerations experienced by the child are oscillating, but these do not reach large values. On the other hand, the excursion and displacements experienced by the child's body is reduced, as seen in Table 5, although the head jerks too much. For option B, in the deceleration curve, the maximum peak of the average decelerations experienced by the infant's body is approximately 2.6 G's, being the only peak registered. Subsequently, the decelerations begin to decrease while oscillate. The decelerations experienced by the minor are oscillating, but these do not reach high values. The excursion and displacements experienced by the infant's body is reduced and the head does not jerk a lot. At last option C the behaviour is like B answers. The maximum and only peak recorded was approximately 2.6 G's and the accelerations decreased oscillating. While the excursion of the body was also like B answer.

CONCLUSIONS

This research has allowed deepening the knowledge to increase passive safety in people affected by OI, by designing a damping device for CRS. Among the main conclusions that can be reached once this research has finished, are the following.

- It is possible to recreate a physical model in 2D (dummy), which represents those affected with OI, from the physical parameters. Obtained from data bases collected using statistical data on the anthropometric parameters of people suffering from OI.
- The recreation of a dummy in 2D with the physical characteristics of a OI patient, allows an application for future research allied to this condition and passive vehicle safety.
- Although the representative dummy modelling of the community with OI worked to study the behaviour of the damping device for CRS, it is necessary to create a 3D model in order to obtain results closer to reality as possible.
- It is possible to approximate a polynomial as a function of time ($\ddot{x}(t)$) to a deceleration curve obtained in previous studies, using interpolation techniques, which can describe the behaviour of the accelerations experienced by a child user of a CRS, during a vehicular frontal impact.
- With the polynomial ($\ddot{x}(t)$) and the mass of the passenger (m), it is possible to obtain a polynomial as a function of time that roughly describes the force ($F(t)$), which a passenger experiences during a vehicular impact.
- It is possible to implement a damping system using a Cartesian mechanism and a set of dampers, springs and mass concentrators.
- The addition of two mass concentrators in the Cartesian mechanism allows the system to behave as a vibration absorber.
- It is possible to study the response of the Cartesian mechanism face a force input as a function of time, by modelling the proposed damper device in dynamic simulation software and the polynomial F (t),
- From the dynamical simulations of the Cartesian mechanism, is concluded that the best behaviour is obtained when the elastic coefficients of the springs are small and those of the dampers are almost equal to twice the first.
- By the above configuration, the system response with few oscillations that allows the positive displacement of the main slide (B1). While the return to its origin is with a logarithmic and soften performance, as can be seen in the graph of Figure 18.
- When the coefficients of the springs are too high and those of the small dampers the system has a response, it presents oscillations with large peaks.
- Through the model of Cartesian mechanism, a CRS, a dummy representative of the community that suffers OI and the polynomial F (t), it is possible to know by 2D numerical simulations the behaviour of the occupant's body during a frontal impact.
- After analysing the response of the body and the accelerations experienced during a frontal vehicular accident, it is possible to estimate the level of protection provided by the damper system to the user.
- According to previous research, numerical [28] and experimental [29], the accelerations experienced by an infant occupant of a conventional CRS and using a seatbelt, peaks of up to 100 G's have been recorded in some parts of the body. See the graphs below, in Figures 19 and 20.

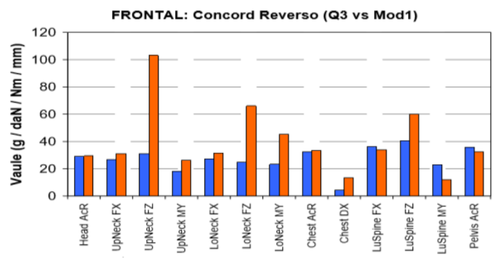
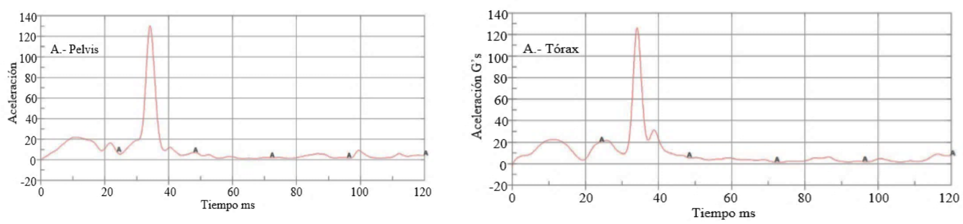


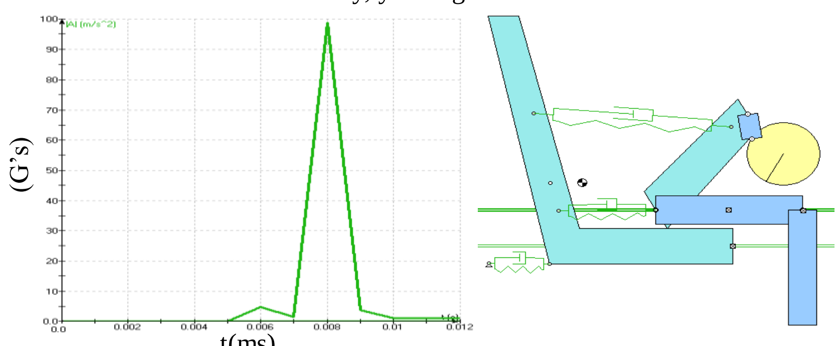
Figure 20: Maximum peaks of acceleration present in some parts of child's body during a frontal vehicular impact at 50km / h under the guidelines of the R129 standard. Develop by an experimental test on a Sled platform with a modified dummy according the physical characteristics of one affected with OI and a conventional CRS [28].



a) *b)*

Figure 20: Acceleration curves in a) Pelvis and b) Thorax, present in the body of a minor during a frontal vehicular impact at 50km / h under the guidelines of the R129 standard, obtained by the finite element method and a conventional CRS [29].

In addition, the behaviour of the average accelerations of the modelled dummy when a normal CRS is used, was studied, as well as the excursion of the body, yielding results like the last researches.



a) **b)**

Figure 21: a) Average acceleration curves, b) Excursion, in the body of a minor during a frontal vehicular impact at 50km / h under the guidelines of the R129 standard, obtained by 2D dynamical simulation using conventional CRS.

- Proceeding the simulation and with a comparison between the graphs shown in Table 5, it can be concluded that it is possible to reduce the accelerations experienced by the body of an OI affected during a frontal vehicular accident allowing the controlled displacement of the CRS by means of a damping device.
- The coefficients of the springs of the damping system must be small, while those of the dampers must be at least twice, otherwise, the system oscillates and the child's head jerks too much.
- It is necessary to design a restraint system for the occupant's head.
- The decrease in decelerations experienced by the body of the child reduces the excursion and displacement of the thorax.
- It is necessary to establish in the guidelines stipulated in the R129 standard for "Special needs", the considerations for the design of an SRI for OI patients.

- Despite the favourable results obtained in this work, it is necessary to manufacture the device in order to carry out experimental tests in a sled platform. In the same line is needed research using the Finite elements method.

Acknowledgment
The authors acknowledge the financial support for the realization of this work to the Government of Mexico by the National Council of Science and Technology (CONACYT), the Instituto Politécnico Nacional, also acknowledge partial support by Projects 20196710 and 1931, as well as EDI grant, all provided by SIP/IPN. And the participation of the biomechanics group of INSIA through the research project "SIRIMOI. Sistema de retención infantil mejorado. Aplicado a la Osteogénesis imperfecta." incorporated to the Universidad Politécnica de Madrid, from Spain.

REFERENCES

[1] Europe, O. I. F. (n.d.). OIFE Statistics. Retrieved October 04, 2018, from http://www.oife.org/index.php/EN/sub-the-oife/oife statistics

[2] Sillence, D., Senn, A., & Danks, D. M. (1979). Genetic heterogeneity in osteogenesis imperfecta. *Journal of medical genetics*, *16*(2), 101-116.

[3] Tipo, I. I. (2002). Tratamiento de la osteogénesis imperfecta. *Anales Españoles de Pediatría*, *56*(SUPLEMENTO 4), 73.

[4] Albert, C., Jameson, J., Smith, P., & Harris, G. (2014). Reduced diaphyseal strength associated with high intracortical vascular porosity within long bones of children with osteogenesis imperfecta. *Bone*, *66*, 121-130.

[5] Imbert, L., Aurégan, J. C., Pernelle, K., & Hoc, T. (2015). Microstructure and compressive mechanical properties of cortical bone in children with osteogenesis imperfecta treated with bisphosphonates compared with healthy children. *Journal of the mechanical behavior of biomedical materials*, *46*, 261-270.

[6] Rauch, F., & Glorieux, F. H. (2004). Osteogenesis imperfecta. *The Lancet*, *363*(9418), 1377-1385.

[7] Sáez, L. M., García, M. D. L. O., Álvarez, A. G., Ruiz, M. E., Torres, C. R., & Miguel, S. (2016, November). Parámetros antropométricos y mecánicos de los afectados por la osteogénesis imperfecta para evaluar su seguridad en vehículos. In *XXI Congreso Nacional de Ingeniería Mecánica: Libro de Artículos* (p. 82). Universidad Miguel Hernández.

[8] Martínez, L., de Loma-Ossorio, M., Pérez, R., Espantaleón, M., Ramírez, V., & Torres, C. R. Injury criteria for children affected by Osteogenesis Imperfecta.

[9] L. M., A. G., M. E., J. M., M. D., & C. T. (2015, December). Research to Increase Passive Safety of Affected by Osteogenesis Imperfecta. Retrieved January 09, 2019, from https://www.researchgate.net/publication/307922380_Research_to_Increase_Passive_ Safety_of_Affected_by_Osteogenesis_Imperfecta.

[10] Calle Pinos, M. J., & Luna Jácome, R. F. (2016). Análisis del comportamiento de los cinturones de seguridad en base a la edad de los pasajeros de furgonetas de transporte escolar de la zona urbana del cantón de Cuenca (Bachelor's thesis).

[11] B. (n.d.). Manual del usuario ECE R44 04. Retrieved November 18, 2018, from https://www.besafe.com/wp-content/uploads/2015/10/BeSafe-iZi-Combi-X3-ISOfix-ES.pdf

[12] EUR-Lex Access to European Union law. (n.d.). Retrieved January 10, 2019, from https://eur- lex.europa.eu/legal-content/ES/TXT/?uri=CELEX:42011X0909(01)

[13] Sáez, L. M., García, M. D., Ruiz, M. E., & San Miguel, C. T. (2015). Estudio antropométrico en sujetos con Osteogénesis Imperfecta para la definición de propiedades de los maniquíes antropomorfos de impacto. V Reunión Del Capítulo Español De La Sociedad Europea De Biomecánica (ESB), 20. Retrieved January 30, 2019, from https://www.researchgate.net/publication/304988518.

[14] Hansen, B., & Jemec, G. B. (2002). The mechanical properties of skin in osteogenesis imperfecta. *Archives of dermatology*, *138*(7), 909-911.

[15] Fan, Z. F., Smith, P., Rauch, F., & Harris, G. F. (2007). Nanoindentation as a means for distinguishing clinical type of osteogenesis imperfecta. *Composites Part B: Engineering*, *38*(3), 411-415.

[16] Sáez, L. M., García, M. D., Ruiz, M. E., & San Miguel, C. T. (2015). Estudio antropométrico en sujetos con Osteogénesis Imperfecta para la definición de propiedades de los maniquíes antropomorfos de impacto. V Reunión Del Capítulo Español De La Sociedad Europea De Biomecánica (ESB), 20. Retrieved January 30, 2019, from https://www.researchgate.net/publication/304988518.

[17] L. B., R. C., & Ramos, N. L. (n.d.). Accidentología vial: Elementos de estudio forense. Cuadernos de Medicina Forense Argentina

[18] Sáez, L. M., Álvarez, A. G., Ruiz, M. E., & San Miguel, C. T. (2014). Diseño y validación de un sistema de retención infantil. Revista Facultad De Ingeniería Universidad De Antioquía, 70, 54-65. Retrieved January 30, 2019, from https://www.redalyc.org/articulo.oa?id=43030033005.

[19] Rey, R. E., Duart-Clemente, J., de la Llana, O. M., & Gúrpide, J. B. (2014). Osteogenesis imperfecta: Treatment and results of a case series. *Revista Española de Cirugía Ortopédica y Traumatología (English Edition)*, *58*(2), 114-119.

[20] L.S. (2007). Resortes de compresión. Retrieved March 01, 2019, from https://www.leespring.com/mx_ compression_spec.asp?springType=C&forWhat=Search

[21] Lee Spring. (2015, April). Resortes Lee Spring, hechos a la medida y en stock. Retrieved January 26, 2019, from http://www.metalmecanica.com/temas/Resortes-Lee-Spring,-hechos-a-la-medida-y-en-stock 103765.

[22] D. (n.d.). Amortiguadores de impacto. Retrieved December 18, 2018, from https://dictator.es/herrajes -y- accionamientos/amortiguadores-hidraulicos/amortiguadores-de-impacto/amortiguadores-de-impacto

[23] Chang, P. C., Lin, S. Y., & Hsu, K. H. (2007). The craniofacial characteristics of osteogenesis imperfect patients. The European Journal of Orthodontics, 29(3), 232-237.

[24] Montpetit, R. J. D. O. D., & Fassier, K. R. F. F. F. (2011). Duval femoral roddingin children with osteogenesis imperfecta receiving bisphosphonates: functional outcomes at one year. *J Child Orthop*, *5*, 217-224.

[25] Brussels, European Commission. (2016). *Annexes to the proposal for a regulation of the european parliament and of the council on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles* (Vol. 31, pp. 110-300). Brussels: European Commission.

[26] L. S. (2007). Resortes de compresión. Retrieved March 01, 2019, from https://www.leespring.com/mx_ compression_spec.asp?springType=C&forWhat=Search

[27] Los amortiguadores de impacto puertas correderas. (n.d.). Retrieved February 11, 2019, from https://es. dictator.de/productos/amortiguadores-hidraulicos/amortiguadores-de-impacto/

[28] Wismans, J., Waagmeester, K., Lemmen, P., Burleigh, M., Carroll, J., Visvikis, C., ... & Martinez, L. (2015). Q10 dummy Report: Advanced Child Dummies and Injury Criteria for Frontal Impact.

[29] Johannsen, H., Trosseille, X., Lesire, P., & Beillas, P. (2012, September). Estimating Q-dummy injury criteria using the CASPER project results and scaling adult reference values. In *Proceedings of IRCOBI Conference, Dublin, Ireland*.