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EVALUATION AND DEVELOPMENT OF RESTRAINT SYSTEMS FOR CHILDREN IN EMERGENCY TRANSPORT

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Abstract. *The child when displaced through one emergency transport, it has exposed to serious injury risk by normally be carried on stretchers that are not adapted to their weight and height, it also considering the fact the ambulances move up at high speeds and need with frequency reduce abruptly velocity. This highlighted the importance of the restraint system effective that is associated with ergonomic factors in cohesion with the physical child characteristics. The aim of this paper is to evaluate and design a model of gurney with an effective restraint system for emergency transport children and small people. The differential our proposal in relation to other, it is a versatility for emergency transport in ambulances and the system allows the rescue in difficult access areas. The main safety factor is associated with the adjustable restraint system, that results in the easy fixing and quick removal of children due to the system of 5-point restraint.*

Keywords: *Transport - Vehicle Safety, Child Restraint Devices, Manufacture of Prototypes*

1. INTRODUCTION

The recklessness and inattention in traffic are presented as current topics of great relevance, especially when observed in mortality rates in traffic accidents. This problem affects not only car drivers but also babies and children on board who are often transported unsafe or reckless.

In Brazil, according to hospital information system of Brazil - Datasus (*Single Health System Database*), only between January and June 2017, approximately 46.495 thousand children between 0 and 9 years old were hospitalized for accidents that caused some kind of child injury. Among these injuries are various types of trauma, fractures, burn, crushing, dislocations and other external causes. In this statistic, about 670 children were hospitalized only for car accidents (DATASUS, 2017). In all cases, emergency transportation needs to be done in ambulances or in difficult-to-rescue areas, preferably with adequate and safe restraints to the location of specialized medical services.

According to Loffredo (2010), traffic accidents in motor vehicle passengers are among the second largest cause of death in the 0-14 age group and the first cause due to run over. In all cases, the transport with safe retention is necessary, be it with ambulances or with gurneys in areas of difficult access to the rescue. Special attention is given to the situation of children as these accidents represent a major cause of child injury Shah *et al.* (2005).

The work of Kahn *et al.* (2001) reviewed 11 years of fatal accidents involving ambulances, which is verified and a concern with accidents due to inadequate retention without ambulance rear compartment, cited as a big question, namely, what is relevant to the occupants of the ambulance. Ambulances present in fatal injuries, especially in situations where abrupt deceleration and inadequate seat belt retention are obtained.

According to Levick *et al.* (2000), who worked with the observation of the arrival of more than 200 ambulances in a large pediatric emergency department, documented little or minimal effectiveness of the use of child restraints. The children were being transported on stretchers and flat benches made to be used only for adults. At other times, some children were also transported in the lap of adults. Although research on ambulances was carried out in the year 2000 on North American soil, there is a worse or similar reality when compared to Brazil.

There is a great concern of the Brazilian authorities and researchers regarding child vehicular safety, but it is almost all directed to devices and tests of children's car seats. It was observed that the Brazilian legislation is lacking regarding norms and recommendations of children's safety in ambulances, considering that the most comprehensive norms in relation to the subject are ABNT NBR 14400 and ABNT NBR 14561 that detail little on the subject.

Based on this motivation was created the Child & Safety research team composed of UNICAMP master's and doctoral students. The group have their research focus at for safe transport of children, giving rise to such research. Then, the aim of this paper is to evaluate and design the best model of gurney with an effective restraint system for emergency transport children through the analysis of 3 gurney models for children. The prototype of gurney was constructed and tested, however that will only be presented in another future paper.

2. LITERATURE REVIEW

2.1 Safety Products and Devices for Emergency Transportation

- **SafeGuard Transport:** This children's stretcher was manufactured by *IMMI* to providing innovative restraints that offer the utmost in safety and ease of use. While no restraint can prevent injury in every situation, proper installation and use of a restraint can substantially reduce a child's risk of serious injury or death. It has a wide range of sizes, ranging from 10 - 90 kg with an average selling cost of R\$ 1,600.00 . Developed in collaboration with Riley Hospital for Children in Indianapolis, it is illustrated in Fig. 1. The product currently meets a service requirement that is not supplied in addition to being the best tested child restraint product in ambulances through rigorous market crash testing (IMMI, 2016).



Figure 1. *SafeGuard Transport* Children's Gurney (IMMI, 2016).

- **Children's Stretcher by USP:** A prototype of a multifunctional infant stretcher for dental, medical and hospital care exclusively for infants and children up to five years of age was developed in the discipline of Pediatric Dentistry of the Faculty of Dentistry of Bauru (FOB) of USP. The author of the project is the designer and university professor Susy Nazaré Silva Ribeiro Amantini. The project is in the process of obtaining the patent. It is a kind of chair to be adapted on top of ordinary stretchers. The estimated financial investment of maca developed in the project was around R \$ 1,000.00 to R \$ 1,200.00 in the "basic" version (without the accessories). However the prospect that the cost can be reduced after some adjustments and reaches the market with value around R\$ 800.00. It is illustrated in Fig. 2 (Amantini, 2014).



Figure 2. A prototype of a multifunctional infant stretcher (Amantini, 2014).

- **Pedi-Mate:** The Pedi-Mate is a pediatric restraint system that quickly adapts to any ambulance stretcher to safely carry children ranging in size from 10-40 lb (4.5-18 kg). Fully adjusted, with 5-point belt system that holds the patient properly. Non-toxic, easy to clean, vinyl rolls compactly for storage and has an average cost of R\$ 1,000.00. The same is illustrated in Fig. 3 (FERNO, 2014).



Figure 3. Restraint System of *Pedi-Mate* (FERNO, 2014).

- **ACR - Ambulance Child Restraint of Quantum:** The Quantum system is a flexible innovation with a five-point safety belt system for safe and effective transport of children in ambulances, color-coded for easy selection in 3 sizes, from 4 kg to 44 kg . Quick release clips docked with the ACR belt system, keeping the patient in place to prevent potentially dangerous movement during transportation, with an average price of R\$ 1,500.00 and illustrated in Fig. 4 (ACR, 2015).

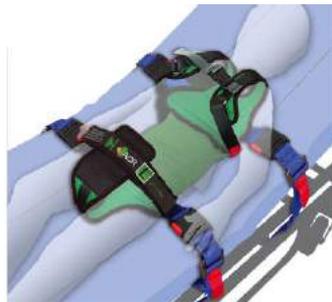


Figure 4. ACR - Ambulance Child Restraint of *Quantum* (ACR, 2015)).

2.2 Ergonomic Factors

Many studies have analyzed the biomechanics of the belt protection components by analyzing the location of the strips passing through the child's body to try to optimize their effect through correct use and thus avoid injury secondary to impact (Arbogast *et al.*, 2005); (Reed *et al.*, 2009). This new way of analyzing and re-evaluating the retention devices was necessary due to the frequent occurrence of lesions found in children even when using the retention device (Lutz *et al.*, 2004);(Ceroni *et al.*, 2004);(Choit *et al.*, 2006);(Mulpuri *et al.*, 2007).

According to de Arruda (2017), Retention devices, by definition and utility, aim to restrain movements and in particular, in the application for vehicle safety purposes in case of collisions, aim to retain relative movements in large decelerations. Certainly a rigid material and high mechanical strength will ensure a better retention, but only a material that absorbs the shock of the movement will prevent the injury.

Kathleen *et al.* (2012) makes clear the advantages of restraint systems by offering protection for different forms of collisions, and over multiple impacts, including rollover. In addition, the force on the occupant is proportional to its mass, if it is distributed correctly, the effect of this load will be minimized.

According to Gouvea (2010), the basic function of the child restraint device in vehicles is to support the child's body, especially the head, by absorbing the energy transmitted in the collision of the vehicle at levels that are acceptable to the structure and organs of the child's body, also has as a function to avoid the aggressive contact of the head and trunk of the child to the interior of the vehicle.

The five-point seatbelt allows for less freedom of movement in normal use when compared to a 3 (three) point belt and especially with a 2 (two) point belt (sub-standard). For Hainoski (2011), the 5-point belt tends to be advantageous in a collision situation because it anticipates the occupant's retention of the chest making the deceleration ramp smoother.

2.3 International Recommendations

Recommendations for the safe transport of children in ambulances are a topic of growing worldwide concern, a topic that has been addressed more frequently over the years, but there is still much to discuss about it, as already mentioned by the researcher Kollen (2002), there are no safety standards for the provision of care or specific recommendations for child retention by age in a moving ambulance.

In Brazil there is a frequent need for clarification regarding the transport of children in ambulances. Several associations of firefighters and humanitarian organizations request mainly from the *Liga dos Bombeiros Portugueses* (LBP), obtaining an opinion on the mandatory retention equipment for minors in ambulance transport vehicles.

The Brazilian regulation that comes closest to a good recommendation in emergency transport of children is NBR 14400 focused on child safety devices and NBR 14561 for emergency care vehicles, these standards consisting of a "simplified" translation into Portuguese of the standard ECE R44 European, in which according to Romaro (2005) some items specifically aimed at European certification were deleted.

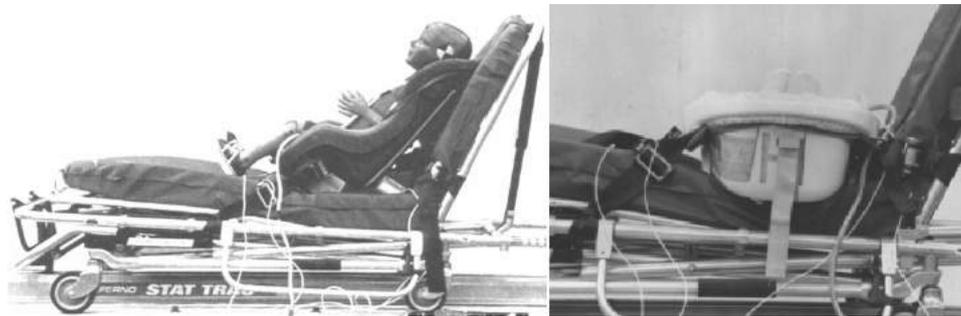


Figure 5. Tests with chairs and cribs overlapping adult stretcher, one for children five (5) years old up to 18 kg and one for infants up to six months with up to 8 kg. (Bull *et al.*, 2001).

According to Bull *et al.* (2001), when transporting a child with a serious medical problem that requires constant monitoring, there is a common practice, to establish a cradle or child's seat that is appropriate to the child's weight and height, superimposed on a retractable articulated stretcher whenever making sure that the belts and straps are positioned on the chest and hip to try to provide a more adequate constraint. Figure 5 illustrates some similar tests performed with *dummies*, the first with a child seat system for a child of approximately five (5) years for up to 18 kg and a slope close to 45° . The second is a crib system, specific for babies with age and weight of approximately six months up to 8 kg.

For children of larger stature who do not fit in a child's seat, we have the researches of Bull *et al.* (2001), which have tested several times a five-point retention system developed through a set of strategically positioned strips to the body logo of a *dummy*, which are anchored in the metal tubes of the high-back retractable stretcher, thereby forming a Safety system simulate a protective vest, tested for children ranging from 18 kg to 27 kg, illustrated in Fig. 6.



Figure 6. Child safety straps overlapped with retractable stretcher using a five-prong restraint system for children 18 kg up to 27 kg. (Bull *et al.*, 2001).

3. EXPERIMENTAL PROCEDURE

In this chapter, we discussed concepts related to the evolution of model constructive through three hypotheses. We also discussed concepts related a structure and design features into the prototype manufacture.

3.1 Evolution of the Proposed Model

The best constructive model was defined in terms of safety, ergonomics, cost of production, manufacturing process, versatility and portability. After the definition of the model, the main characteristics of the constructive design were structured, the ergonomic characteristics of project were detailed.

3.1.1 First version

The first version of the model aimed to attend all patients with less than ten (10) years of age, except for the newborn and premature. The proposal itself was very ambitious, providing two (2) child restraint systems coupled on the same stretcher. However, it would be possible to carry only one type of child at a time. The first system is designed for babies, with the patient's head facing the same direction of movement of the vehicle; would have a special focus belts and strips of appropriate size and weight for children over one (1) year of age. The system would also have 3 (three) head restraints, which would initially be fixed. The design version is illustrated in computerized drawing in Fig. 7.



Figure 7. First version of the project.

In contrast to the first restraint system, the second would be attached to the underside of the stretcher, with the patient's head facing away from the vehicle's movement, it should focus on moorings, locks, anchors and strips of appropriate size and weight for babies less than one (1) year of age. This system would also have 3 (three) supports, one facing the other 2 (two) for the protection of the baby's body, initially would be fixed. The manufacturing process would consist of a straight plank of wood or polyurethane of high resistance that would serve as the basis for the anchorages; then an easy-to-clean waterproof padding would be included; the head and body supports would be made with a soft foam and then wrapped in a seam of waterproof and easy to clean material.

3.1.2 Second version

The second version brings the proposal to transport children and adults of small size, not only for transport in ambulances, but also for rescues in an area of difficult vehicular access. It had as a differential to be a stretcher much more portable than the first version, against starting with the range of reduced age range. The focus was given to transport of small people by ambulances to the height range limited between 800 - 1150 mm and weight 9 - 25 kg or children between 5-10 years old. The proposal offered more consistency and sophistication in design and retention, different from the first version. The second version had only one retention system, but more efficient because it would cover almost the same breadth and height range offered by the previous version. In this model was already idealized in a more compact form because it had a junction in the middle, becoming foldable and having versatility when transporting and storing it.

The design of this model can be seen in Fig. 8, which also identifies the design of a white, smooth and impermeable upholstery that would be riveted on the stretcher for the best comfort of the patient. In this version the patient's head also faces the same direction of movement of the vehicle, the arrangement of the passage of the strips is very similar to that of the final version, with 3 (three) belt heights on the shoulders, 3 (three) configurations (3) between the legs and 1 (one) extra belt passage for the legs.

The structure of design would allow lateral angulation locking, giving the stretcher an advantage of transporting the patient in rescue situations outside the ambulance. After the correct overlapping of the adult stretcher made by strips at 3 (three) fixed anchorage points, the constructive solution would bring the option of unlocking the lateral couplings so that it could accompany the angular variation of the adult stretcher.

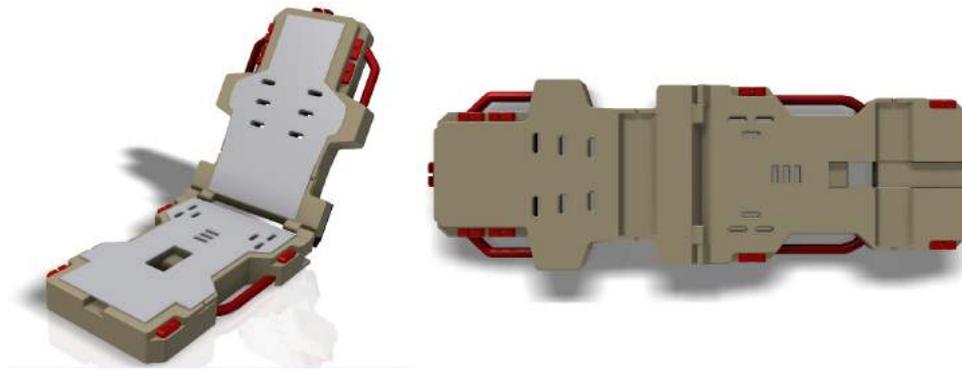


Figure 8. Second version of the project.

3.1.3 Third version

The third version of the stretcher model remained with the same objective, but with more feasible processes and manufacturing methods for the prototype and greater range of patient sizes. With much more viable production costs because much of the materials and equipment available at the University itself are used. The design was simplified to the maximum, without losing its primary proposals of functionality and thus, stabilized a more elaborate process of craftsmanship, but more realistic to the present work environment and more detail as art of confection.

The first differential of the version was in relation to the choice of the child restraint system that was improved by choosing one that had a mechanism with a more simplified tightening adjustment. It eliminated the need to drill a customized center hole in the bottom of the foldable bed base, simplifying the manufacturing process, labor and discarding any possible ergonomic inconveniences when adjusting children's belts. A relevant point that differentiates the final version from previous versions is the improvement of the positioning of the anchor points. It is possible to check a height recess seen in the lower part of the stretcher, positioned in the holes of the passage of strips. This hole-height recess was designed so that the straps did not come in contact with the floor, as this would undermine the fit of the belt. The image of the prototype is illustrated in Fig. 9.

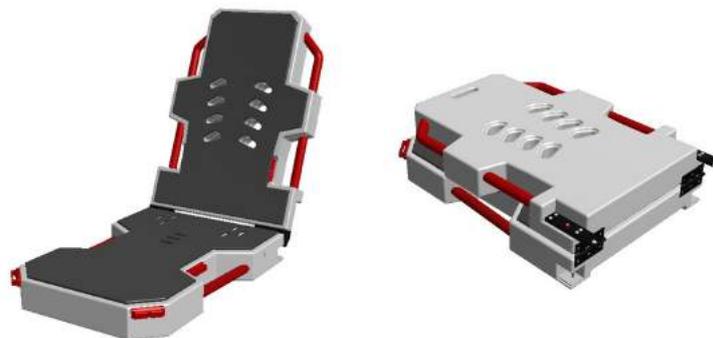


Figure 9. Third version of the project.

Hand rests were presented as a differential in relation to the other stretchers on the market, as they have the function of a rigid anchorage point for fastening belts and straps, which can be used in both adult stretcher and rescue mechanisms difficult to access. The improvements were grounded and compared with the work of researchers and manufacturers, such as (Levick and Grzebieta, 2009); (Bull *et al.*, 2001); (IMMI, 2016); (FERNO, 2014); (Loffredo, 2010) and (NHTSA, 2010). Using such preparation methods, a greater gain was obtained in relation to the mechanical resistance of the prototype for tests, in comparison to the second version that was very fragile. There was also greater sophistication in mechanical devices and design when compared to the first version.

4. RESULTS AND DISCUSSION

In this section, we discuss the structure and the characteristics of constructive design used to create a model of prototype of the infant stretcher. We detail the ergonomic characteristics of project and through these, the best constructive model was defined in terms of safety, ergonomics, cost of production, manufacturing process, versatility and portability. Finally, factors of inspiration to improve the versions developed and proposals for the fabrication as an end product.

4.1 Physical Characterization of the Model

In partnership with the State University of Campinas, the prototype of an emergency transport stretcher was evaluated, made for children's measurements. It has the following advantages, summarized in the Tab. 1 below:

Table 1. Advantages of the prototype of infant stretcher.

Number	Advantage
1	Adapted for emergency transport - ambulances / areas with difficult vehicular access
2	Designed for fast handling and storage by being foldable
3	Suitable for transporting children or small people with a wide range of weights and heights
4	Used in ambulance transport: 9 - 80 kg / 800 - 1500 mm
5	Used in rescue outside the ambulance: 9 - 25 kg / 800 - 1150 mm
6	Open base height: 1280 mm / Base height closed: 630 mm
7	Width 460 mm and weighs approximately 9 kg
8	Easy fastening and removal of the child (5-point retention system) and it has an extra leg strap
9	3 (three) fixed anchorage points for restriction on articulated adult stretcher
10	Side tubular supports on almost any lateral extension of the stretcher

The children's stretcher has an overlapping installation on the articulated adult stretcher in an easy way, by the fact it is performed by three anchor points with adjustable straps. Having one anchorage at the top of the stretcher and two of the type clamp tweezers at the bottom of the stretcher, which can be seen in in Tab. 2 (a) and (b). These anchors restrict their movement when installed in the adult stretcher, in this situation it is possible to unlock the straight angulation of the infant stretcher, allowing the backrest to accommodate 45° angulation without difficulties.

Gurney designed for fast handling and accommodation multiple positions from horizontal to fully upright, allowing easy access to the patient during transport. Integrates easily into ambulance operations, stowing efficiently in space-limited storage areas. The design and assembly of the prototype was started by designing the structure in CAD drawings (Computer Assisted Drawing), as well as the assembly devices and their elements. The 3D software used was *Autodesk Inventor Professional 2014*, the following topics detail the entire designed structure. We have all advantages described in Tab. 2 and illustrated in 3D drawing of the prototype with its internal devices in Fig. 10 (a) and (b) soon below.

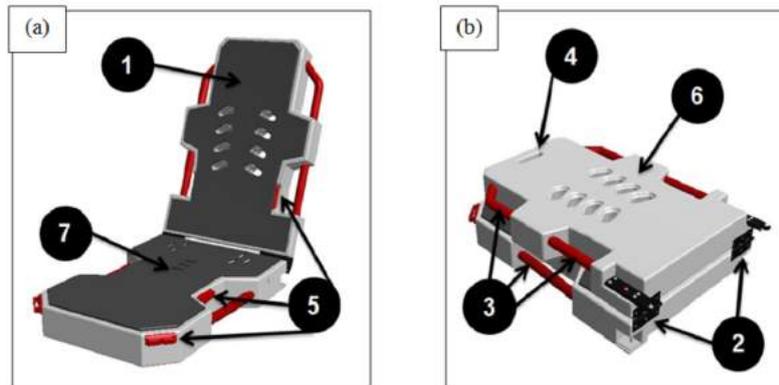


Figure 10. Gurney Child Prototype. (a) Open Prototype Base; (b) Closed Prototype Base.

Table 2. Decomposition of the prototype base structure.

Structure	Description
1 ^(a)	Folding gurney base
2 ^(b)	Hinge with rotation axis in conjunction with side lock couplings
3 ^(b)	Tubular hand grips, also having the anchor point function of strips
4 ^(b)	Hand support for fast transport of the gurney without a patient
5 ^(a)	Anchorage of passage of strips in the attachment of the gurney
6 ^(b)	Hole System for Passing the Five-Point Belt Strips
7 ^(a)	Comfortable padding, waterproof, easy to remove and clean

^(a) Open Prototype Base ^(b) Closed Prototype Base

4.2 Ergonomic Characterization of the Model

The prototype of infant stretcher is composed of several integrated retention elements, defining a good retention system, which shows versatility, comfort and confidence to the occupant in case of abrupt decelerations or collisions. This advantages are evident by the proper choice of the restraint system, coupled with a good passageway arrangement.

4.2.1 Anthropometric and Anatomical Analysis

The retention system chosen was that of 5 (five) points of strips, united by a single lock that is illustrated in Fig. 11, is the most indicated and used to allow an efficient distribution of loads in the regions of the bone structure with greater strength (clavicle and pelvis) in the case of loading. Its firm fit on the bony structure of the pelvic region, works in a way to prevent it from slipping through the tissues, making the possibility of underwater effect difficult. Another great advantage is the fact that it can engage and disengage the belt with a single drive, it also has a height adjuster and body adjustment already linked in the own strip system of the *evenflo* manufacturer, company specialized in producing child safety devices and equipment.



Figure 11. Child restraint system with 5 (five) stitches of straps joined by a single clasp.

The arrangement of the seat belts is another crucial element for good child restraint. Since only a sophisticated strip system is not sufficient to perform a safe transport, the anchor positioning of the strips should be in accordance with the anthropometry of the patient. The best positioning will depend primarily on the anatomy of the patient and the weight and height of the patient, so the important thing on the stretcher is to have a wide possibility of strip crossing points. Arrangement was carefully planned through ergonomic and anthropometric infant studies. The arrangement of the seat belts are illustrated in Fig. 12.

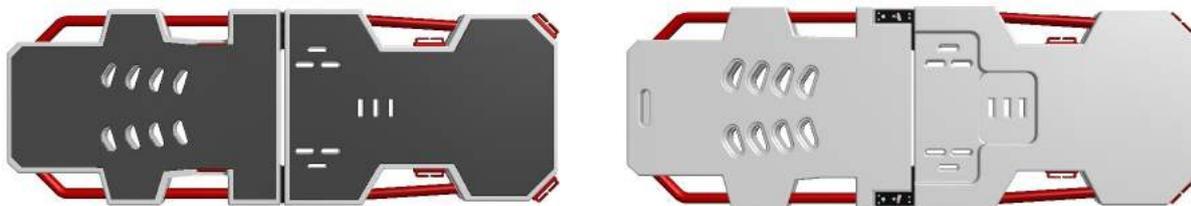


Figure 12. Top view of the prototype for viewing the strip passage.

One of the standards used for the ergonomic studies were followed from Group +0 to Group III, tabulated by ABNT NBR 14400: 2009 (ABNT, 2009a), which are used for child safety seats in automobiles. References based on the ABNT standard NBR15860: 2016 - Furniture - Children's cots and folding cots for domestic use - Part 1: Safety requirements (ABNT, 2016a) and Part 2: Testing methods (ABNT, 2016b). Another norm consulted that helped a lot in the anthropometric studies was ABNT NBR 15800: 2009 - Clothing - Reference of measures of the human body - Dressing of baby clothes and children and youth (ABNT, 2009b), as well as the dimensioning of adult litter, to which will serve as support for child's stretcher which is regulated by NBR 14561: 2000 (ABNT, 2000).

However, the limitations specified above are valid only if the infant stretcher is properly anchored and overlapped with the articulated adult stretcher. Because by attaching the two systems, one gets the freedom to support the patient's legs out of the stretcher and support them on the mattress of the adult stretcher, increasing the possibilities of height and weight in the transport.

4.2.2 Biomechanical Analysis

Anthropometry studies are essential for good vehicle safety, but biomechanical studies are also important in this situation. Studies have been made of both external biomechanics, which studies the physical forces acting on the bodies, and the internal biomechanics, which studies the mechanics and physical and biophysical aspects of joints, bones and histological tissues of the body. From these concepts, it was made the adoption of a five (5) point child safety belt. The aim is to retain the patient in the best way, which tends to move in the direction of the vehicle's movement when a strong deceleration occurs. The need for body retention is also bound to the difficulties of some patients to stay straight for an extended time.

In rescue situations in areas of difficult vehicular access, where the infant stretcher is not attached in the articulated adult stretcher and the ambulance does not have access to the accident site, the performing its function as a rescue stretcher. Then, it is recommended that the system be used only for patients with a weight range of 9 kg - 26 kg and height ratio between 800 and 1,300 mm. Such recommendation may be associated after analyzing the biomechanics of the children, it was also associated by the norm ABNT NBR 14400: 2009 (ABNT, 2009a).

A smaller range of height and weight for rescue situations is justified for patient safety, since the maximum length of the stretcher is 1300 mm. Considering a weight over 30 kg would force the stretcher structure, Then, it would not attend to the need for rescue and possibly would have a patient with the lower limbs off the stretcher.

The provision of these belt passes are inspired by reference products, especially of *evenflo, SafeGuard and Pedi-Mate*. Its description is discussed initially by the upper passage holes of the straps over the shoulder, the present stretcher has 6 (six) belt passage holes, located on the upper part of the foldable base. Thus, it contains 3 (three) different height for children. In the lower part of the folding base, it has 3 (three) lateral holes of passage of abdominal strip in the right and another 3 (three) holes in the left, totaling 6 lateral holes, containing in the end 3 (three) different provisions of passage of lateral belts. Further down, there are more 3 (three) strip passage holes, but facing the ideal height of the strip between the legs, allowing you to adjust 3 (three) different points.

The prototype of infant stretcher was designed to carry easy manual transport when it is without patient, because it has hand supports built into the upper part of the folding base, facilitating the work of the medical rescue team when transporting or storing the equipment. Another important aspect presented in the stretcher for performing rescue is the system of six tubular hand rests. The system consists of two bent tubes and installed all over the upper side and two other straight sides installed in the lower part of the foldable base. Ergonomically designed and designed to facilitate the work of the medical rescue team. The prototype of infant stretcher is characterized by containing 3 (three) anchoring points, which aim to restrict the same in Brazilian standard stretcher made for adults. The positioning system of the anchors follows international recommendations, since there is no standard for infant stretcher or official regulation in relation to its anchorage superimposed on the adult stretcher.

5. CONCLUSIONS

Initially, the research was done on the issue of emergency transport for children, searches on products abroad, as well as the main ergonomic factors for the emergency transportation of the children and small people. The technical information collected allowed to establish parameters, recommendations and essential ergonomic needs to design three proposals for stretcher. It was observed that the infant gurney model presented a practical ergonomic design. The differential of the project in relation to other children gurneys existing in the international market, it is a versatility to perform both transport in ambulances and in difficult rescue vehicle access area. The main safety factor is associated to adjustable restraint system, that results in the easy fixing and quick removal of children due to the system of 5-point restraint. It is also attentive to the fact that the Brazilian country does not yet have stretchers intended for the emergency transportation of children and small people. However, to be implemented as a product, it must be manufactured with light and high resistant material, with that it will have a reduced weight. When analyzing some manufacturing processes, some proposals stand out: the most usual would be with plastic injection molds, but the mold is extremely expensive. Therefore, there is another well-regarded process through rotomolding, which is based on a versatile thermoplastic transformation process where molds do not need to be designed to withstand high (injection) pressure. This results in extremely lower costs for the manufacture of molds, also highlighting the great versatility to manufacture various shapes and sizes.

6. ACKNOWLEDGEMENTS

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