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REPORT: FINAL PROGRESS REPORT

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TRANSPANSPORT SYSTEM

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**FINAL REPORT FOR DEVELOPMENT OF
EMT BACKBOARD TRANSPORT SYSTEM**

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ABSTRACT

This NIOSH grant was awarded to create a backboard/patient transporter to significantly reduce the musculoskeletal (back) injuries to EMS (Emergency Medical Service) paramedics while transporting patients on stairs or under adverse conditions when the patient is secured to a backboard. Specific aims of the project are as follows:

- Aim 1: To determine the optimum track design for providing secure stair engagement without slippage.
- Aim 2: To develop a foot pedal mechanism capable of propelling the loaded Backboard Transporter during stair ascent.
Modified to minimize pedal force.
- Aim 3: To design a frame for the Backboard Transporter that meets the strength, weight, and physical mounting requirements for the tracks, handles, lift system, and backboard mounting.
Modified to limit total transporter weight to approximately 38 lbs.
- Aim 4: To develop an efficient backboard securing system.
- Aim 5: To design the Transporter mechanical components to maintain a safe center of gravity for all transport inclinations.
- Aim 6: Configuration of the functional Backboard Transporter to fold to fit into limited ambulance space.

Aims added by Fire Department input during product development:

- **Added Aim 7: Design for a patient weight capacity increased from 400 to 600 lbs.**

- **Added Aim 8: Design to transport seated and backboard secured patients.**

Aims 7 and 8 are crucial aims that were added in response to recommendations from area firemen, which were made as a result of their field experience.

In developing the foot pedal powered patient lifting system it became apparent that the two additional aims must be included for the transporter to be accepted by EMS personnel; first the device must transport both seated and backboard secured patients. Also the patient weight limit must be raised to 600 pounds. EMS personnel are presented with 400 to 600 pound patients on a routine basis today where this was a rare occurrence only 5 to 10 years ago. The existing manual lift patient transport chairs are actually not adequate for today's heavier patients and nothing exists today that will allow a paramedic to safely transport a 400 pound plus patient up a narrow flight of stairs. For this reason, the specifications for the new transporter developed in this grant were expanded to include seated patients and 600 pound capacity.

Validation for this product is clearly defined by the quote from the Intergovernmental Risk Management Agency IRMA located in Northern Illinois.

"IRMA continues to struggle to find the most effective way to mitigate the significant adverse loss trend arising from strain/sprain injuries to our firefighter/paramedics. The vast majority of these musculoskeletal injuries result from lifting and carrying patients. The most frequent and most severe cause of fire department workers' compensation losses during 2007, was "Strain/Sprain Lifting/Holding/Carrying" resulting in 65 injuries and \$750,304 of claims experience. This is more than twice the frequency of any other cause of loss.

During the three-year period from 2005-2007, IRMA fire departments incurred 286 strain/sprain injuries resulting in \$5, 879,962 of total incurred workers' compensation losses. IRMA fire departments continue to report that patient weight has increased dramatically over the past few years and in many cases the patient's weight can reach 300 to 500 pounds. There are also several claims where the employee is permanently disabled and will never return to work again. In these

cases, there is additional financial impact from the Public Safety Employee Benefit Act (PSEBA), which can require government to provide life long health insurance to the injured employee and college education funding for their children. IRMA members need more effective tools in order to mitigate the significant adverse impact this trend is having on firefighter/paramedic injuries. "1

During the development part of this project a number of fire department personnel were consulted. These firemen suggested modification to the aims for this grant including minimizing product weight, and reduced foot pedal energy required to lift the patients. These two modifications were directed to minimize the physical force required for patient transport and for ease of hand carrying the transporter up multiple flights of stairs.

In the transporter developed by Livingston Products, Inc. the mechanical method utilized to accomplish this patient lifting task incorporates a tracked type carriage system with triangular cleats. The track design also allows the product to remain stable when traversing uneven surfaces. Environmental conditions including mud, ashes, or fire debris was also considered when designing and selecting materials for this product.

The patient lifting force is produced by a reciprocating foot pedal powered 2-speed chain transmission. This transmission is rugged and lightweight. Included in this transmission are braking and anti-slip control components for safely transporting patients both, up and down stairs.

Patient comfort and safety are also enhanced by a pivoting system built into the seat and backboard mount that maintains the patient and system center of gravity. This inventive transporter (US patent office patent application serial no. 12290770) describes a system having a combination of power stair climbing, and system center of gravity control in a single device for safe patient transport.

The functionality of the new transporter was verified in a simulated patient lifting test. The narrow stair well typically found in the basements of residential environments proved to be far more dangerous to the paramedic than originally considered. Due to the limited space a maximum of four firemen, and normally only two, could have direct contact with the patient lift system at any time. This presents a significant risk of injury condition to the firemen as they shifted position to proceed up the next step. The backboard transporter minimizes this risk to the firemen.

The backboard transporter includes a pedal assisted lift device enabling emergency medical personnel to be in an upright position to eliminate most of the risk of injury to themselves and the patient being transported. This device can also replace the stair chair now in use in most ambulances and therefore not require additional storage space in the ambulance.

Highlights/Significant Findings

Testing of simulated patient lifting on narrow stairs and steep inclines proved that this task can be extremely hazardous. Only the special controlled laboratory conditions prevented our testing personnel from being exposed to risk of back or other musculoskeletal injury. During simulated patient lifts the limited space of the test stairwell duplicating the narrow stairwells as typically found in residential homes prevented more than four paramedics, at any one time, from having direct access to a patient on a stair chair or backboard. Many times during stair ascent or descent, particularly during a turn in the stairway, there were moments in time where only one paramedic was actually supporting the patient. Extreme coordination between the paramedics was required to ensure at least two paramedics were supporting the patient while the other two were repositioning and moving to the next step. Loads lifted by using old methods and equipment were not able to be safely lifted when exceeding 250 pounds even under simulated conditions. The pedal powered transmission, incorporated in this device, proved to be essential to the safe transport of heavier patients.

The backboard transporter to be produced combines all of the aims of this grant and is essential to providing an efficient, safe and stable system for meeting the goal of transporting all patients on stairs and steep inclines.

For all of the grants aims to be successful the designed product first required a track and cleat system to be lightweight and able to grip to various stair materials in any environment or stair configuration. The track developed for this purpose utilizes a series of triangular cleats on the outside perimeter of a fiber reinforced rubber track. The leading side of each triangular cleat is textured to provide for secure stair gripping in both wet and dry conditions. The backside of each triangular cleat provides the vertical stability required for each cleat to hold its shape under load. This track and cleat design is easily cleaned and can be made from wear and fire resistant rubber that economically fulfills the demanding requirements for this component.

A two gear ratio foot pedal powered transmission designed for this product meets the requirements of providing for safe and controllable ascent and descent of stairways and steep inclines.

The two gear speeds incorporated are essential to provide efficient transport of light and heavy weight patients. This transmission has to be lightweight and absolutely foolproof in its operation. Any release of the device by the EMT, whether accidental or on purpose must result in the system remaining stable and under control. To accomplish this complete control a dual input chain system, that is always engaged in low or high gear was designed. This transmission has no neutral or between gear condition that can cause an uncontrolled stair descent. One-way bearings are incorporated on the single axle transmission to prevent a binding condition between the two input gear speeds. A combination clutch/brake disc operated by hand controls provides for a safe controlled descent from inclined surfaces to the design limit of a 45° angle. This transmission also provides for low friction motion when the device is being used on level surfaces. Ease of use in both routine and emergency transports is essential to its acceptance by emergency personnel.

The frame and patient holding system will require two models of the patient transporter to meet all of the structural weight and desired cost objectives. To meet the devices weight goal of approximately 38 pounds, a combination of carbon fiber and tubular aluminum is required. The carbon fiber components will significantly increase the frame cost, therefore resulting in a higher cost model. This more expensive model and the lower cost all aluminum model both meet the same operating specifications, with the all aluminum lower cost model being approximately 8 pounds heavier.

Significant issues of EMT safety and patient comfort were found that relate to maintaining the patients' weight over the system center of gravity. For seated patients, tilting the patient back, and traversing inclines presented minimum difficulty for the test technicians to safely transport the simulated patients. Backboard secured patients create an extremely high elevated center of mass and must be properly pivoted for the patient and transport device to maintain a save center of gravity when transiting from level to inclined surfaces. Fire department protocol requires two paramedics on each call. Therefore the lifting system was designed for the "up stair" paramedic to provide the lifting pedal power and the down stair paramedic to control patient pivoting to maintain proper system balance. The down stair paramedic has two handles that fold out and lock in place to provide for patient pivot control. This second "down stair" paramedic also assists in guiding the system around turns in stairways and other high maneuvering requirements. The device is designed to securely hold the patient on a backboard as low as possible to minimize the affect the patients weight has on the system center of gravity. A groove in the base of the transporters frame and adjustable straps at the top securely hold the backboard and patient to the transporter.

Multiple pumping of the foot pedal drive system on this device proved to be sufficient to transport heavy weight patients safely up stairs and steep inclines. Continuous control of the patients' weight over the transporter center of gravity to maintain proper system balance was also found to be essential to the safety of both the patient and emergency medical

personnel. Speed of transport is important but was reduced in priority to ensure the safety and the transporters operation. Environmental conditions also were demanding and required the device to be operated in a burning building environment and at the same time not mar a polished wood floor when used on a routine transport call. The combination of track, transmission, and pedal power can successfully provide the means to transport patients up to 600 pounds with significant reduction in risk of injury to both the EMT and patient.

Translation of Findings

The patent pending components of track and cleat, pedal powered two-speed transmission, and patient balance system developed in this grant can be used in combination for the patient transporter device or potentially as individual components to enhance the safety of patients and medical personnel. The discovery that patient transport on narrow stairwells can create a condition that potentially only one EMT may actually be supporting the patient is cause for immediate attention. Training procedures for paramedics and firemen should stress the requirement for coordination of the transport team to ensure the safety of patients and firemen. The transporter developed in this grant has the potential to significantly reduce musculoskeletal injuries relating to emergency patient transport. This product will ultimately provide the EMT with a solution for transporting heavy weight patients that does not exist today.

The simulated testing procedure utilized in this grant to observe the step by step process of patient transport can be used to discover other hazardous conditions presented to firemen. Routine and emergency procedures could be simulated and reduced to small increment movements for detailed evaluation. Equipment and procedures can then be developed to improve the capability and reduce injuries to fire department and emergency medical personnel.

Outcomes/Relevance/Impact

The simulated staircase provided an effective and safe means to test the stair lift transporter. This test environment enabled observation of the stair ascent and descent task in close detail. The most significant observation noted was the affect narrow stairwells have on the number of paramedics that can contribute to the lifting effort at any given time. Close coordination and teamwork including verbal calling out of lift/step and repositioning movement is essential. As noted by fire department personnel and the IRMA, 300 to 500 pound patients are encountered with much greater frequency than only 5 to 10 years ago. Transport for patients over 250 pounds is extremely hazardous and is in need of equipment that is not available today. Equipment and training programs must be incorporated to reduce the high number of sprain/strain injuries incurred by emergency medical personnel each year.

The stair ascent transporter developed in this grant required extensive modification to meet the increased lifting weight requirements added to the project. The greatest impact this development grant will have is to emphasize to fire departments the high risk of injury incurred when lifting heavy patients. The equipment developed in the grant will have the capacity to significantly reduce the risk of serious, debilitating and costly injury to fire department personnel.

An overview of 2007 as published in the NFPA journal November/December 2008 issue estimates that 80,100 fire fighter injuries occurred in 2007. Sprain/strain injuries accounted for 45% of fire ground and 57.8% of non-fire ground injuries. The data does not define the percentage of injuries related to patient transport, but interviews with firemen have indicated the vast majority of sprain/strain injuries occurs in patient transport. Therefore it can be estimated that approximately 41,500 sprain/strain injuries were reported by firemen in 2007. By further estimating that 70% of these injuries relates to patient transport, these statistics indicate that at least 20,000 firemen were injured in patient transport in 2007. The product developed in this grant will have a significant impact on reducing the quantity of these sprain/strain injuries and in improving the training for patient transportation. By

correlating the national fire protection association data, above, with the IRMA claim cost data, as follows, the national yearly cost of sprain/strain injuries to firemen in patient transport is 29,050 patients x \$20,559.00 per injury cost totaling \$597 million dollars per year. This is only the per year dollar cost and does not include the long-range cost of the permanent injuries or the pain and trauma endured for years after a back injury.

The device developed in this grant is for the safe transport of patients on stairs and hazardous environments. The original aims were directed to backboard secured patients but the aims of this project were expanded to include seated and extremely heavy weight patients. Interviews with fire department and emergency medical personnel clearly indicated the transport device developed in this grant must be able to include all patients and environments. The added requirements of the extremely heavy and seated patient's device resulted in significant changes in the track, frame and propulsion system for this stair climbing patient transport system.

SCIENTIFIC REPORT

The background for this development grant builds on a NIOSH ROI research grant awarded to Drs. Karen Conrad, Paul Reichelt, and Steven Lavender, in which a lab prototype of an EMS patient handling device that attaches to a backboard was developed. Extensive interviews with fire department personnel conducted in this NIOSH ROI grant and simulated patient transports clearly defined the high risk of stair well patient transport. The details of the high economic cost of injuries to firemen in performing patient transport tasks also was presented and resulted in fire departments and the insurance industry actively supporting the development of a new product for use in patient transport.

The national fire protection association in its November/December publication shows the high numbers of musculoskeletal injuries to firemen and a summary letter from the IRMA defines the cost of these injuries and confirms the problem of increasing patient weight. Specific aims for this project relate to the functional capability of each of the component parts of this device to meet the goal of safe transportation for emergency patients.

Aim1 is to create a track and cleat design that can operate in emergency, fire, as well as in normal home environments. Minus 20° to 120° Fahrenheit and open flame exposure is typical of the environment this device may see. Fire debris with wet or damaged stairs must be traversed safely. Narrow stairwells and uneven stair spacing must be efficiently navigated and the tread and track system also must not mar or damage polished wood or marble floors or carpets. The track and cleat designed for this task is a fiber reinforced rubber track, with square drive wheel engaging notches on the inside perimeter, similar to an automotive timing belt. This material and design is proven to provide reliable performance in this environment. The stair-engaging cleat is a modified equilateral shaped pyramid spaced in 11-inch increments for effective stair step leading edge engagement. The point of attachment of the cleat legs to the track belt is notched to allow the cleat to smoothly roll around the track support wheels without stretching and creating an additional load on the fireman to push the device on level ground. The triangular cleat is designed so that the leading triangle leg interfaces with each stair step edge with a textured tread shape to grip securely on wet or contaminated stair surfaces. The top of the triangular cleat is flattened and smooth to prevent scratching of polished floor surfaces under normal patient transport.

The cleat must maintain its' stair gripping shape under load, therefore the back side of the triangular cleat provides a vertical support for each cleat to maintain uniform stair engagement when climbing or descending stairs. The triangular cleats are hollow for weight reduction and to allow for some flexing to match varying shapes of stair step leading edges. 60 durometer automotive style rubber gives this track system the capability of meeting both its' functional and cost requirements.

Aim 2 is for the foot pedal powered transmission utilized by this product to propel the patient up a stairwell. Other methods of powering this device were met with extreme pessimism by the interviewed firemen. No battery, air, or liquid fuel powered motor could meet all of the requirements of this patient transport system. The ultimate concern of all firemen involved was that the power sources fail half way up a flight of stairs leaving the EMT and patient in an unsafe and potentially uncorrectable situation. Back up battery powered assistance was considered until the added weight eliminated this option. A pedal powered dual speed chain drive transmission has been designed and patented for this device. The requirements for this transmission are as follows:

- Dual gear ratio input for heavy and normal patients
- 6 pounds maximum weight
- Automatic fail-safe operation
- Built in clutch braking system for up and down stair power and movement Low friction capability for level surface transport
- Single foot pedal powered input
- No between gear disengagement or "neutral" condition

- Water, ice, debris, fire, and harsh weather operation

A patented single axle chain drive transmission has been designed for this application. One-way bearings allow for incrementing up stair motion but automatically lock to prevent the device from uncontrolled movement down stairs as the firemen reposition themselves for each foot pumping motion. This one way bearing system also allows the transporter to move freely when transporting patients on level ground. A built in hand brake can be engaged when necessary to provide a secondary lock, or holding condition to prevent transporter movement.

The two input gear chains are connected to significantly different sized sprockets to provide for a high and low gear input ratio. The low gear chain produces the low speed, high mechanical advantage force required to incrementally advance a heavy patient up each step. A second higher gear input ratio chain is also linked to the single foot pedal drive. This gives the patient transporting device two lifting capabilities selectable for the weight of the patient. Both input chains are connected to the transmission drive shaft. To prevent binding of the two different gear input ratios, a one way bearing connects the faster moving lightweight patient input chain to the drive shaft. This allows the chain sprocket to remain engaged and to over run on in the drive shaft without binding. A second one-way bearing prevents uncontrolled down stair motion in the event of any transmission component failure. The clutch/brake system incorporated on this drive shaft is spring loaded in a braking mode and only allows the transporter to move when the paramedic applies hand lever force to release the brake. This chain drive system is lightweight, extremely rugged in its operation and can be cleaned with a garden hose. Minimal maintenance requirement and ease of service are also reasons for selecting a chain drive mechanism. Increasing the aim for this device from 400 to 600 pound lifting capacity required extensive modification of the originally conceived components. The added capability and related safety margin required the gear ratios and braking system to operate with 37% increased capability.

Aim 3 defines the requirements for the frame and patient securing components. Rectangular cross section aluminum tubing is utilized in the load bearing mainframe.

Various sizes of tubing and wall thicknesses are incorporated to meet each component parts load carrying requirements to meet the system weight goal of 38 pounds the main track bearing frame and two vertical patient support arms must be made with a combination of aluminum and carbon fiber. This combination reduces the system weight but the carbon fiber components significantly increase the overall system cost. These structural components also support the transmission and foot pedal components. The patient holding components and paramedic handles are attached to the frame by pivoting members that are utilized to maintain the patient's weight over the transporters center of gravity. One set of straps secured the backboard or seated patient. A slotted plate at the base of the frame can be folded down for either a footrest or backboard support. All aluminum components are anodized or urethane coated for environmental protection and welding is incorporated wherever possible to maximize the strength of each frame component.

Aim 4 and the additional Aim 8 of the transporter system are for a safe holding system for both backboard reclining patients and seated patients. Patients on backboards present a unique problem due to the high center of gravity created by the vertical patient and variety of backboard designs. Each backboard manufacturer has their own board thickness, shape, and handle configurations. This requires the stair transporter to adapt to hold all backboards. The seated patient foot rest doubles as a backboard receiver. A VEE notch captures the various board thicknesses and the footrest sides tilt in to provide a tapered opening to hold different board widths. This notch type holding system also allows the backboard to be mounted as low as possible to maintain a low system center of gravity. Two seat belts are incorporated for attaching the middle of the backboard to the transporter and for securing the chest and lap of seated patients.

The transporter system is designed to pivot the patient relative to the stair climbing track system as will be further defined in Aim 5. This pivoting action allows the transporter backrest

to fold down creating a nearly flat platform to receive the backboard secured patient. The patient and board are lifted at the head end and the transporter is rolled under the backboard for attachment at the patients' feet. After securing the mid board seat belts the entire board, patient, and transporter support arms are safely pivoted into a near vertical position for moving the patient as required.

Aim 5 is for the patient transporter to maintain a safe center of gravity while moving on level ground or on stair inclines. The transporter is equipped with two extension handles controlled by the down stair paramedic. These handles pivot up and down through a mechanical linkage to enable the paramedic to safely pivot the seated or backboard secured patient forward or backward to maintain a proper system center of gravity. Each handle has a finger grip control for releasing the pivot mechanism to allow the paramedic to control the patients' position with either hand. The pivoting handles are linked to the patient support arms with a high mechanical advantage, enabling the paramedic to safely pivot the heavier weight patients.

Aim 6 is a convenience requirement to enhance the storage of the transporter and is not essential to paramedic safety. The developed device will fold in half to minimize the volume required for storage in an ambulance.

The addition of Aim 7 increasing the patient weight from 400 to 600 pounds required extensive increases in the design demands on the patient transporter. The weight issue and structural safety margins of 50% resulted in many component parts requiring a complete redesign. The resultant size change of a 400 to 600 pound person also produced new problems in providing seating capability and new challenges for eliminating pinch points in the pivoting mechanism. Additional simulated patient testing will be required before all of the technical issues of extremely large patients are ready to be tested on live patients.

At this time paramedics are at extreme risk of injury to themselves and the patient when required to transport morbidly obese patients. Six or more paramedics are typically required to lift and carry these patients. Where space or access to the patient is limited to less than 6 paramedics no adequate solution is available for the paramedic to provide safe transport. This device fills a void not available today for the paramedic.

The additional Aim 8 was defined with Aim 4 as the seated and backboard secured patient is now a combined requirement.

References:

Summary Report, Dan S. LeTourneau, ARM, Director of Risk Management Services, IRMA [November 2008]

² NFPA Journal Article, Michael J. Karter, Jr. and Joseph L. Molis [November/December 2008] NFPA Reports Firefighter Injuries for 2007