Design of a Pressure Measuring Syringe

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Endotracheal intubations are performed on thousands of patients each day. Intubation is achieved by inserting a small plastic tube down a patient's trachea, allowing oxygen and anesthetics to be delivered directly to the lungs. The tube is held in place by inflating a small cuff on the distal tip, which also serves to seal the trachea. The use of a manometer to measure the pressure within the cuff is essential to keep the practice safe. Hyperinflation of the cuff can put too much pressure on the trachea, leading to tissue death and post-procedure patient discomfort. A hypo-inflated cuff results in a poor seal within the patient's airway and can lead to ineffective positive pressure ventilation, or gastro-inflation, which can in turn lead to vomiting, putting the patient at risk for asphyxiation. The latter complication can cause hypoxia and death. Manometers used to measure cuff pressure are costly, cumbersome, and potentially inaccurate. A pressure measuring syringe has been designed, tested, and verified to meet physicians' needs for a simple, low-cost pressure measurement device. New data suggest that overblown cuffs are very common during surgery (2009, Abstract 3AP1-1, presented at the European Society of Anaesthesiology, Milan, Italy). In fact, most are inflated to a pressure greater than the recommended 25 cm H_2O, and past studies on patients in critical care settings corroborate these observations (Jaber, S., et al., 2007, "Endotracheal Tube Cuff Pressure in Intensive Care Unit: The Need for Pressure Monitoring," Intensive Care Med., **33**, pp. 917–918). A pressure-sensing device that gives physicians a tool to help avoid over- and underinflation of the endotracheal tube (ETT) cuff was able to provide an accurate, repeatable measurement of the intracuff pressure. A deterministic design process was used to develop a set of functional requirements for a pressure measuring device that accomplishes both inflation of the cuff and a simultaneous measurement of the cuff pressure. A silicone bellow inside the body of the plunger acts as a single elastomechanical measurement device, permitting a highly repeatable measurement of the intracuff pressure. The design also maintains most of the traditional syringe design in that only the plunger is modified to accommodate the bellows. The components of the syringe are also scalable in order to allow the design to be utilized for other pressure sensitive procedures. The current iteration of the syringe can accurately measure pressure within a range of 0–40 cm H_2O. Prototypes for the syringe were 3D printed and tested, and silicone rubber bellows were outsourced. In the final prototype, the plunger is injection molded. The total estimated final cost of the syringe is about $1.50, which is comparable to the cost of a typical syringe. Because of this, the pressure measuring syringe is a viable candidate for low-cost mass production. The calculated pressure-deflection relationship of the bellows was experimentally verified, further demonstrating the scalability of the design. In conclusion, a simple and cost-effective syringe manometer has been developed, which controls and measures air pressure in ETT cuffs.

Ankle Rehabilitation via Compliant Mechanisms

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A flexure-based ankle rehabilitation device utilizes the linear elastic force-deflection characteristics of certain types of flexure beams to measure the forces and torques output by the human ankle joint complex (AJC). Three sets of flexures, placed so as to allow rotation about the three primary rotational axes of the AJC, allow for a measurement of all three major rotations applied by the ankle joint and coupled motions essential for walking, balancing, and running. Currently, there is no method or universally accepted device used to measure and quantify the strength, speed, and stabilizing ability of the AJC. This is especially important when it is considered that ankle injuries are perhaps the most common type of musculoskeletal injury. Furthermore, AJC integrity is recognized as critical to the maintenance of balance and prevention of falls among older adults. We have developed a device that would primarily be used by physicians or rehabilitative professionals as part of a more standardized methodology of musculoskeletal care and to determine the extent of an ankle's recovery after injury. It has potential to help researchers better understand the recovery process and the mechanics of ankle injuries. Additionally, it could be useful to the footwear and orthopedic industries as a means of evaluating products for AJC protection and recovery. The architecture of the device could also be modified to fit other multi-DOF joints, such as the wrist, shoulder, hip, or spine. Single-DOF devices could also be developed to potentially increase efficacy of rehabilitation practices for single-DOF joints such as the knee and the elbow. Upon fulfilling its initial functional requirements, this device still has a lot of potential for further development. The current design can be tuned fairly easily by exchanging different flexure modules of varying stiffness. This allows for testing of different materials, stiffness values, and flexure module designs. Furthermore, it would be possible to expand on the design so that it can be used as a training tool, instead of just as an evaluation device. A rehabilitation program utilizing such a device would serve to isolate the ankle much more than current recovery exercises, helping to reduce the chances of reinjury. Current technology used to evaluate ankle rehabilitation focuses solely either on the foot's range of motion or on the joint's ability to balance the rest of the body. While the former ignores the ankle strength, the latter disregards any information regarding the ankle beyond the standing configuration. The flexure-based ankle rehabilitation device measures ankle strength and power output through a range of motion that is anatomically similar to walking, running, etc. Also, measuring power output is not feasible with currently available devices and is believed to be very important for further injury prevention. Also, a wide range of foot configurations can be achieved, suggesting that regardless of the patient's physical abilities, the device can still be used to safely and effectively rehabilitate a person's injured joint and return it to a healthy state. Results from the initial prototype suggest that an ankle rehabilitation device utilizing compliant mechanisms can measure the expected torque outputs from the ankle joint. Use of compliant mechanisms allows for the design of a more cost-effective, compact device that can be handled by physicians even outside of a hospital setting. The final paper will present the second design iteration and the results of measurements that will be performed on patients' rehabilitating ankles in the interim so as to determine what other adjustments need to be made in the system to account for the coupled motions of the ankle joint. A full working system including data acquisition equipment utilized to collect patient information and the final device iteration will be presented in the final technical paper.

