

## Brief communication

## Utilization of a pneumatic exoskeleton after total knee arthroplasty

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## ABSTRACT

Exoskeletons are wearable, powered devices intended to support and augment limb function. With the aging population and increasing demand for total knee arthroplasty, exoskeletons could prove a valuable tool for regaining function and minimizing the number of patients discharged to skilled nursing facilities. However, the safety of these devices in postoperative populations remains unexplored. A lightweight pneumatic device was piloted on three patients after primary total knee arthroplasty. The patients were asked to perform simple locomotive tasks followed by a questionnaire to assess their experience and safety using the exoskeleton. All patients indicated the exoskeleton did not interfere with their wound and made them feel stable on their feet, and two of the three patients stated it was manageable and safe to operate. This report pilots the general safety of a pneumatic exoskeleton, laying the groundwork for larger and more comprehensive studies.

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## Introduction

Total knee arthroplasty (TKA) is one of the most common orthopaedic elective surgeries in the United States [1]. In 2010, approximately 4.7 million Americans were living with knee replacements. [2] With the aging population and the increased focus on quality-of-life procedures, it is expected that by 2030 the demand for primary TKAs will increase by 673%, and revision TKAs are projected to increase by 601%. [3] Symptomatic osteoarthritis of the knee affects 10% of men and 13% of women above the age of 60 in the United States, with those numbers also expected to rise due to the aging population and the increase in the prevalence of obesity. [4]

Exoskeletons are rigid, externally wearable devices that provide torque assistance at joints with the aim of easing load bearing and/or enhancing strength. [5] TKA patients often have considerable decline in range of motion and quadriceps strength in the month following surgery, making an assistive device desirable. [6] One of the main challenges of designing wearable exoskeletons for TKA

patients is the limitation associated with the size and weight of conventional metal-based exoskeletons. [7] In this safety pilot study, we present a lightweight pneumatic exoskeleton for use in patients after TKAs with the goal of enhancing knee function by providing assistive motion and a rigid loadbearing scaffold. The use of air compression instead of traditional motors to induce torque allows for a lightweight exoskeleton. The device, produced by Roam Robotics, San Francisco, CA, is externally wearable and consists of a hinged knee brace (4.6 lbs), air compressor, waist belt (5 lbs), and a hand-held trigger (Fig. 1). Velcro straps secure the device in place, with two straps superior to the knee hinge and two below. The exoskeleton allows for 90° of flexion around the knee joint and is triggered by the patient's motion as detected by a force-feedback control and a nonlinear spring assist. The exoskeleton was piloted on three patients within the first 24 hours after TKA, with the goal of assessing the general safety of such a device, especially with regards to wound interference and dehiscence. As exoskeleton use is largely lacking in the arthroplasty literature, this study is meant to serve as a pilot of pneumatic exoskeleton safety. Evaluating usability, wound interference, and changes in pain is important in laying the foundation for future studies with larger patient populations.

## Material and methods

The three patients in the pilot study had their primary TKAs performed at Stanford Hospital and Clinics (Palo Alto, CA). Depending on the patient's side of surgery, either right-sided or

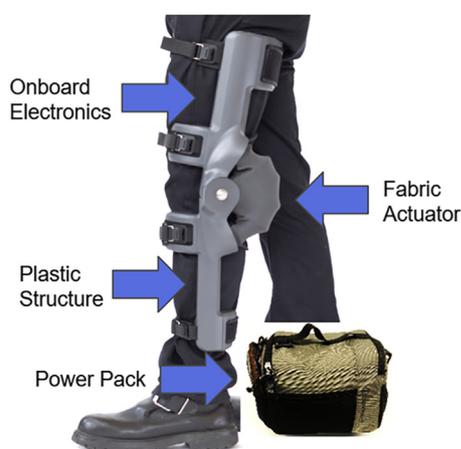
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**Figure 1.** Pneumatic exoskeleton with the hinged knee brace, air compressor, and scaffolding.

left-sided exoskeletons were fitted with the brace always facing the lateral side. The exoskeletons were fitted by the patients themselves under guidance of the medical staff, all within the first 24 hours after their procedure. The device was secured by tightening four straps, two above the knee joint and two under. The patients were asked to independently perform simple tasks, such as walking fifteen feet and go up and down a flight of stairs three times. After completing the mobility tasks, all three patients filled out the questionnaire (Appendix).

## Results

All three patients received a primary TKA due to an osteoarthritic knee. The mean age was  $59 \pm 3$  years, with the device being fitted on the right knee in two cases and left knee in one case. None of the patients had a history of neuromuscular conditions or displayed any long-tract signs. All patients had 5/5 preoperative strength with hip flexion, hip extension, knee flexion, knee extension, ankle dorsiflexion, ankle plantar flexion, and great toe dorsiflexion. None of the patients felt the device interfered with their wound. All three reported that the device made them feel stable on their feet and did not add to their knee pain after fitting the device or during device operation. Two patients felt the device was manageable, safe to operate, and facilitated climbing stairs. One patient felt the device was cumbersome and not safe to operate and hence did not operate it on stairs. Two patients indicated the device was innovative and assistive and had potential. One patient commented that the exoskeleton needs improvements in fit and force control as this patient felt the pressure necessary to inflate the device.

## Discussion

One of the main challenges of TKAs is the need for assistance in the immediate postsurgical period. A fraction of elderly patients also require transfer to skilled nursing facilities for a period of recovery, which is a costly process. Physiotherapy is a possible tool for improving patient postsurgical mobility and minimizing pain, but the costs are often prohibitive and definitive data on its effectiveness are lacking. [8,9] Furthermore, recent data suggest that replacing outpatient rehabilitation with unsupervised rehabilitation at home

is not associated with any adverse effects. [10] Accordingly, exoskeletons could be an alternative for some patients in providing continuous loadbearing assistance at a fraction of the cost. The pneumatic exoskeleton allows for a lightweight device, which has long been a limitation of exoskeleton use. Having built in force-feedback control and nonlinear spring assist also allows the device to detect the patient's intent to move and provide continuous assistance. The feedback obtained from the patients is encouraging as they generally felt supported, comfortable operating the device, and did not indicate the exoskeleton interfered with the wound. The device could also prove protective to patients when falling as it keeps the knee extended and distributes the load to the brace. One of the current limitations of the device is the lack of customizability in device length.

## Conclusions

Based on the questionnaire data, pneumatic exoskeletons hold promise for assisting and maximizing patient autonomy after TKA while minimizing dependency on skilled nursing facilities. The exoskeleton could be offered to a patient likely to be discharged to skilled nursing facility. If that patient felt comfortable and safe operating the exoskeleton. Our preliminary data suggest a lack of interference with the wound. Although the patients generally had favorable reviews, there are improvements that have to be made to ensure complete safety and comfort, specifically optimizing the sensitivity of the force-feedback system to maintain smooth mobility as well as ease of fitting the external brace to ensure independent operation of the exoskeleton. Furthermore, this pneumatic exoskeleton needs to be tested on patients with pin sites after computer- or robotic-assisted surgery to ensure the straps do not interfere with accessory incisions as well.

## Appendix. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.artd.2019.02.008>.

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