

# TRANSFORMING HOW WE PHYSICALLY INTEGRATE EXOSKELETONS WITH THE HUMAN BODY TO AUGMENT MOVEMENT

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## INTRODUCTION

Exoskeletons are being designed, built and sold at a growing rate, and with increasing capabilities [1]; however, an often overlooked aspect of exoskeleton design is the physical interface between the device and the human body. In terms of augmenting human movement, the physical interface places a fundamental limit on performance enhancement from exoskeletons. For instance, it has been estimated that up to 50% of the mechanical power generated by exoskeletons may be lost in transmission to the body [2]. Thus a large portion of the exoskeleton power supplied is not used to augment movement, but is absorbed in compression of soft tissues, or lost to device migration (a combination of skin/tissue stretch and slippage of the exoskeleton with respect to the skin).

It is critical to improve the ability of exoskeletons to transmit power (via forces) to the body in order to effectively augment human capabilities. This requires that exoskeletons attach to the user in a way that is both comfortable and secure (i.e., limits device migration). Secure attachment can be difficult when coupling to human body segments such as the thigh or shank, particularly when a component of exoskeletal loading is applied axially along the leg. One technique for limiting device migration is anchoring devices against bony prominences; however, this can be uncomfortable and such prominences are not always conveniently located. For example, to prevent migration of a knee exoskeleton, one may need to run a cable up to bony prominences on the pelvis, which introduces additional (undesired) torques about the hip. An alternative would be to run a rigid strut from the knee exoskeleton all the way down to the ground (via a hinged ankle joint), to transfer forces to the ground and limit migration. But this also adds unwanted structure, weight and joint constraints.

Although the difficulties of coupling exoskeletons to the human body are well-known, remarkably little quantitative data is available that characterizes the performance of different attachment methods. While technological advances in exoskeletons abound, there are a lack of new innovations aimed at improving how exoskeletons are biomechanically coupled to the body. The goal of this research is therefore two-fold: (1) to characterize the load bearing capabilities of common, conventional attachment methods, and (2) to evaluate the performance of a new (patent-pending) exo-interface that we developed to improve physical human-exoskeleton integration.

## METHODS

We conducted an initial case study to quantify the load-bearing performance of a conventional attachment method vs. a new exo-interface we developed. Conventional “shell and strap” style attachments are found on nearly all commercially-available braces, orthoses and exoskeletons, and can be fastened atop clothes or directly on top of the skin. These systems consist of a rigid (or semi-rigid) shell with one or more strap-style fasteners and padding for subject comfort. The new exo-interface we developed replaces this padding with a conformable layer that interfaces more securely to the skin. This layer is comprised of a sleeve of thermoplastic elastomer, which is a material commonly used in prosthetic liners for amputees (other liner materials can also be used, such as silicone). The sleeve surrounds and conforms to the surface area of the body segment (e.g., thigh, shank). A semi-rigid shell is then affixed on top of the liner, and provides a point of connection for the rest of the exoskeleton. In this study we also tested a third condition, which we termed the adhesive interface. For this condition we applied Hypafix® retention tape to affix a semi-rigid

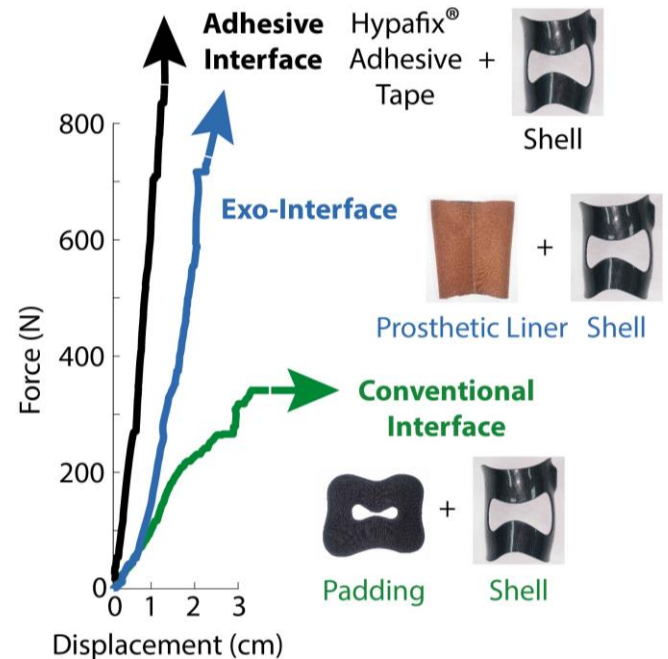
shell directly to the limb. This condition served as a control, to measure best-case performance (i.e., minimal migration, due to skin stretch), but was not intended as a practical or long-term attachment solution.

We attached each interface sequentially to one male participant's shank while he stood at rest. We then applied a vertical load to the interface (axially along to leg). Loading was applied manually, until either the interface failed (completely slipped down the leg), or until a practical limit (pulling strength or subject discomfort) was reached. Loading was measured via a force transducer, and migration was quantified using motion capture (by tracking the relative motion of the interface with respect to markers located on the malleoli, bony prominences of the ankle). Of note, we also performed load testing when coupling to the thigh, which yielded qualitatively similar results.

## RESULTS AND DISCUSSION

We found that conventional "shell and strap" interfaces were indeed severely limited in terms of loading-bearing capabilities and exhibited large migrations; however, the new exo-interface we developed was able to increase load-bearing capabilities at least two-fold (Fig. 1). The conventional interface had a load capacity of ~350 N before failing (i.e., slipping completely down the shank). As a point of comparison, calf muscle forces during walking are on the order of 1000-2000 N [3], which means that this type of conventional interface would be a poorly suited foundation for the development of a biomimetic ankle exoskeleton (with calf muscle-like forces). Our new exo-interface sustained over two times that loading (around 750 N), with much lower migration (2 cm). At 350 N of axial force our new exo-interface reduced migration by 75% (from 6 to 1.5 cm), compared to the conventional interface. The exo-interface did not completely slip, but rather manual loading limits (around 800 N) were reached. The adhesive interface performed even better, exhibiting <1.5 cm of migration at 750 N, which we interpreted as an estimate of skin stretch.

We are now preparing to conduct a more comprehensive, systematic characterization of these interfaces, using a custom-built mechanical loading system. Studies will involve testing more subjects, under both static and dynamic loading conditions.



**Figure 1:** Force applied vs. interface migration.

## CONCLUSIONS

A better understanding of the physical human-exoskeleton interface is needed to improve the performance of human augmentation devices. Here we present preliminary data that characterizes the load-bearing capabilities of different exoskeleton attachment methods. We found that a novel exo-interface could significantly increase load-bearing capabilities while reducing migration. Innovations in how we physically couple to the body have the potential for broad applications, and could enable transformative advances in human augmentation technology.

## REFERENCES

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