Robotic exoskeletons can reduce metabolic cost in healthy individuals and restore mobility in clinical groups (such as patients with peripheral artery disease [1]). Depending on the estimation methods, up to 40% of the metabolic cost of walking comes from the hip muscles [2]. Assisting at the hip has the advantage that the exoskeleton mass is positioned close to the center of mass, which minimizes the energy cost due to added mass. Soft exosuits have the advantage that they allow greater freedom of movement. However, soft exosuits often cannot apply the same torque magnitudes as rigid exoskeletons, and they rely on friction with the skin to remain anchored. The purpose of this work was to develop a semi-rigid hip exoskeleton that can connect to and be powered by an existing actuation unit, to address the limitations of current existing soft exosuits. We evaluated the device performance by analyzing the match between desired and actual torque applied to the hip joint.

II. METHODS
We developed a semi-rigid hip exoskeleton end-effector, which allows complete freedom of movement. The waist-belt and thigh pieces are semi-rigid, and they do not solely anchor to the wearer via friction and compression, but they also stay locked on the body as a consequence of the moment from the actuation (Fig. 1). We developed a new high-level temporal force-tracking controller that allows applying a sinusoidal extension and flexion moment profile as a function of the stride cycle percentage on each leg [3]. The low-level controller developed by HuMoTech communicates with the motor and adjusts its velocity to minimize the error between the actual force [4]. To obtain an idea of the responsiveness independent of the movement of the participant, we conducted a bandwidth test where the tether was attached to a fixed anchor. We applied a sinusoidal torque profile over a range of simulated step frequencies from 0.5 to 5 Hz.

III. RESULTS
In walking tests, we have been able to achieve relatively good force tracking. However, the achieved bandwidth was markedly lower than recent high-performance hip exoskeletons (e.g., [5]), 18 Hz, potentially this is in part because our device is not a rigid exoskeleton: The results (Fig. 2) show that the system has a 3-dB cutoff of about 3.7 Hz and a 34° phase delay at 3.7 Hz. Since the stride frequency of walking is close to 1 Hz, the system is more than fast enough to pull once per stride but slightly slower compared to more subtle walking movements as the frequencies content of walking is about 6 Hz [6].

IV. DISCUSSION AND CONCLUSIONS
We believe the semi-rigid design can have advantages in comfort in patient populations because it requires less friction and compression than soft exosuits.

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REFERENCES

Fig. 1. The hip exoskeleton setup (A). Hypothesized differences in anchoring between semi-rigid waist belt (B), and soft waist belt (C).

Fig. 2. A) Gain plot of fixed-endpoint bandwidth test. B) Phase plot of the bandwidth test.