Characterization of Mechanical and Electrical Vacuum Pumps for Use in Vacuum-Assisted Suspension

S. Fatone, PhD, BPO(Hons), S. Wood, MS, R. Caldwell, CP, W. Chen, PhD, C. Sun, PhD, A. Hansen, PhD, O. Komolafe, PhD

NORTHWESTERN UNIVERSITY FEINBERG SCHOOL OF MEDICINE

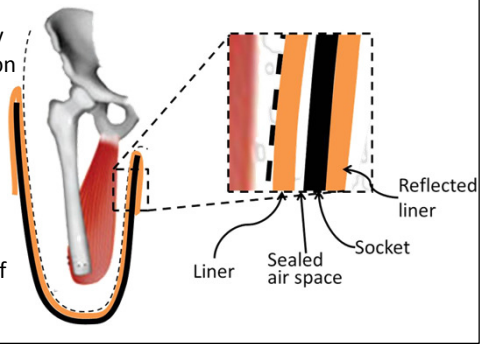
NORTHWESTERN UNIVERSITY

Background

Vacuum-Assisted Suspension

Vacuum assisted suspension (VAS) of prosthetic sockets uses electrical or mechanical pumps to create a negative pressure differential (i.e. vacuum) between the interior of a prosthetic socket and the surface of a liner clad residual limb.

Despite increasingly widespread adoption of VAS systems in prosthetic clinical practice, there remain gaps in the body of scientific knowledge guiding clinicians' choices of existing products.

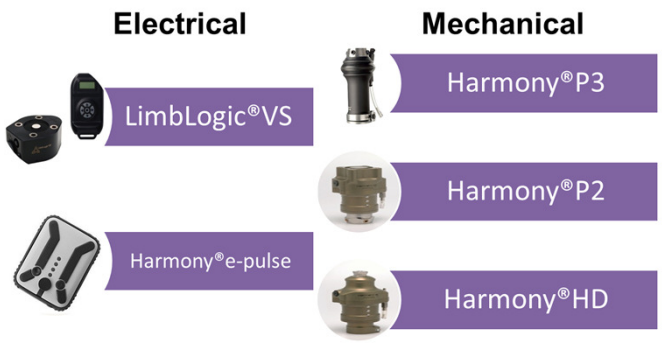


Purpose of the Study

To identify pump performance metrics and develop techniques to objectively characterize the evacuation performance of prosthetic vacuum pumps.

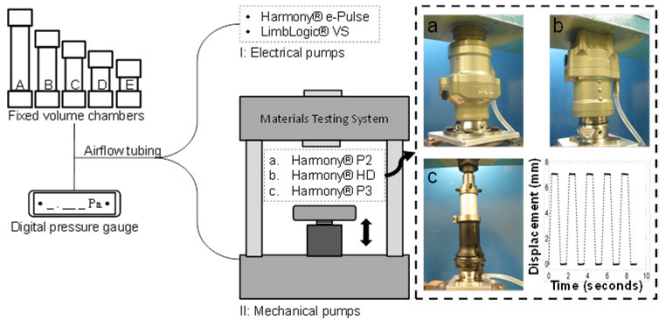
Methods

Prosthetic Vacuum Pumps Tested



- P2 and HD pumps are configured for different user weights using tension adjustments of an elastomer rod (3 weight settings).
- P3 was configured for different user weights using bladders of varying resistance to compression (functional rings "0" to "4).

Experimental Setup for Electrical and Mechanical Pumps



- Inserts show the fixture attachment within the materials testing machine for (a) Harmony® P2, (b) Harmony® HD, and (c) Harmony® P3. The bottom right insert is the displacement loading profile for the mechanical pump tests.

Volumes of PVC chambers				
A	B	C	D	E
2.05E-4 m^3 [12.54 in^3]	1.40E-4 m^3 [8.52 in^3]	1.06E-4 m^3 [6.46 in^3]	7.52E-5 m^3 [4.59 in^3]	4.41E-5 m^3 [2.69 in^3]

- For each chamber, "evacuation time" was defined as the total time from initial pump activation (start-time) to achieving a vacuum pressure of 5.76E4 Pa [17 inHg] (end-time).

A Electrical Pumps (n=2)

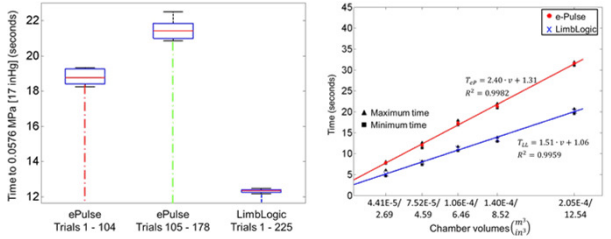
- Inconsistent evacuation times suggested pump performance was dependent on level of battery charge.
- Dependence was assessed by repeatedly evacuating chamber "C" to 5.76E4 Pa [17 inHg] until Li-Ion battery was depleted.

B Mechanical Pumps (n=3 pumps, 8 settings)

- Each functional ring was "pre-compressed" for 15 minutes prior to testing and allowed to equilibrate to testing temperature and humidity for 24 hours before testing.
- Piston ram configured to compress piston-actuated pumps by manufacturer's recommended displacement and cadence of 100 steps/min with a 50:50 of single and double limb stance.
- For all settings and chambers, 3 trials of 200 loading-unloading cycles were applied to the piston actuated pumps and 3 trials of 300 loading-unloading cycles were applied to the compressible bladder pump.

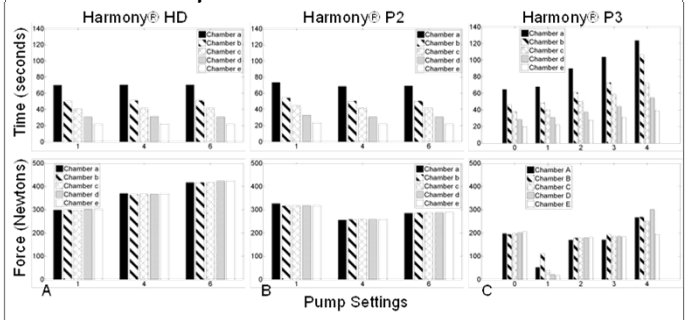
Results

A. Electrical Pump Battery Depletion Test



Left: Boxplot indicating substantially lower median activation time for LimbLogic compared to both groups of data from the e-Pulse. **Right:** Plot showing average evacuation time vs exact chamber volumes. Evacuation times of the e-Pulse (T_{eP}) are consistently higher than evacuation times of the LimbLogic (T_{LL}).

B Mechanical Pump Results



Top: Time to evacuate chambers to 5.76E4 Pa [17 inHg] for pump settings (x-axis). **Bottom:** Maximum force exerted by testing system for each chamber: (a) P2, (b) HD and (c) P3.

Conclusions

- The proposed techniques demonstrated sensitivity to the different electrical and mechanical pumps and to a lesser degree, the different setting adjustments of each pump.
- The sensitivity was less pronounced for the mechanical pumps and future improvements for testing of mechanical vacuum pumps were proposed.
- Overall, this study developed techniques feasible as standards for assessing the evacuation performance of prosthetic vacuum pump devices.

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