INTRODUCTION
Motorized prostheses represent a new opportunity to improve the walking ability of individuals with lower-limb amputation (Sup et al. 2008). The basic idea is to use battery-operated servomotors to provide a controlled amount of positive energy during walking, thus compensating the lack of a physiological muscle action. Unfortunately, battery operated servomotors have a limited power density: the higher the power, the greater the weight. Whereas positive prosthesis power reduces amputees’ walking effort (Au et al. 2009), increased prosthesis weight, has marked negative effects on it (Selles et al. 2004).

Currently available motorized prostheses are dimensioned considering the power requirements of heavy patients (e.g., 100 Kg). Therefore, their weight is significantly high. The goal of this study is to show that by tailoring the design of the prosthesis to the specific power needs of patients, we can reduce the prosthesis weight, while still providing physiological joint power.

During walking, joint torque and power increase proportionally to body weight (Winter & Robertson 1978). So, we can use patient body weight as a discriminant to define power requirements for the design of motorized prostheses. In addition, elastic elements acting in series and parallel to motors can be used to store and release energy, thus reducing the motor power requirements.

METHOD
We developed an optimization algorithm that takes as input a patient’s body weight and desired battery autonomy, and selects the best motor and elastic element configurations to reduce the overall prosthesis weight. The algorithm analyzes a large DC-motor database containing electro-mechanical specifications from all major motor producers, and optimizes spring stiffness as well as transmission ratio for obtaining the best electrical power efficiency.

For the purpose of this study, we used the algorithm to optimize the design of an ankle-foot prosthesis considering 1 hour of walking autonomy, and a patient body weight ranging from 60 to 100Kg. Three different actuator configurations are considered in the simulation: stiff actuator (i.e., motor-gearbox), series elastic actuator, and series elastic actuator with a parallel plantarflexion spring (Au et al. 2009).

RESULTS
As reported in Figure 1, the series elastic actuator with a plantarflexion spring obtained the lowest weights (373g to 592g); the series elastic actuator placed second (426g to 658g); and the stiff actuator needed the heaviest motor and batteries (564g to 740g). Table 1 shows the linear fitting results of spring stiffness values as a function of patient body weight.

DISCUSSION
The optimization algorithm found a proper solution for all patient body weights and all actuator configurations. By adapting the power requirements to patient body weight, we could reduce the motor and batteries weight to about 5g/Kg for all actuator configurations.

CONCLUSION
Optimizing the actuator design on the specific power needs of patients allows us to reduce the prosthesis weight proportionally to the patient body weight.

CLINICAL APPLICATIONS
Our study suggests that by tailoring the motorized prosthesis design to patient body weight, we can reduce the prosthesis weight. This would allow lighter patients to better benefit from the use of motorized lower-limb prostheses.

REFERENCES