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Editorial

Invasive versus Non-Invasive Neuroprosthetics of the Upper Limb: Which Way to Go?

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Abstract: In this editorial, a topic for general discussion in the field of neuroprosthetics of the upper limb is addressed: which way—invasive or non-invasive—is the right one for the future in the development of neuroprosthetic concepts. At present, two groups of research priorities (namely the invasive versus the non-invasive approach) seem to be emerging, without taking a closer look at the wishes but also the concerns of the patients. This piece is intended to stimulate the discussion on this.

Keywords: neuroprosthetics; upper limb; invasive; non-invasive; augmented reality; 3D printing; finite element method; computer-aided design

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If we had a time machine and could travel to the year 2040, we would certainly be in a better position to decide which way — invasive or non-invasive — would have been more appropriate for developing intelligent neuroprosthetic approaches of the upper limb. The work of Ortiz-Catalan et al., for example, recently published in the *New England Journal of Medicine*, is undoubtedly very impressive [1]: In four patients, the authors presented an implant that was anchored to the humerus through osseointegration, allowing for bidirectional communication between a prosthetic hand and electrodes implanted in the nerves and muscles of the upper arm.

Whether this method will in future be the method chosen by the majority of patients and, if at all, paid for by health insurance companies, is open to discussion [2,3]. Certainly, simpler, non-invasive approaches should be considered, such as electrode-free visual control of the prostheses with augmented reality (AR) glasses [4] and providing the user with sensory input in a different, non-invasive way: Marasco et al. [5], for instance, integrated kinesthetic feedback in three hand amputees by vibrating the muscles used for prosthetic control via a neural-machine interface, improving movement control within few minutes. Last but not least, today's inexpensive multi-material 3D printing offers the possibility of producing personalized prostheses based on design data, 3D scans, or magnetic resonance imaging data. Physical models implemented by computer-aided design (CAD) using the finite element method (FEM) analysis also allow for developing improved mechanical components of existing or planned prostheses (Figure 1).

Already 20 years ago, there were many approaches to control prostheses with electrodes, mainly via electromyography or electroencephalography signals. Electrodeless control via AR glasses did not exist at that time, since the development of the AR glasses was still in its infancy, and 3D printing was also just in the beginning stages. Today, however, we can cost-effectively incorporate both 3D printing and AR glasses into our thinking about developing novel smart neuroprostheses.

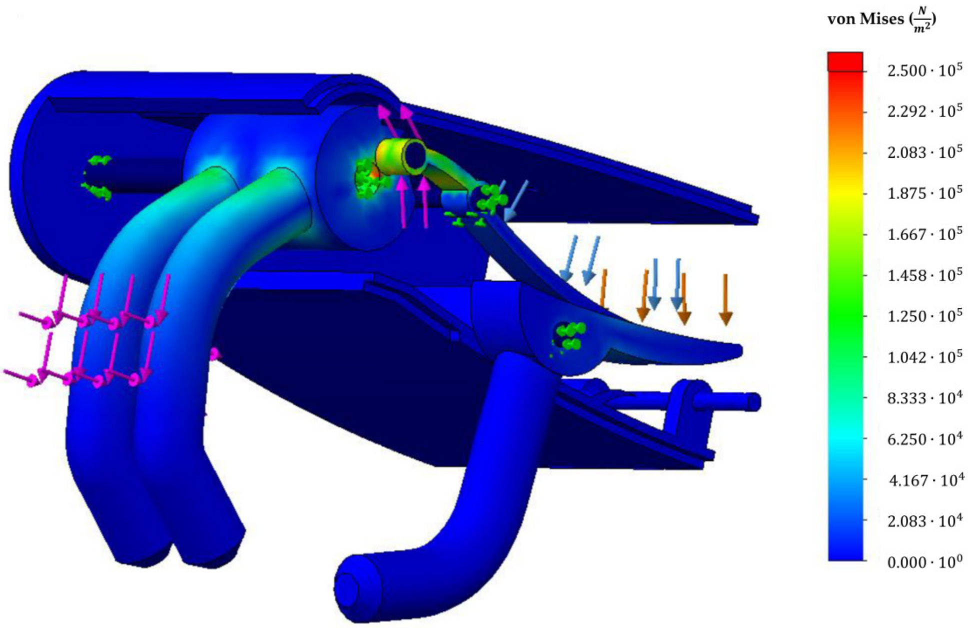

Figure 1. Finite element method (FEM) analysis of a part of the CAD-reconstructed historical first hand prosthesis of Götz of the Iron Hand (Götz von Berlichingen 1480–1562) [6–8]: The analysis shows increased forces mainly in the thumb lever; the maximum stress of this analysis is about $2.5 \times 10^5 \ \frac{N}{m^2}$ (von Mises).

Maybe in 20 years, we will say that it would have been good to combine both approaches, i.e., ideas from the invasive approach with ideas from the non-invasive approach. Parallel development of these, without looking at the other idea, as we currently deem to observe, is probably the wrong move. The degree of invasiveness is ultimately determined by the possibilities that the non-invasive approaches will provide. The more convincing non-invasive approaches we develop, the better. The lynchpin should ultimately be the user, depending on various factors such as age, health status, financial status, etc. Akin the situation with deep-brain stimulation [9], it would be the onus that an open dialogue between engineers and physicians should take place for the development of neuroprosthetics of the upper limb.

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