Effect of surface modification on 3D-printed NiTi alloys for cardiovascular applications

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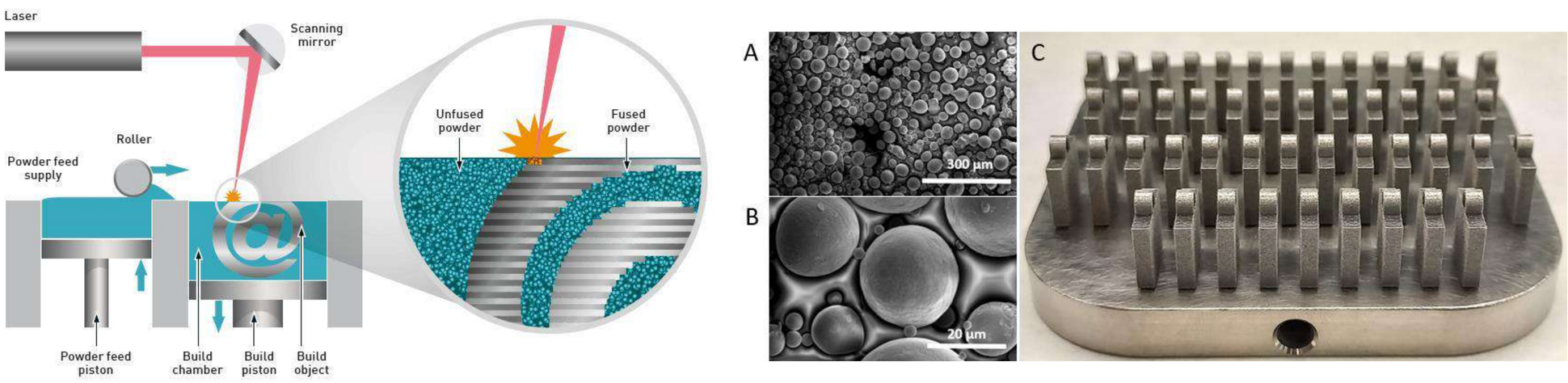
Additive manufacturing of cardiovascular devices

Although the fabrication of metal cardiovascular devices (such as stents or cardiac valves) is well stablished and significantly growing, some important challenges are still encountered, especially when addressing areas that are difficult to access or have complex geometries, such as blood vessel bifurcations. Additive manufacturing (AM) can help surpass these limitations and push the production technology towards a more personalized approach. Nevertheless, AM-produced devices can present some weaknesses, such as a poor surface quality that can potentially cause inflammation, thrombosis or restenosis at the implantation site.

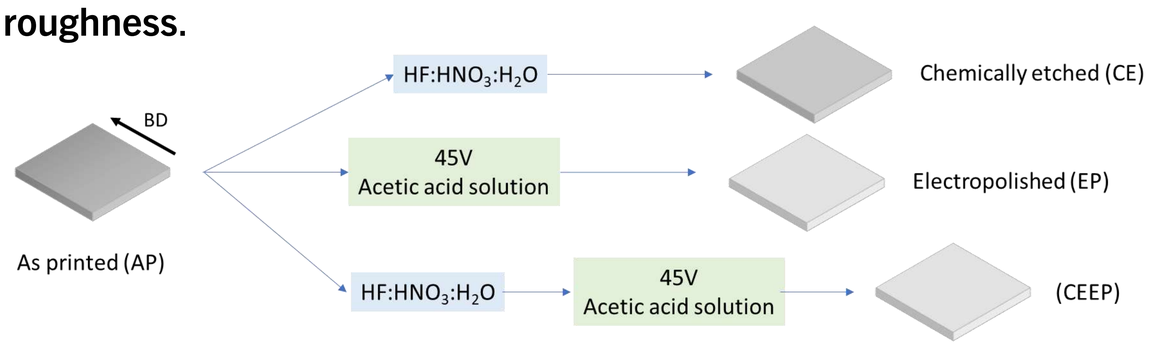
In this work, we used Laser-Powder Bed Fusion (L-PBF) additive manufacturing to produce nitinol structures (Ni-Ti alloy) and evaluate the effect of different surface treatments on the quality, biocompatibility and hemocompatibility of the material for cardiovascular applications.

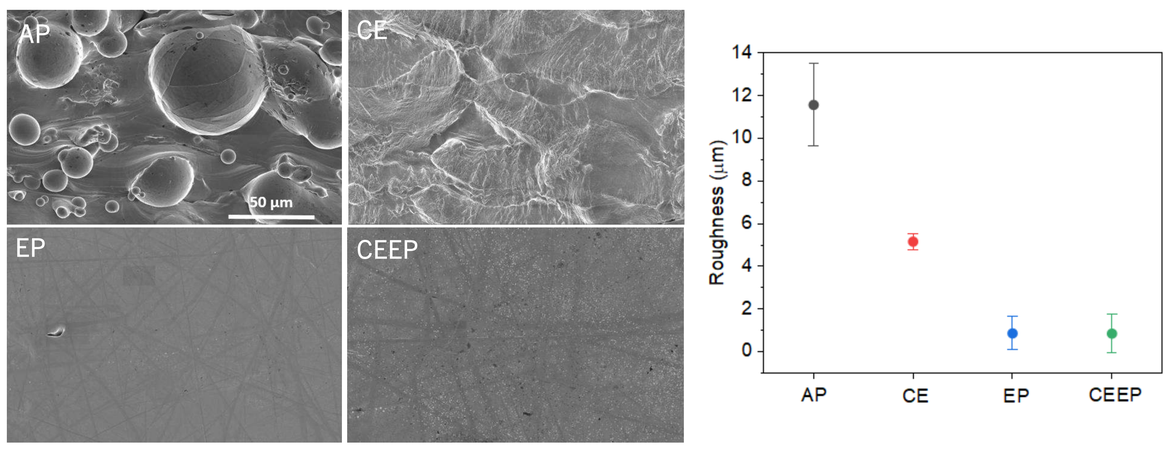


(Left) Schematic of L-PBF [Reproduced from Malvern Panalytical]. (Right) A and B: SEM images of starting nitinol powder. C: Nitinol structures produced by L-PBF.

Surface treatments

As printed (AP) nitinol samples were subjected to chemical etching (CE) in a $HF:HNO_3:H_2O$ solution, electropolishing (EP) in acetic acid or a combination of both (CEEP), achieving different **surface quality and roughness.**

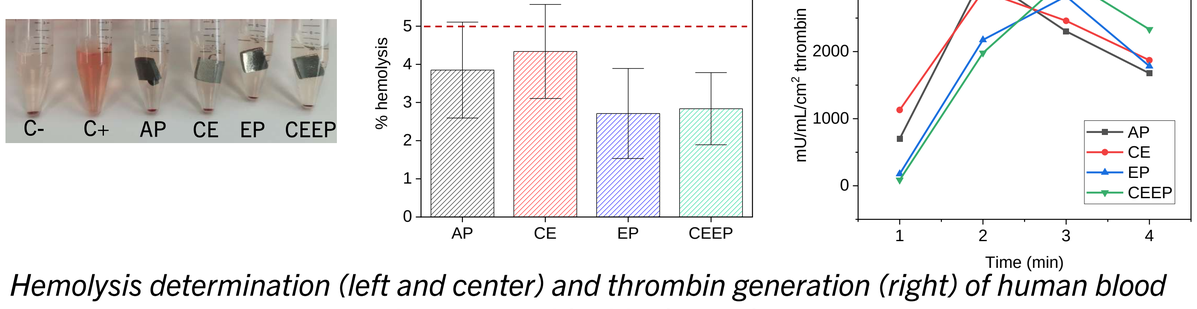




SEM images and roughness of the surface of treated nitinol samples

Hemocompatibility

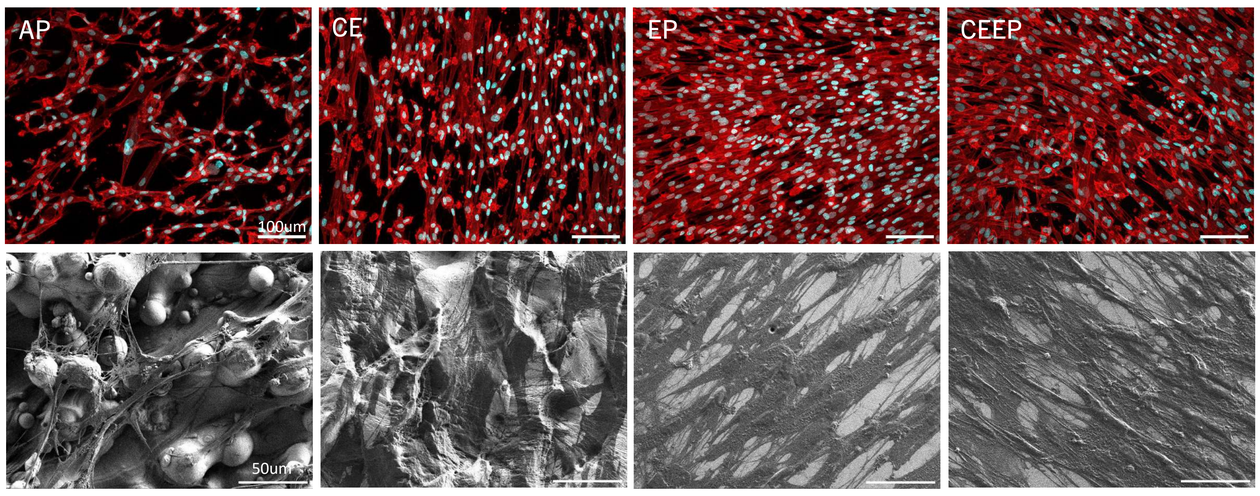
Nitinol samples were incubated with human blood (CTCM, Spain). All samples showed **hemolysis** values lower than 5% (threshold for hemolytic materials), with EP and CEEP surfaces showing values below 3%. In addition, the generation of thrombin, key enzyme for **coagulation**, was also delayed in these two samples.



Hemolysis determination (left and center) and thrombin generation (right) of human blood in contact with nitinol samples

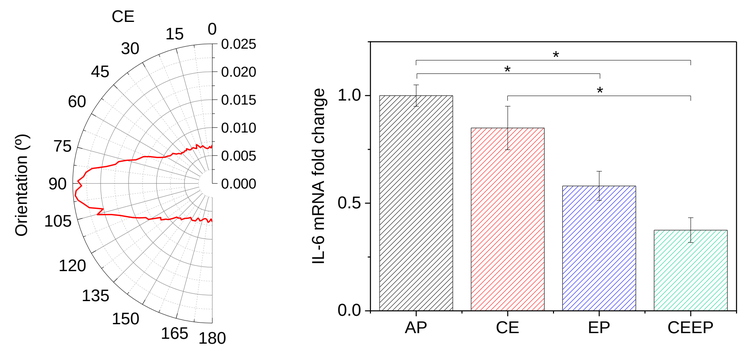
Biocompatibility

Human **endothelial** cells (hEC) and **smooth muscle** cells (HASMC) were cultured on the different nitinol surfaces. While none of the surfaces showed to affect cell viability or proliferation, **cell attachment and morphology** was influenced by surface roughness, particularly on smooth muscle cells:



Confocal (top) and SEM (bottom) images of HASMC on nitinol samples. Red: actin, blue: nuclei.

Interestingly, HASMC showed a clear cell **orientation** perpendicular to the building direction (BD) only on the CE sample.



(Left) Orientation analysis of HASMC on nitinol CE samples. (Right) IL-6 gene expression of HASMC.

In addition, the expression of **IL-6** by HASMC was significantly **reduced with the roughness** of the surface, a cytokine involved in inflammation and typically associated to stent restenosis.

Conclusions

Overall, we have provided new data on the potential use of different surface treatments to improve the quality of AM nitinol cardiovascular devices, in terms of surface roughness, biocompatibility, inflammation or hemocompatibility.

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