Three-Dimensional Printing of Metal Loaded Polycaprolactone Wound Dressings

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Purpose
3-dimensional printing (3DP) is a new technology which offers the potential to revolutionise the future of pharmaceutical manufacturing. In fused-deposition modelling (FDM) printing, a polymer filament is heated and extruded through a small tip and solidified on a build plate. FDM technology has the advantages of cost, the ability to fabricate objects of selected shapes and to print patient-tailored dose formulations with pharmaceutical-grade polymers. Polycaprolactone (PCL) filaments were loaded with different metals (silver, zinc and copper) used widely as antimicrobial compounds by hot melt extrusion to manufacture personalised-shaped wound dressings. The antimicrobial effect of the 3D printed wound dressing was evaluated by isothermal calorimetry.

Methods
Metal-loaded PCL filaments were obtained by hot melt extrusion using a filaments extruder.
A pharmaceutical grade PCL was dissolved in an appropriate solvent (tetrahydrofuran or dichloromethane) and mixed with a solution of one or more metal compounds (AgNO₃, CuSO₄ or ZnO). The solution was evaporated and the remaining mixture was cut into small parts and then extruded using a single-screw filament extruder, Filabot hot melt extruder (temperature 60-80 °C, nozzle diameter 1.75 mm). The extruded filaments obtained were protected from light and kept in a vacuum desiccator until printing.

Dressings were fabricated from the metal-loaded filaments with a standard FDM 3DP, MakerBot Replicator 2X. The templates used to print the dressings were obtained by 3D scanning (Sense 3D scanner, 3D systems, USA) and exported as a stereolithography file (.stl) into the 3D printer software (MakerBot Inc., USA). 3D templates of different anatomical body parts (e.g. ear, nose or hand) were printed adapted to the shape and size of the individual patients.

Antibacterial efficacy of 3D printed wound dressings against S. aureus was evaluated using isothermal microcalorimetry (IMC) in a Thermal Activity Monitor 2277 (TAM) (TA Instruments, UK).

Results
Different PCL filaments were successfully obtained, containing one metal or combination of silver, zinc and copper, using a filament extruder with appropriate characteristics for use in FDM 3DP.
It was not possible to obtain a filament containing all the metal together due to chemical incompatibility.

3D scanning and 3D printing allow the fabrication of wound dressing from the metal-loaded filaments fully adapted in shape and size to the wound of the patient. The right selection of the printing parameter is an essential requisite to obtain dressings of appropriate characteristics in terms of resolution.

Silver and copper loaded wound dressings showed the highest bactericidal activity against S. aureus which is a common pathogen in skin infections. The analysis of wound dressings combining different metals showed the existence of synergic antibacterial effects.

Conclusion
We have demonstrated the feasibility of using hot melt extrusion to obtain filament that can be printed by FDM 3DP to fabricate devices for wound dressing. The combined use of 3D scanning and 3D printing allowed obtaining personalised wound dressing with intricate shapes fully adapted to the anatomy of the wound.
The 3D printed dressing showed different grade of antimicrobial effect against S. aureus depending on their composition.
The results suggest that the combination of hot melt extrusion and 3D scanning/3D printing could offer a potential new method of manufacture for personalised-devices for wound dressing.