In recent years, 3D printing (3DP) has found a multitude of applications in Trauma & Orthopaedic surgery. These techniques fall into four main categories:

1. Pre-operative templates
2. Implantable Scaffolds
3. Intraoperative guides
4. Implants and prostheses

In all cases, a 3D model is constructed through computer-aided design often from existing radiological images, commonly CT or MRI. The resulting model is then printed. There are a variety of methods of 3DP which include selective laser sintering (SLS), stereolithography (SLA), fused deposition modelling (FDM) and direct metal laser sintering (DMLS). We will briefly discuss the four categories outlined earlier and give examples of their clinical applications.

**Pre-Operative Templates**

Pre-operative planning is key to all successful interventions in orthopaedic surgery. The construction of patient-specific pre-operative models, or templates, is useful as it allows computer-assisted planning. This includes the selection of the appropriate intervention and approach, prediction of the risks associated with an approach or technique, as well as assessment of the anatomy and pathology.

A number of papers have demonstrated that the use of 3DP templates in spinal surgery gives a greater appreciation of the anatomy and pathology in complex cases. There is evidence that 3DP reduces operative time, blood loss, transfusion requirements, fluoroscopy exposure and screw malposition rates in spinal surgery.

Three-dimensional printing is also useful in complex pelvic surgery, where appreciation of the anatomy is crucial. The use of pre-operative templates has been shown to increase accuracy and can alter the approach and surgical technique to allow the...
templates help inform and involve the patients, facilitating the consent process, as well as surgical planning.

**Implantable Scaffolds**

The construction of patient-specific, implantable scaffolds with control of porosity, pore size and macroscopic structure, has led to novel advances.

Titanium is widely used as a result of its inherent inertness and biomechanical strength. The ideal porosity (500µM) is a compromise between that required to maintain mechanical strength and that required to encourage bony ingrowth\(^\text{16}\). Patient-specific, implantable scaffolds reduce operative time, infection and the number of screws required compared with commercially available meshes\(^\text{17}\). Whilst the inert nature of titanium reduces in-vivo inflammation and fibrous ingrowth, its reduced biological activity compromises the osteoinductive properties of the scaffold. This is addressed by calcium phosphate (CaP) coating\(^\text{18,19}\). Alternatively, magnesium based scaffolds can be used, as they have favourable osteoconductive behaviour\(^\text{20}\).

CaP based ceramics have both osteoconductive and osteoinductive properties, and are biodegradable over time. Their main disadvantage is their reduced mechanical strength, however, this can be offset by reducing the porosity of the scaffolds\(^\text{21,22}\) or incorporating calcium sulphate\(^\text{23}\), zinc or silica oxide\(^\text{24}\) powders into the ceramic to increase the overall compressive strength.

Bioglasses are inherently bioactive\(^\text{25}\), although it is only recently that manufacturing techniques have developed to give the requisite strength for use in 3DP scaffolds. Nevertheless, it is only with a much smaller pore size of 100µm, and therefore reduced porosity, that the bioglasses are strong enough for in-vivo use\(^\text{26,27}\). Polymers, both synthetic (e.g. poly-\(\varepsilon\)-caprolactone) and natural (e.g. starch-based), can also be used; they have favourable compressive strength and biocompatibility\(^\text{28,29}\).
Intraoperative Guides

The ability to fabricate patient-specific, intraoperative guides allows the surgeon to navigate and accurately place their implants, screws or devices. This technology, like pre-operative templating, is of particular benefit in complex cases. These guides have been developed in spinal surgery to accurately insert pedicle screws. They have been shown to reduce fluoroscopy time, improve the accuracy of screw placement, reducing operative time and blood loss.

Intraoperative guides are also used in pelvic and hip surgery for curved peri-acetabular osteotomies, complex total hip replacements and pelvic tumours. The use of guides can be supplemented with patient specific instruments. The improved accuracy of 3DP intraoperative guides has also been shown, in total knee replacement, to reduce the blood loss and operative time. It has also been reported in a single case of mosaicoanly of the knee with favourable results.

Implants and Prostheses

There are large variations in patient anatomy, as well as of the trauma or pathological process. Therefore, the fabrication of patient-specific implants and prostheses is of interest.

Upper Limb Surgery

Implants to replace eroded glenoids following total shoulder replacement surgery have produced excellent results. Furthermore, replacement of the entire scaphoid or lunate, following avascular necrosis has shown favourable clinical results. The replacement is modelled on the contralateral wrist. Further applications in hand and wrist surgery include customised wrist splints for hand therapy.

Lower Limb Surgery

In total hip replacement customised acetabular cages have been used with success. Creating models of commercially available prostheses allows pre-operative simulation and helps make a decision as to the most appropriate implant. In knee replacement customised titanium augments for large defects and patello-femoral joint replacement have been performed. As with hip replacement, a 3D model of the patient’s knee can be matched to a library of commercially available implants to establish the most anatomically appropriate implant. Customised guides and implants have also trialled in unicompartmental knee replacement. Patient-specific foot and ankle orthoses have been shown to better align and match patient anatomy. These include AFOs and in shoe orthoses.

Tumour Surgery

Patient-specific proximal tibia hemi-knee implants using computer-assisted design, computer-assisted modelling and 3DP has been described for tumours. Similarly, the normal half of the pelvis can be modelled and used to reconstruct the pelvis in patients undergoing hemipelvectomy for pelvic malignancy. In upper limb malignancy, polymethylmethacrylate implants have been manufactured to replace the proximal and distal humerus following bone loss. This gave favourable results when compared to conventional intramedullary nailing.

Trauma Surgery

Cadaveric studies using patient-specific external fixators optimise reduction and increase stability. Ongoing developments include fabrication of patient-specific sockets for lower limb amputation surgery. These are anatomical and give an increase in the overall strength and durability. There are ongoing attempts to construct sockets with inbuilt cooling channels to reduce skin maceration and breakdown. Furthermore, a combination of 3DP components and robotics has allowed the advent of functional prosthetic hands.

Conclusion

In conclusion, 3DP has allowed advances in Trauma and Orthopaedic surgery. The clinical applications are increasing. The technique gives obvious benefit in pre-operative planning, as well as intraoperatively providing guides, implantable scaffolds and implants. The role of 3DP is not limited to the operating theatre as it can help in the manufacture of better orthoses. Whilst initially the products of 3DP were used for complex cases, it is now becoming routine, and is likely to have a significant impact on all of our practices in the coming years.

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