3D Printing for Orthopaedics

Alberto Leardini D.Phil.
President-Elect of the International Society of Biomechanics

P. Caravaggi, M. Ortolani, S. Durante, G. Durastanti, C. Belvedere

Movement Analysis Laboratory, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy

Webinar BI_REX
Applicazioni del AM nell’ortopedia per una medicina personalizzata
24th September 2020

ISTITUTO ORTOPEDICO RIZZOLI

- More than 150 physicians, 300 researchers, 300 publications/yy;
- 20,000 treated patients/yy;
- 120,000 out-patient visits/yy;
- 258,000 medical services/yy on aggregate.
- Research activities (Labs) on biomechanics, biology, oncology, biotechnology, immunorheumatology, tissue regeneration etc…
**MOVEMENT ANALYSIS LAB**

- Planning the correct surgery
- Supporting prosthesis implantation
- Monitoring functional performance
- Making earlier prognosis of implant failure
- Designing new prostheses … custom-made (because developments in additive manuf.)

**3D Fluoroscopy**

- Joint Modelling

**Pre-Operative**

- Prosthesis Design

**IntraOperative**

- Surgical Navigation

**PostOperative**

- 3D Fluoroscopy

**R.S.A.**

**WHAT ABOUT ‘PERSONALISATION’**

In Orthopaedics (‘invasivity’ order):

- Anatomical models: communication/education/planning
- External devices (braces, sockets, insoles, shoes …)
- Surgical instrumentation (cutting jig, custom-made, etc.)
- Endoprostheses (hip, knee, ankle, shoulder, etc…)
- Implantable grafts (suitable sizing and bone adaptation)
- Engineered tissues, scaffolds, etc. (trabecular structures)
IMPLANT PERSONALISATION! WHY

- Full 3D picture of each single patient condition
- Better accuracy and less bone removal
- No longer size related issues
- Minimal invasiveness
- Partial replacement / resurfacing
- Respect of natural patient physiology
- Surgical time shortening via customized fixation and
- Less invasive, for shorter recovery
- Longer survivorship, and less failures and revisions
- Communication / Education / Training / Planning! …
- Cheaper (?): manufacturing, stock, efficacy, operation-time, contentious …
- Less travelling, for patients, surgeons, implants …

Patient-Specific Instrumentation in TKR:
Ensini - Leardini - Giannini - Belvedere

- 3D Printing of custom-fit cutting blocks for femoral /tibial resections, derived from
  lower-limb scan acquisitions (CT, MRI, X-Ray)
- Faster, more accurate and cheaper (no additional instrumentation!) ?

Massive Osteoarticular Reconstruction

Custom-Made Total Talonavicular Replacement:
Giannini - Cadossi - Mazzotti
Belvedere - Leardini - Durante
Mosca - Ensini - Zaffagnini

- From CT scans of the contralateral
- Prosthesis in cobalt-chromium alloy powder melting

Pelvic Reconstruction in Oncology

Custom-made implants for revision and bone tumor surgery:
Donati - De Paolis - Frisoni - Taddei - Leardini - Belvedere

- De Paolis et al. Orthopeadics 2020
Vertebral body replacement

Spine surgery, custom-made implants:
Gasbarrini - Girolami
Leardini - Fini - Caravaggi - Belvedere - Russo - Graziani

- Titanium alloy, lightweight (density 10%), also to favour bone ingrowth
- Surgical time from 12 – 30 hours, to 7
- Four patients, max F.U. 14 MM

Elbow surgery

Anatomical models for pre-op plan & patient communication:
Rotini - Marinelli – Ruffini - Guerra

- 2007: 56 ys, elbow arthritis
- 2016: 30 ys, post-traumatic intrinsic elbow contracture
- 2017: planning and tools for coronoid reconstruction with an osteochondral radial head autograft

- Large osteochondral fragments inside the joint: high correspondence among CT scan, 3D model and the removed fragment; of value for pre-op planning
Bioprinting platform

Biological custom-made implants (pre-clinic analysis):

Sequential development for custom-made implants (replacements and scaffolds):
- Collection of radiographic images (CT ‘dual-energy’)
- 3D image processing, analysis, design
- 3D printing via bioplotters, in biomaterials (calcium phosphate, hydroxyapatite, collagens) or biological composite material human cells (hydrogel); also Elettrospinning technology


Hip Revision Surgery

- Failure of THR, with massive bone loss
- 3D planning, manufacturing, surgery; plan- vs post-op
Personalised TAR: test new designs

Image- and experimental- based study of the morphology of the articular surfaces of natural and prosthetic ankle joint

Belvedere - Ensini - Caravaggi - Durante - Leardini (IOR)
Siegler - Namani (Drexel University, Philadelphia)
Fortunato - Liverani (CIRI-MAM, UniBO)

- Test of 4 different artificial joint shapes, 3DP both in ABS and CoCr
- 10 cadaver lower limbs with normal ankles

CT images
Bone modelling
3D geometrical analysis
Design & Manufacturing
Testing: 3D Kinematics and Kinetics Analyses

Personalised TAR: effect of imaging

To compare Geometrical Models from different Imaging Technologies:
Std.CT, DualEnergyCT, MRI1.5T, MRI3.0T and CBCT

- A single fixed specimen, with multi-modal mrks, in the five technologies
- Registration via SVD and ICP, Distance-Mat-Analysis

Standard CT+ 1.5T MRI
Standard CT+ 3.0 T MRI
DE CT+ 1.5T MRI
DE CT+ 3.0 T MRI
CBCT+ 1.5T MRI
CBCT+ 3.0 T MRI

* Siegler et al. Clin Biomech 2014
* Durastanti et al. Quant Imaging Med Surg 2019
Personalised TAR: clinical process

INITIAL EXPERIENCE ON PATIENTS

TAR - 3. Anat/Func Approach

BOX customisation: patient #1
TAR - 3. Anat/Func Approach

Metal 3DP: the experience of ‘Gruppo-Laser’

i Machine Setup and Operation

Fortunato - Liverani - Tomesani (CIRI-MAM UniBO)

Define also better interfaces, to promote bone regeneration and therefore improve osseointegration, and also prevent infections

ii Final prosthesis components manufacturing

* Liverani et al. Materials and Design 2016
Personalised TAR

According to … PATIENT DIMENSION & SURGEON PREFERENCES!

3D-Printing technology:
- Caravaggi et al., J Biom Mat Res: Part B - Applied Biomaterials, 2019

TAR & Surgical Correction of Flat Foot

CT in weight-bearing, for 3D models and printing

Faldini - Mazzotti - Belvedere - Ortolani - Durante - Leardini

- Complex cases, with flat-foot deformity: 3D reconstruction and 3D printing, for indication & planning of surgery
Personalised HTO: ‘T.O.K.A.’ procedure

Tailored Osteotomy for Knee Alignment

Belvedere - Caravaggi - Durante - Leardini
Zaffagnini - Grassi - Marcheggiani Muccioli

- ‘In-silico’ tests in 28 + 28 legs, in ClinicalTrials.gov!

Surgery for Cervical Spine Deformity

Ortolani - Belvedere - Caravaggi - Durante - Leardini
De Iure (Ospedale Maggiore)
Surgery for Thorax/Sternum reconstruction

- Model in ABS for pre-op planning, support to surgery, and design of implants

Joint Orthesis/Cast & Insoles

Clinical trial for feasibility and efficacy:

- Laser scans of the joint (wrist, ankle, ... etc.)
- Planar 3D printing, for thermoplastic material, to be arranged about the patient joint

Personalized AFO:

- Design of the two shells from scans (shank and plantar foot)
- ... full process still under testing
CUSTOM-MADE IMPLANTS

Via combination of multi-instrumental/disciplinary activities

- Overall plan of the treatment
- Data capture (scans, medical imaging, ...)
- Medical imaging analysis
- Geometrical modelling
- Biomechanical modelling
- Design of the device (clinical, surgical, technological)
- Prototyping
- Implantation procedure: pre-op planning
- Final manufacturing (additive)
- Final implantation
- Tests: Mechanical, Functional & Biological

Personalized Implants: Organisation models

Clinical
Radiology

Surgery (implant)
Modelling Design
Pre-op planning

Modelling Design

3D-printing
Finishing – Polishing - Sterilising
Packaging - Tracking
Developments in Health-Care …

Cloud Services

Developments in Health-Care

Health systems

Patients

Orthopaedic surgeons

Industry (Med. Dev.)

Technology (3DP)

Research