



## 3D Printing for Orthopaedics

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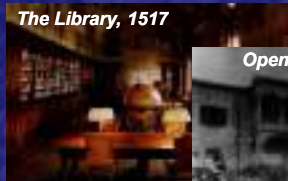
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*Webinar BI\_REX*

*Applicazioni del AM nell'ortopedia per una medicina personalizzata*  
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## ISTITUTO ORTOPEDICO RIZZOLI

*The Library, 1517*



*Opening, June 1896*



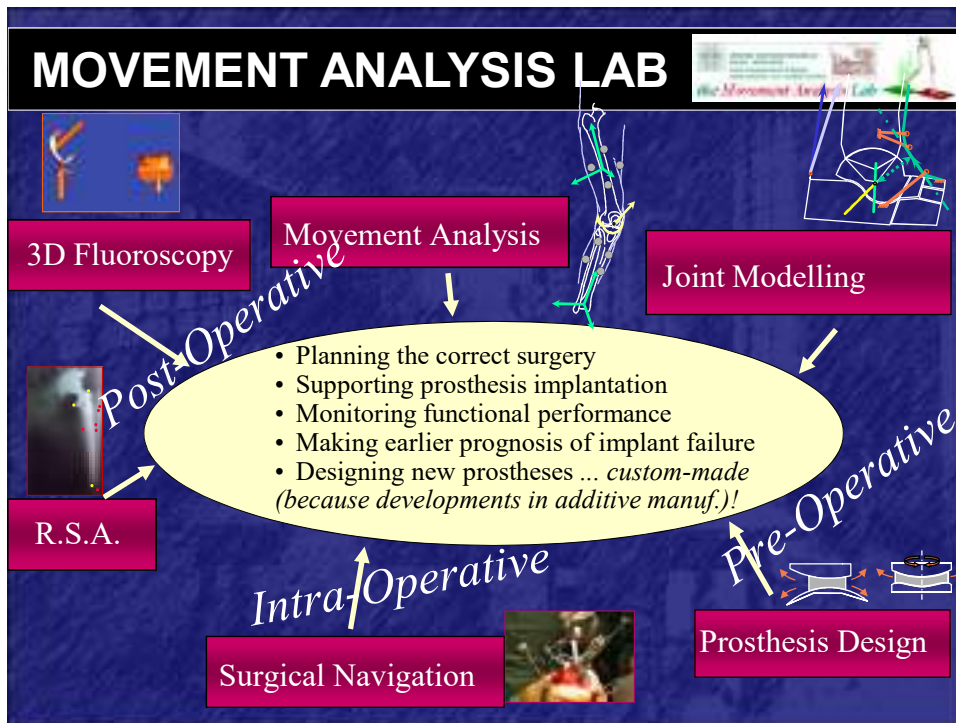
*Prosthetics*



*BORS at IOR1921*



- 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...



## 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.)
- Endoprotheses (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 ...

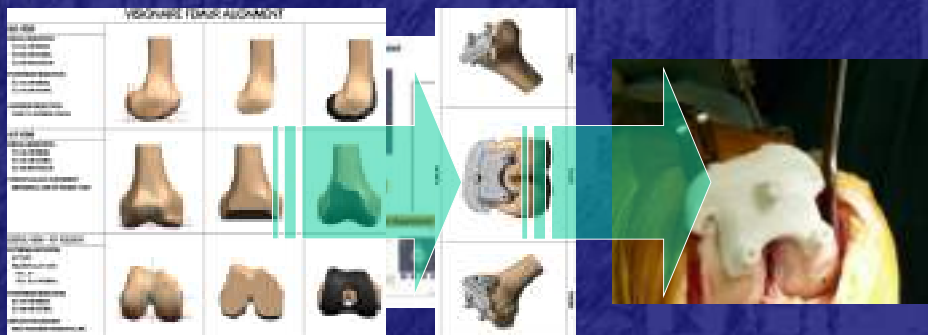


# PSI in Total Knee Replacement

## 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!)?



- Belvedere et al. Int J Med Robot 2007; Cenni et al. J Orthop Res 2014; Ensini et al. Knee Surg Sports Traum Arthr 2014



# 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



▪ Giannini et al. J Foot Ankle Surg 2015; Belvedere et al. J Foot Ankle Surg 2017 & 2020

# Pelvic Reconstruction in Oncology

## Custom-made implants for revision and bone tumor surgery:

*Donati - De Paolis - Frisoni - Taddei - Leardini - Belvedere*

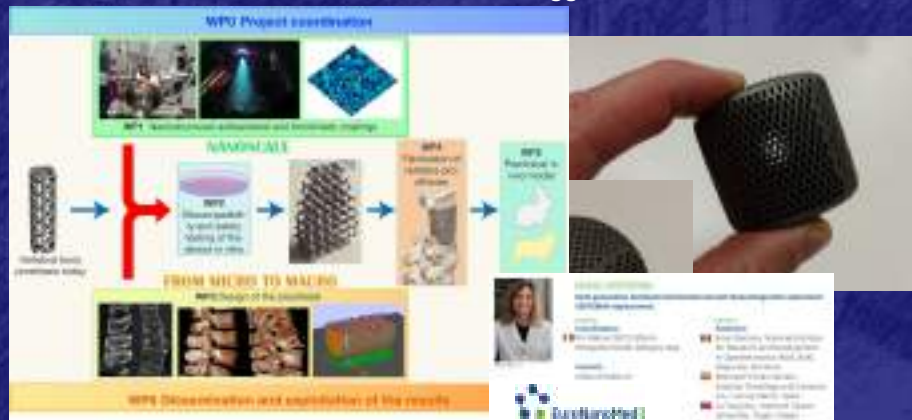


▪ De Paolis et al. Orthopaedics 2020

# 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:

➢ 2007: 56 ys, elbow arthritis

*Rotini - Marinelli - Ruffini - Guerra*



➢ 2016: 30 ys, post-traumatic intrinsic elbow contracture



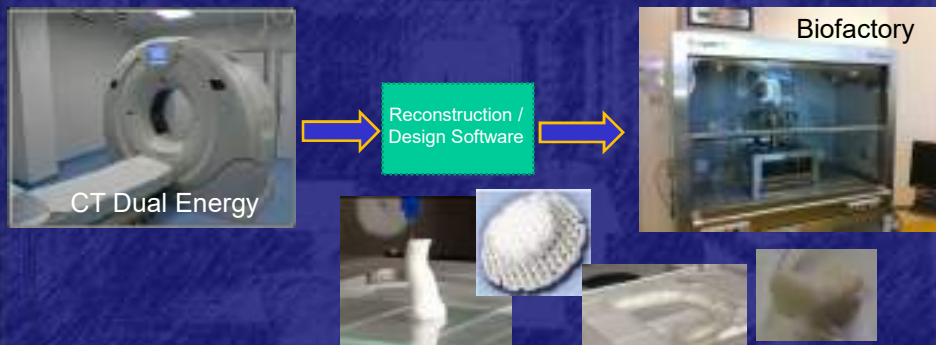
➢ 2017: planning and tools for coronoid reconstruction with an osteochondral radial head autograft

- 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):

Mariani - Grigolo - Petretta



### 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

▪ Roseti et al. Materials 2018; Filardo et al. Bone Joint Res 2019

## Hip Revision Surgery

Romagnoli - Traina - Zaffagnini

- 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



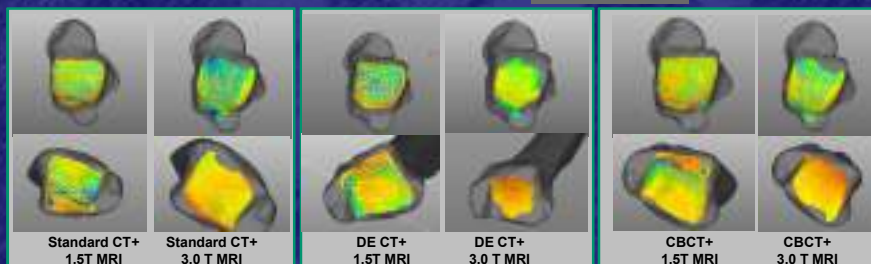
Testing: 3D Kinematics and Kinetics Analyses

▪ Siegler et al. Clin Biomech 2014 ▪ Belvedere et al. J Biomech 2017, 2018, J Orthop Res. 2019

## 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

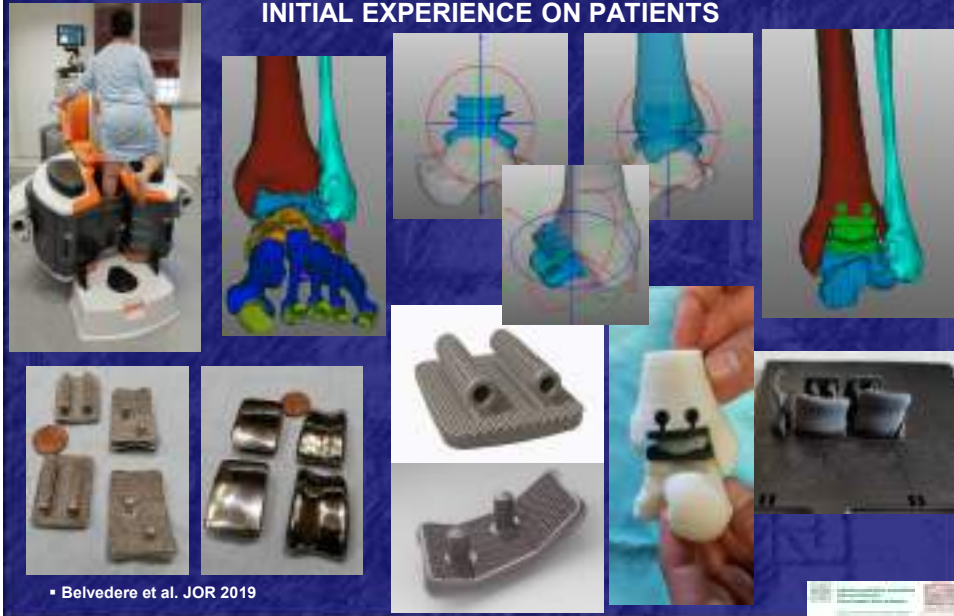


▪ Durastanti et al. Quant Imaging Med Surg 2019

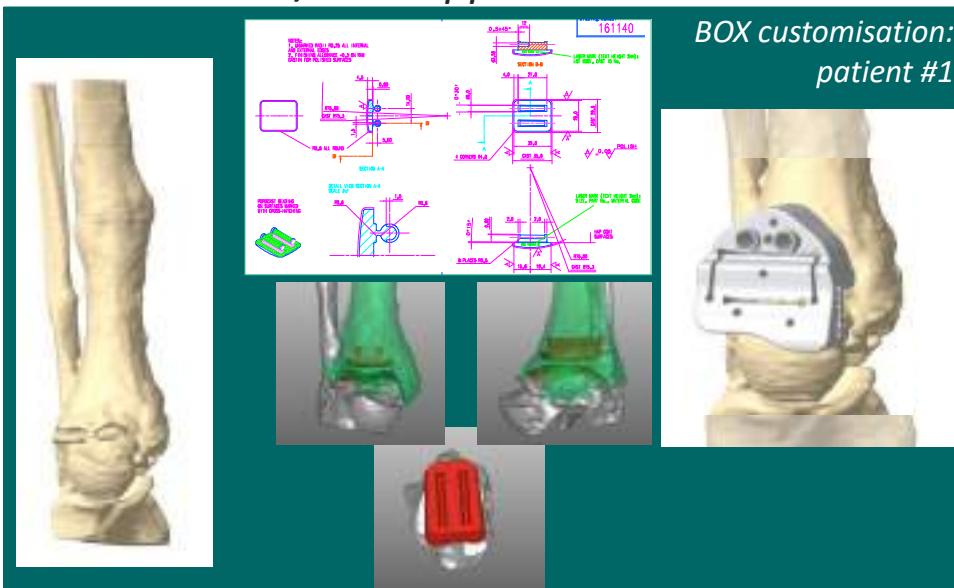


# Personalised TAR: clinical process

## INITIAL EXPERIENCE ON PATIENTS



## TAR - 3. Anat/Func Approach







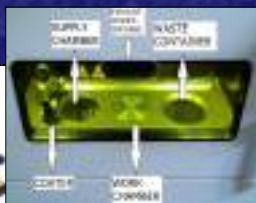
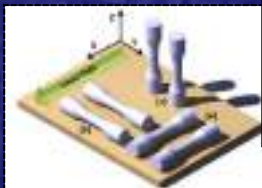
## TAR - 3. Anat/Func Approach



## Metal 3DP: the experience of 'Gruppo-Laser'

### i Machine Setup and Operation

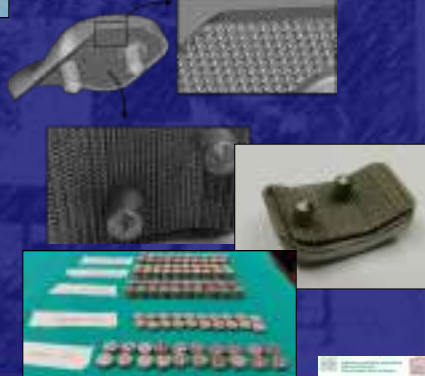
Fortunato - Liverani - Tomesani  
(CIRI-MAM UniBO)



### iii

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

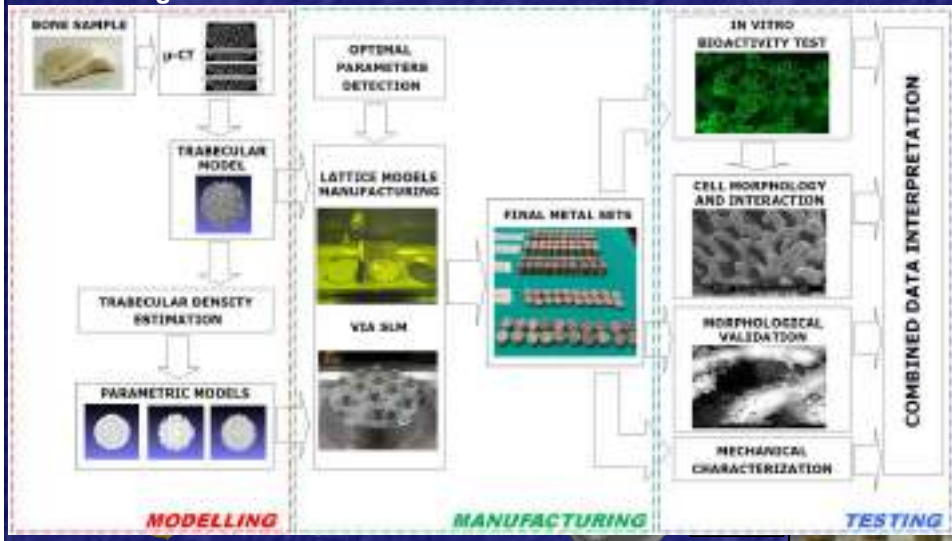
### ii Final prosthesis components manufacturing



• Liverani et al. Materials and Design 2016

# Personalised TAR

According to ... PATIENT DIMENSION & SURGEON PREFERENCES!



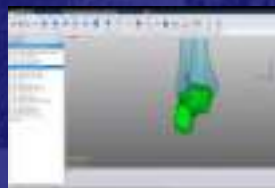
• Caravaggi et al., J Biom Mat Res: Part B - Applied Biomaterials, 2019

# 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



# Surgery for Cervical Spine Deformity

Ortolani - Belvedere - Caravaggi - Durante - Leardini  
De Iure (Ospedale Maggiore)  
fusion )

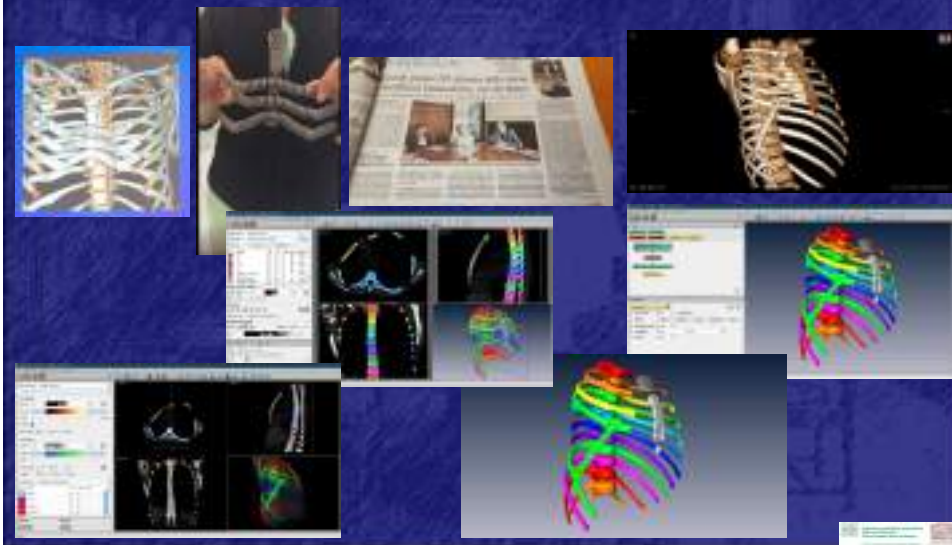




## Surgery for Thorax/Sternum reconstruction

*Rocca - Ortolani - Belvedere - Caravaggi - Durante - Leardini*

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



## Joint Orthosis/Cast & Insoles

Clinical trial for feasibility and efficacy:

*Vivarelli - Maso - Fornasari*



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

### Personalized AFO:

*Leardini - Caravaggi - Giangrande - Berti - Lullini*



- 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

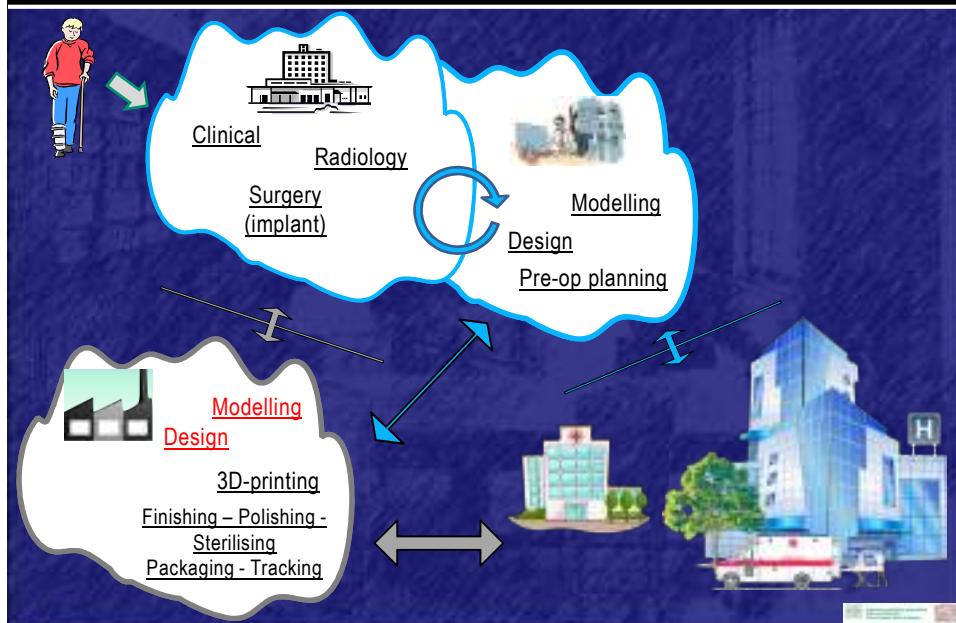
NEEDS:

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

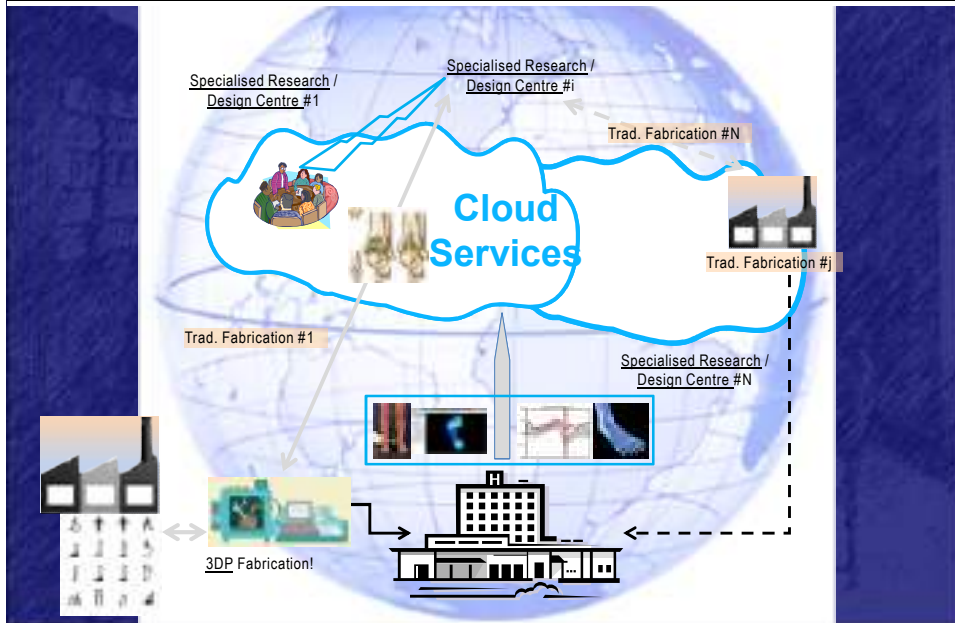
PRINTERS



## Personalized Implants: Organisation models



## Developments in Health-Care ...



## Developments in Health-Care

