The Digital Twin Knee
Value-Based Personalized Knee Care

dr. Rob Janssen MD (2,6, 10-13), prof.dr. Jan de Boer (1), dr.ir. Jasper Foolen (2), dr. Marieke van der Steen (10,11,13), dr. Wai-Yan Liu (10,13), dr. Mitchel van den Eeden (6), dr.ir. Richard Lopata (3,4), dr.ir. Gerard Schouten (7), dr.ir. Taede Punter (8), dr. René van Donkelaar (2), prof.dr. George Fletcher (9), prof.dr. Ward Cottaar (5) prof.dr. Keita Ito (2)

1. BioInterface Science, Dept. of Biomedical Engineering, TU/e
2. Orthopaedic Biomechanics, Dept. of Biomedical Engineering, TU/e
3. Cardiovascular Biomechanics, Dept. of Biomedical Engineering, TU/e
4. Eindhoven MedTech Innovation Center
5. School of Medical Physics and Engineering, Dept. of Electrical Engineering, TU/e
6. Value-Based Health Care, Dept. of Paramedical Sciences, Fontys University of Applied Sciences
7. AI & Big Data, Faculty of ICT, Fontys University of Applied Sciences
8. High Tech Embedded Software, Faculty of ICT, Fontys University of Applied Sciences
9. Database Group, Data and Artificial Intelligence Cluster. Department of Mathematics and Computer Science, TU/e
10. STZ Center of Expertise Complex Knee injuries, Máxima Medical Center
11. ESSKA PAMI European Research Center for Pediatric ACL Injuries, Máxima Medical Center
12. Task force AI & Task force Knee, Nederlandse Orthopaedische Vereniging
13. Orthopedie Groot Eindhoven (Dept. of Orthopaedic Surgery & Trauma Máxima Medical Center & Catharina Hospital)

Introduction

Knee disorders are very common in patients of all ages. They vary from congenital disorders, trauma- & sports injuries to osteoarthritis. Osteoarthritis (OA) is the most common musculoskeletal disease.[1] OA is highly prevalent in the United States and around the globe.[2] It affects 1 in 3 people over age 65 and women more so than men (more than 32.5 million adults in the United States).[2] Almost half of these patients suffer from symptomatic knee OA (14 million people in the US in 2018).[3] Notably, more than half of these patients were <65 years of age.[3] In the Netherlands, 1.467.200 people were estimated to have OA in 2018.[1] The prevalence of OA is rising due to the increasing prevalence of OA risk factors such as obesity, physical inactivity, and joint injury.[1, 2, 4-6]

OA is a leading cause of disability and negatively impacts patients' physical and mental well-being.[1, 3] OA-related joint pain causes functional limitations, poor sleep, fatigue, depressed mood and loss of independence.[3] Compared to age and sex-matched peers, OA patients incur higher out of pocket health-related expenditures and substantial costs due to lost productivity.[2] In a population-based study in Sweden, the greater risk for sick leave or disability among those working in female- or male-dominated job sectors was attributed to knee OA.[3]

Knee osteoarthritis & other medical conditions

Most people with OA (59-87%) have at least one other chronic condition, especially cardiometabolic conditions.[2] There is also increasing evidence that OA is a risk factor for cardiovascular disease development. A meta-analysis found that the risk of myocardial infarction was significantly increased in OA and other types of arthritis.[3, 7] Other studies similarly linked coronary heart disease with OA.[3, 8] In parallel, the Chingford Cohort study found an increased risk of cardiovascular disease-specific and all-cause mortality among women with symptomatic knee OA compared to women without signs or symptoms of OA.[9, 10] Symptomatic knee OA may impair the ability of people with cardiometabolic conditions to exercise and lose weight, which is core to the management of these condition.[1, 2] In longitudinal cohort studies, hip and knee OA is associated with higher risk for all-cause and cardiovascular death, largely due to OA-related difficulty walking.[2] Besides affecting people's physical health, OA may also negatively impact people's mental health. Data from the Osteoarthritis Initiative (OAI) study demonstrated that those with lower limb OA had greater odds of developing depressive symptoms than those without the disease.[3] Another study found a strong relationship between OA and perceived memory loss that was partially mediated by sleep and mood impairment.[3] Sleep disorders are common in patients with symptomatic knee OA as well as during the first 3 months post-surgery.[1]

Patients with OA and other chronic conditions are less likely to receive a diagnosis and recommended treatment.[1] Furthermore, in these individuals the most effective and safest treatment is physical activity/exercise coupled with self-management strategies.[1-3] In practice however, this treatment strategy is poorly implemented.[11] A large regional network led by 17 orthopedic surgeons of Máxima Medical Center and Catharina Hospital (Orthopedie Groot Eindhoven) has recently started a large pilot "Zinnige Zorg" project with Insurance Company VGZ, PoZoB (association of general physicians Zuid-Oost Brabant) and 15 physiotherapy practices in the region of Eindhoven implementing a proven rehabilitation strategy from Denmark for knee and

hip OA patients (Good Life with Osteoarthritis Denmark = GLA:D ®).[11, 12] Given the already high and growing burden of OA, enhanced effort is required to identify better - more effective and safe - treatments for the majority of patients with OA who are living with other chronic conditions.[2, 11]

Costs of knee osteoarthritis

Healthcare resources and costs associated with managing OA are substantial.[1, 3, 4, 13] In fact, OA was the second most costly health condition treated at US hospitals in 2013. In that year, it accounted for $16.5 billion, or 4.3%, of the combined costs for all hospitalizations. OA was also the most expensive condition for which privately insured patients were hospitalized, accounting for over $6.2 billion in hospital costs.[13] The economic burden due to OA is the result of direct costs to the health care system, indirect costs to individuals living with OA, and the intangible costs of living with a chronic disabling condition.[13]

Knee osteoarthritis & research

There is increasing evidence that there are different OA phenotypes that reflect different mechanisms of the disease. Various person-level risk factors are recognized, including sociodemographic characteristics (e.g. female sex, African-American race), genetic predispositions, obesity, diet-related factors, and high bone density/mass.[1, 3] Joint-level risk factors include specific bone/joint shapes, thigh flexor muscle weakness, joint malalignment, participation in certain occupational/sports activities, and joint injury.[1, 4, 6, 14-20] Recent studies have enhanced the understanding of pre-radiographic lesions associated with OA.[3, 21] Application of new findings may allow to develop innovative strategies and novel therapies with the purpose of preventing onset of OA and minimizing OA progress.[1, 3, 4, 16, 18, 20, 22-35]

The development of knee OA is multifactorial.[1] An important modifiable risk factor for knee OA is optimal treatment of knee injury.[4, 5, 22] Injuries of the anterior cruciate ligament (ACL), meniscus, cartilage and other knee ligaments frequently occur in cutting and pivoting sports such as football, field hockey, indoor sports, alpine skiing and tennis.[4-6, 16, 17] Surgical knee reconstructions techniques, diagnostic imaging techniques and rehabilitation have continually improved over the years.[4, 15, 28, 36-38] Reconstructive orthopaedic surgery is the number 1 intervention that has the largest impact on sustained quality of life.[39] However, various clinical issues are still unresolved. Examples are re-injury rates of the ACL graft in both adult and pediatric ACL surgery (up to 30% in children), long-term OA after knee ligament surgery (54%), limited return to sports after ACL reconstruction (65%), and 20% patient dissatisfaction after total knee arthroplasty.[1, 5, 6, 16, 17, 22, 25, 27, 31-34, 40-44] In addition, patient-related factors such as osseous morphology, gender, ACL graft type, type of sports, comorbidities, genetics, kinesophobia and rehabilitation influence patient outcome.[4, 15, 20, 26, 28, 35-38, 45-48]

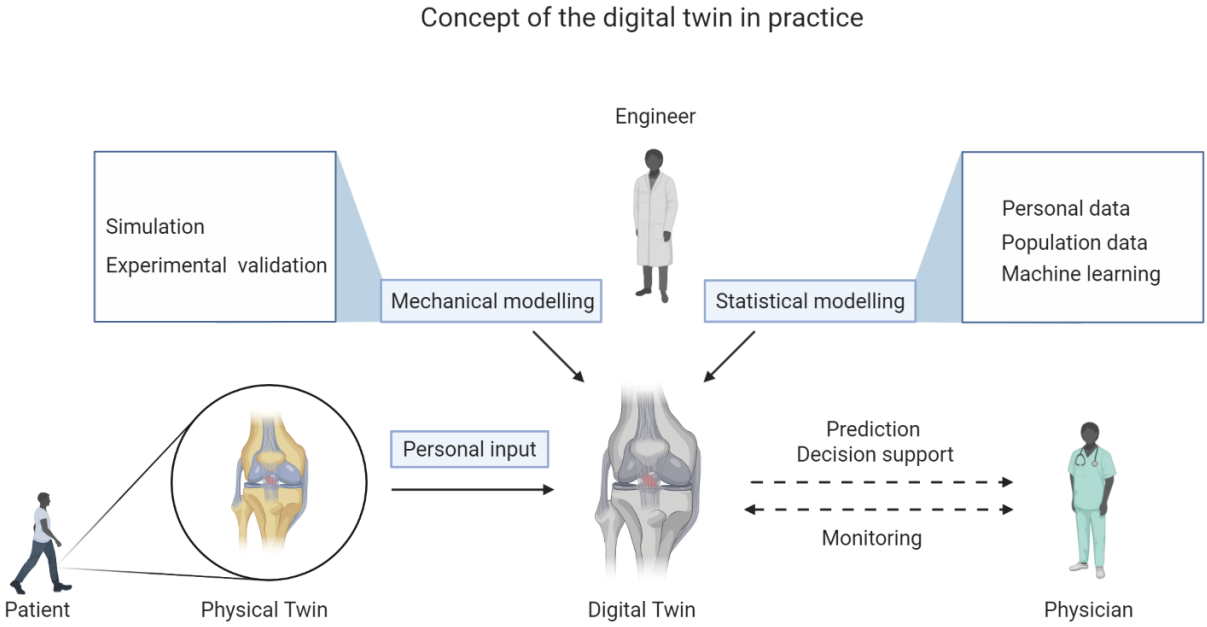
The human knee is a complex organ in structure and function.[4] Prediction models, algorithms, shared decision programs and apps are being developed to improve patient stratification and prediction of outcome after treatment of knee disorders based on subjective and objective patient outcome, artificial intelligence and biomechanical tissue characteristics.[14, 20, 24-27, 30, 33, 35, 43, 49-59] All these models add to the knowledge of knee reconstruction but do not embody all the necessary information for patient-specific decision making and optimal treatment outcome.

Digital Twin Knee

If physicians could use a scientific method to better understand and predict the outcome of a patient's condition, they could more effectively screen patients at hospitals and deliver personalized care.[60] Digital twins stand to revolutionize healthcare in the 21st century, paving the way to more personalized, preventive and participative treatment options that support a shift from reactive to proactive healthcare.[60, 61] A digital twin (DT) is a digital replica of an object, process or system. They are used in design and to better understand how the system will behave over its lifecycle. The DT concept is already being used in product prognostics and product health management, as well as product design and manufacturing.[62, 63] The DT of a product consists of combining a mechanical model (to understand and explain the physical state) and statistical models (to identify and predict patterns concerning the state). An important aspect is the connection between the physical object and the digital object, usually done by tracking markers in the physical state through sensors.[64, 65] Aspects of the DT approach have been applied in health care, showing a great improvement in precision cardiology for example.[66] DT might be a cost-effective way to overcome limits in personalized healthcare. Recently development of a Digipredict DT has started to predict whether Covid-19 patients will develop severe cardiovascular complications and, in the long term, detect the likely onset of inflammatory disease. It makes use of data science and special biomarker detectors.[60]

Primary goal of the *Digital Twin Knee* (*DT Knee*) is to provide a decision support for both patient and the treating physician to optimize value-based personalized knee care *(Fig. 1)*.

Fig. 1. Concept of the *Digital Twin Knee* in practice

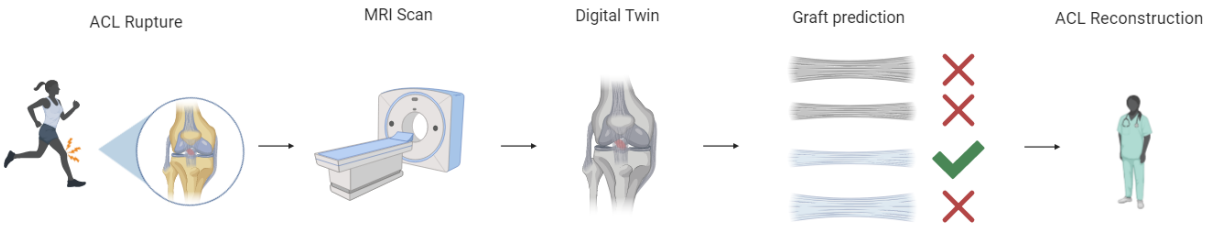


Development of *DT Knee* will encompass translational research involving patients, engineers, data scientists, orthopedic surgeons, imaging experts and health care technology providers as well as legislation for privacy and data management. Research will focus on creating the DT of an injured knee. *DT Knee* serves to select the best type of knee treatment for each patient. It will allow patient-specific shared decision making between the patient and the physician as well as prediction of outcome considering all necessary subjective and objective parameters. Development of *DT Knee* can build upon current and future joint translational research between clinicians, TU/e engineers and major health care technology providers. It would incorporate current research lines at TU/e, Fontys University of Applied Sciences and Máxima Medical Center & Catharina Hospital on tissue level computer models to simulate damage accumulation in cartilage, biological platforms to evaluate tenocyte performance and clinical prediction models, surgical techniques, patient stratification, rehabilitation and value-based health knee care (clinical outcome and costs) *(Table 1,2).* Furthermore, Orthopedie Groot Eindhoven/Máxima Medical Center is research partner in various PhD projects at Maastricht University, Radboud UMC Nijmegen, University of Leiden, AmsterdamUMC and Erasmus MC Rotterdam to accelerate valid data collection on prediction models, apps and treatment algorithms for knee disorders *(Table 2).* New joint research ventures are currently investigated with the Dept. of Electrical Engineering TU/e (prof.dr.ir. Cottaar; PDEng Clinical Informatics, PDEng Qualified Medical Engineer; SPME), Dept. of Mathematics and Computer Science TU/e (prof.dr. George Fletcher), Lectoraat AI&Big Data Fontys University of Applied Sciences (dr. Gerard Schouten), e/MTIC, Philips, Arthrex, VisualSonics, OnlinePROMS, Games for Health, BG. Legal (legislation for AI clinical data), TU Twente, Erasmus University, Utrecht University and Maastricht University *(Table 2).*

Recently, an NWO Demonstrator research project has started to explore the possibilities of the *DT Knee*

concept in graft selection for anterior cruciate ligament (ACL) reconstruction: *Developing the Digital Twin ACL (Fig 2).*[67]

Fig. 2. Developing the Digital Twin ACL [67]



Several clinical issues in ACL reconstruction led to this project. Knee injuries and ACL rupture are important risk factors for development of knee OA.[4, 35, 37, 38] Considering the increasing number of patients at (pre)-adolescent age with this type of injury, this will present a significant burden on patient well-being and cost of health care in the near future.[4, 5, 16] There seems to be graft-specific risk for knee OA.[38] Monitoring capacities for the patient-specific healing process of the ACL graft after surgical reconstruction are limited.[22, 46] Non-invasive assessment such as MRI imaging is available but is expensive, time consuming and cannot currently predict outcome.[4, 28] Re-rupture risk of an ACL graft is age-dependent with various phenotypes.[5, 45] With the annual increasing number of ACL reconstructive surgeries, a more effective way to monitor patient-specific graft choice and rehabilitation based on ACL graft remodeling is needed.[4, 20, 22, 46, 47, 68]
The first step to create *DT ACL* is to build a virtual representation of the physical ACL itself and its environment.[66] This geometric and physical model will be made using FEA-software and validation will be done in the lab by mechanical experiments performed on human and animal ACLs. By developing this mechanical model, the foundation will be laid to further work towards a functional *DT ACL*.[67] Due to the importance of the connection between the physical model and the digital model, a method has to be developed to process data from the physical state that can be used in this mechanical mode.[63] As the DT approach also has its use as a design framework, the ACLs designed from the novel decellularization protocol from porcine tendons as well as human specimen ligament testing can be combined with the mechanical model to yield recommendations in design decision making for ACL reconstruction.[69, 70] Current joint translational NWO Demonstrator / PhD research on tissue decellularization, biomarkers and photo-acoustic imaging for cartilage damage maps & human ACL graft remodeling contributes to this project (Dept. of Biomedical Engineering TU/e and Máxima Medical Center Eindhoven).[20, 28, 47, 67, 70-72] [68]

***Digital Twin Knee* & university curricula**
DT Knee is incorporated in three university curricula.
Since 2019, 20 BSc students and a PhD candidate are working on patient expectations, experience, PROMs, outcome and costs in Value-Based Health Knee Care at Fontys University of Applied Sciences in cooperation with Orthopedie Groot Eindhoven (Máxima Medical Center & Catharina Hospital). The program is incorporated in the BSc Minor Personal Leadership in Value Based Collaborative Health Care (PLUSH).
In February 2021, the first group of TU/e engineering students started on a proof of concept challenge for the *DT Knee*. This is initiated by TU/e Innovation Space Bachelor End Product for Honors Master Academy and challenge owner is Orthopedie Groot Eindhoven. This challenge on prediction models for knee reconstruction will involve engineers from various TU/e departments, designers, data scientists and physicians.
Since February 2021, the new USE LL (User, Society and Entrepreneurial Learning line) *Digital Twin Health* at TU/e will further enhance continuity in developing *DT Knee & DT ACL* submodel for value-based personalized knee care. From Sept 2021, 10 students will annually participate in the learning line Digital Twin Knee focusing on patient remote monitoring through sensor/brace technology in daily and sports activities.

The future
Essential for *DT Health* is reliable clinical & research data in interconnected health information systems.[73] *DT Knee* & *DT ACL* require enhancement of knee scale finite models, biological platforms for cartilage and tissue remodeling and enhanced diagnostics (e.g. motion-biosensors, arthrometry systems for joint instability, biomarkers and (non)-invasive dynamic imaging techniques). In addition, patient remote monitoring would

allow diagnosis in real life situations when the patient experiences the specific complaints. Remote patient management will allow for better value-based knee care by new transmural health care models as well as reduction of hospital visits and hospital stay. Holistic tracking of ADL/sports activities will also help to personalize rehabilitation for each patient feeding their *DT Knee* with personalized data.[73] Smart analytics in AI & Big Data need to be developed for personalized prediction and decision support.[73] This also applies to the necessary legal and ethical issues for use of AI and large-scale personalized clinical data in *DT Health*. Block chain technology may have the potential to transform health care, placing the patient at the center of the health care ecosystem and increasing the security, privacy, and interoperability of health data.[73] Furthermore, the relationship between knee OA, cardiovascular and sleep disorders offers opportunities for joint research on a larger scale by clinicians, TU/e engineers and health care technology providers. *DT Knee* offers elaborate translational research possibilities on materials for regenerative medicine, diagnosis & surgical reconstruction techniques and profound analysis of the pathologies in the complex structural system of the knee. The current translational research, education, strong clinical relationship and (inter)national network form a solid basis for cooperation with new partners and stakeholders in the future.

Table 1. Current contributors *Digital Twin Knee* Eindhoven

Máxima MC/STZ Center of Expertise Complex Knee injuries/European Research Center Pediatric ACL injuries (Chair dr. Rob Janssen MD)
2 Senior researchers (dr. Marieke van der Steen, dr. Wai-Yan Liu)
1 Research assistant (Tessa van de Kerkhof BSc)
2 PhD candidates (Martijn Dietvorst MD, Sander van Eijck MD)
2 MSc students Maastricht University (Ninne Mille BSc, Daan Janssen BSc)

Orthopedie Groot Eindhoven (Dept. of Orthopaedic Surgery & Trauma, Máxima MC & Catharina Hospital)
8 Orthopaedic surgeons (Marijn van den Besselaar MD, Willem den Boer MD, Janneke Bos MD, dr. Hans Hendriks MD, dr. RPA Janssen MD, Coen Jaspars MD, Robin van Kempen MD, Remco van Wensen MD)

Value-Based Health Care, Faculty of Paramedical Sciences, Fontys University of Applied Sciences (Chair dr. Rob Janssen MD, lector)
2 Senior researchers (dr. Mitchel van Eeden, dr. Madelon Pijnenburg)
12 Lecturer-researchers (Team Interprofessioneel Samenwerken)
1 PhD candidate (Anouk Konings-Pijnappels MSc)
43 BSc students in 5 research lines on value-based health care (since Sept. 2019)

AI & Big Data, Faculty of ICT, Fontys University of Applied Sciences (Chair dr.ir. Gerard Schouten, lector)
1 Senior lecturer – project leader AI & Big Data (Michiel Groenemeijer MSc)
1 Senior researcher-lecturer (dr.ir. Simona Orzan)

High tech Embedded Software, Faculty of ICT, Fontys University of Applied Sciences (Chair dr.ir. Taede Punter, lector)

Orthopaedic Biomechanics, Dept. of Biomedical Engineering, TU/e (Chair prof.dr. Keita Ito)
2 Associate professors (dr. René van Donkelaar, dr. Rob Janssen MD)
2 Assistant professors (dr.ir. Jasper Foolen, dr.ir. Wouter Wilson)
3 PhD candidates (Marc van Vijven MSc, Meike Kleuskens MSc, Janne Spierings MSc)
5 MSc students (Despina Stefanoska, Joyce Kimenai, Meike Boef, Pieter Zwerver, Wietske Velthuis)

BioInterface Science, Dept. of Biomedical Engineering, TU/e (Chair prof.dr. Jan de Boer)
1 Postdoc (dr. Jorge Uquillas Paredes)
1 PhD candidate (Aysegul Dede-Eren MSc)
3 MSc students (Janne Spierings, Marloes van den Hengel, Antonio van der Lande)

Cardiovascular Biomechanics, Dept. of Biomedical Engineering / e/MTIC (dr.ir. Richard Lopata)
1 Assistant professor (dr. Min Wu)

School of Medical Physics and Engineering, Dept. of Electrical Engineering, TU/e (Chair prof.dr. Ward Cottaar)
1 annual PDEng Clinical Informatics and PDEng Qualified Medical Engineer

Database Group, Data and Artificial Intelligence Cluster. Dept. of Mathematics and Computer Science, TU/e (chair prof.dr. George Fletcher)

Innovation Space Bachelor End Project for Honors Masters Academy, TU/e
1. Challenge owner (dr. Rob Janssen MD)
3 Academic coaches (prof.dr. George Fletcher, dr. Jasper Foolen, dr. Peter Ruijten-Dodoiu)
1 MSc student (Kim Geelink, BSc)
3 BSc students TU/e (Jovan Sakovic *Datascience,* Délano Gaasbeek *Psychology&Technology*, Kelly Morrenhof *BME*)

USE LL (User, Society and Entrepreneurial Learning line) Digital Twin Anterior Cruciate Ligament
1 Professor (prof.dr. Jan de Boer, coordinator)
1 Associate professor (dr. Rob Janssen MD)
2 Assistant professors (dr.ir. Jasper Foolen, dr. Burcu Gumuscu)
1 Postdoc (dr. Jorge Uquillas Paredes)
1 PhD candidate (Sander van Eijck, MD)
2 MSc student (Kim Geelink BSc, Antonio van der Lande BSc)
4 BSc students TU/e – UMCU (K. Morrenhof , D. Brink *BME*, T. Haning *Med Wet & Tech*, L. Vlootman *Psych & Tech,* R. Ganesh *Med)*
25 annual BSc students TU/e from September 2021 in Digital Twin Health Program

Table 2. Subprojects

Current and finished projects and related publications (principal investigator)

Name	Goal	Partners	Funding
ACL reconstruction & accelerated rehabilitation in adult and pediatric patients[4-6, 15-17, 22, 26, 35-38, 40, 42, 45, 46, 50-52, 55, 57]	Optimal treatment conservative vs surgical reconstruction & rehabilitation: outcome, return to play, osteoarthritis, remodelling, complications and PROMs. (3 national guidelines on rehabilitation)	MMC, OGE, UM, Aarhus University (DK), Charité (Berlin DE), NVA, FMS, NOV, KNGF, ESSKA	Dept. Orthopaedics MMC (2 PhD's)
Knee & hip osteoarthritis[14, 18, 19, 27, 29, 31-34, 41, 43, 53, 54, 56, 74]	Patient expectations & satisfaction, outcome, prediction models in knee and hip surgery and physiotherapeutic treat-to-target rehabilitation after orthopaedic surgery	MMC, ErasmusMC, NOV-LROI, OGE, Fontys	Dept. Orthopaedics MMC NOV (1 PhD)
Remodelling ACL grafts and rehabilitation in adult and pediatric patients[16, 20, 22, 28, 46, 47, 67, 68, 70-72, 75]	Development of a decellularized ACL allograft & tissue platform for predic-ting graft remodeling and rehabilitation strategies	MMC, TU/e (BME: OB & BS; IS, USE LL), OGE, UMCU, BisLife, MUMC+, OCON, StAntoniusZH, StAnna, PSV	Dept. Orthopaedics MMC TU/e, NWO (2 PhD's, 1 postdoc)
Knee reconstruction and cartilage degeneration[23]	To develop and evaluate an ex-vivo human osteochondral culture model	TU/e (BME: OB), MMC, OGE, UMCU	TU/e (1 PhD)

Current multicenter projects and related publications (MMC participating center)

Name	Goal	Partners	Funding
ROTATE trial[76]	To compare a new algorithm to usual shared-decision making for treatment strategies in ACL injured patients	ErasmusMC, MMC, MartiniZH, StAntoniusZH, TergooiZH, Noord-westZH groep, HaaglandenMC	ZonMW (1 PhD)
STARR trial[77]	To compare arthroscopic resection vs. rehabilitation in traumatic meniscal injury	ErasmusMC, MMC, CZE, HaaglandenMC, StAntoniusZH,	ZonMW (1 PhD)
Personalized m/eHealth Algorithm for the Resump-tion of Activities of Daily Life, Work and Sport after knee arthroplasty[25, 59]	To analyze cost-effectiveness of a transmural integrated care program for knee arthroplasty patients in the working population	AmsterdamUMC, MMC, Amphia, MUMC+	ZonMW (1 PhD)
CREDO[21]	Developing and validating diagnostic criteria for early hip & knee OA	ErasmusMC, MMC, LUMC, AmsterdamUMC, UMCU	ZonMW (1 PhD)
Patient empowerment through timely information[49]	App development for personalized rehabilitation in orthopaedic medicine	RadboudUMC, MMC, OGE, OnlinePROMS, ViecuriMC, StAnna, ViaSana	RadboudUMC, OnlinePROMS external PhD (1)
"Choosing Wisely" recommendations in degenerative knee disease[58, 78 79]	Implementation of cost-effective treatments and rehabilitation in patients with degenerative knee disease	LUMC, MMC, UMCG	ZonWM (1 PhD)

Planned projects and related publications

Name	Goal	Partners	Funding
Remote patient management / EHealth in orthopaedic surgery[80]	To develop value-based digital strategies for remote patient manage-ment in diagnosis & rehabilitation	OGE, MMC, CZE, TU/e (IS, SMPE, ID, USE LL), UM, OnlinePROMS, B.G. Legal. Fontys. PSV? e/MTIC? Philips?	Dept. Orthopaedics MMC, OGE (1 PhD), 1PDEng QMEPDEng
Good Life with Osteoarthritis NL[12, 74] (n=521, April 2021)	Transmural value-based health care for knee and hip osteoarthritis (outcome,	OGE, MMC, VGZ Zinnige zorg, Fontys, PoZoB, regional network 15	OGE, MMC, Fontys, VGZ. Application

	costs, bundled payments). Pilot to be followed by national implementation NL	physioherapist practices, University South Denmark (DK). LUMC?	currently being written (1 PhD)
Digital Twin Knee[81-83]	Mainframe for value-based personalized knee care. Blueprint can be translated to other fields of orthopaedics and medicine	OGE, MMC, CZE, TU/e (BME: OB, IS, CB; IS; USE LL; SMPE), TUTwente, ErasmusMC, OnlinePROMS, Games for Health, RadboudUMC. Fontys, NOV, PSV. Philips? e/MTIC?	Dept. Orthopaedics MMC, OGE, TU/e (3 PhD's). Further options are currently explored
Imaging of knee for biomechanics, cartilage, meniscus and remodeling ACL[29, 34]	To develop new (non-)invasive techniques in ultrasound and photoacoustic imaging for personalized rehabilitation	OGE, MMC, TU/e (BME: OB, BS, CB; USE LL), UMCU. Arthrex, VisualSonics. Philips? e/MTIC?	Applications currently being written (2 PhD's)
Rehabilitation in pediatric ACL injured patients	Develop value-based strategies for personalized rehabilitation in children	OGE, MMC, StAnna, KNGF, PSV, NVA, ESSKA, PAMI. e/MTIC?	Dept. Orthopaedics MMC, StAnna, NVA (1 Postdoc, 1 PhD)
Data platform orthopaedic medicine	To define a data/application structure for a health platform to relate all current orthopaedic/radiology systems	OGE, MMC, TU/e, NOV, Fontys. e/MTIC? Philips?	Dept. Orthopaedics MMC, Fontys, TU/e (SPME) (1 PDEng, 1 postdoc)
Biofeedback technology for personalized rehabilitation	To develop a hometraining easy to use biofeedback tool to stimulate quadriceps training with gamification	OGE, MMC, TU/e (ID), Fontys. e/MTIC? Philips?	TU/e (ID) (1 MSc), 1PDEng QME

Abbreviations:

MMC	Máxima Medical Center Eindhoven
OGE	Orthopedie Groot Eindhoven
UM	Universiteit Maastricht
NVA	Nederlandse Vereniging voor Arthroscopie
FMS	Federatie Medisch Specialisten
NOV-LROI	Nederlandse Orthopaedische Vereniging – Landelijke Registratie Orthopedische Implantaten
KNGF	Koninklijk Nederlands Genootschap voor Fysiotherapie
ESSKA	European Society for Sports Traumatology, Knee Surgery and Arthroscopy
PAMI	Pediatric Anterior cruciate ligament Monitoring Initiative
BME	Dept. of Biomedical Engineering, TU/e
OB,BS,CB	Orthopaedic Biomechanics, BioInterface Science, Cardiovascular Biomechanics (BME, TU/e)
IS;USE LL	InnovationSpace; User, Society and Entrepreneurial Learning line (students from all departments TU/e)
SMPE	School of Medical Physics and Engineering (PDEng Clinical Informatics), Dept. of Electrical Engineering, TU/e
ID	Industrial Design, Dept. of Electrical Engineering, TU/e
UMCU	Universitair Medisch Centrum Utrecht
MUMC+	Maastricht Universitair Medisch Centrum
OCON	Orthopedisch Centrum Oost Nederland
CZE	Catharina Ziekenhuis Eindhoven
LUMC	Leids Universitair Medisch Centrum
UMCG	Universitair Medisch Centrum Groningen
PoZoB	Praktijk ondersteuning Zuid-oost Brabant
e/MTIC	Eindhoven MedTech Innovation Center

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