THINK

Mass Personalization for Medical Device Therapy: How to Go from Successfully Treating One Patient to One Million

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The slow revolution of personalized medicine

In the 16th century, the Belgian anatomist Andreas Vesalius wrote his masterpiece, *De Humani Corporis Fabrica Libri Septem*. It proved to be one of the most significant scientific studies to advance our understanding of the 3D structure in human anatomy. In the centuries following, we evolved from having a generic understanding of macroscopic anatomy to being able to use modern data acquisition technologies to capture individual phenotypes and genotypes, as well as be better able to diagnose and treat patients according to their own genetic makeup. This approach leads to what is often described as *"precision medicine,"* or the ability to cluster patients into strata based on data and develop targeted therapies for subpopulations.

It was only in the 21st century that rapid advances allowed for the fruition of precision medicine in the development of, *"personalized medicine,"* a term that connotes improved prevention and diagnostics, more effective drugs, and increasingly targeted treatments.

Alyssa Glennon, Principal Clinical Engineer at Materialise, noted, "I've never seen an instance where a personalized approach was not better than a traditional approach," referring to her experience in treatments for bone defects with osteotomies planned with precision.

Due to the individualized focus, however, personalized medicine has proven to be a slow revolution as technical, regulatory, legal, ethical, and economic barriers [2; 3] must be overcome in order to take advantage of personalized medicine's promise and introduce further innovations in the healthcare system.

The most recent development–**mass personalization**–seems like a contradiction in terms. Juxtaposing the opposing meanings, however, make sense. Personalization implies a preference or tailored solution at the individual level; mass refers to how scaling the preference can reach a large number of people. Put together, mass personalization perfectly embodies the advantages that singular, personalized medicine cannot fully achieve: a sustainable global healthcare approach.

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One size fits no one

Mass personalization in other industries

Foundational technologies such as cloud computing, additive manufacturing (also known as 3D printing), and AI-based data analysis are opening the doors to disruption in the medical device field by offering entirely new personalization avenues. In other industries, such as eyewear or music, these technologies already enable large-scale personalization, essential to satisfying ever-evolving consumer expectations.

Often termed mass customization in other industries, mass personalization refers to products tailored to individual customer needs. An array of examples can be found in the Configurator Database [3]. Compiling overviews of web-based platforms for mass customization, the ***Configurator Database*** currently contains more than 1,350 entries of customized products, proving mass customization's broad adoption.

Customized products create customer value by modifying **fit** *(Tailored-Fit.com's ski boots* [4]*)*, **function** (personalized eyewear by Materialise uses a uniquely manufactured lens-centered design to improve the wearer's optical experience [5]), **aesthetics** (Timberland lets customers create an individual shoe [6]), **relevance** (Spotify creating personalized playlists based on your listening behavior [7]), or **experience** (Stitchfix offers personalized styling [8]).

These non-healthcare examples illustrate how companies increase customer experience, improve customer loyalty or increase profit margins for high-end products.

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To achieve personalization in healthcare for the masses, overcoming specific challenges are needed in order to build a system where all children born today can have access to the best healthcare available. To prepare for this new reality, Materialise has gathered insight from its 30-year history to demonstrate the medical device industry's progress and opportunity. We determined that five pillars must be addressed in order to realize the benefits of mass personalization in support of the healthcare industry at large: **Health Economics & Regulation; Next-Generation 3D Printed Devices, Cost-Effective & Scalable Operations; Predictive Planning,** and **Personalization at the Point-of-Care**.

Health Economics & Regulation

When is a personalized medical device meaningful and where does it offer value?

Personalization increases device performance in a number of ways: improved patient outcomes, higher predictability, operational efficiency gains, and simplified logistics for better sustainability.

Operational efficiency gains
On average **5-7 minutes** are saved by using a patient-specific instrument approach in TKA versus conventional.

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Higher predictability
When using 3D printed heart models to prepare for congenital heart surgery, **more than 96%** of physicians reported a better understanding of the congenital heart disease. [12]

Improved outcomes
Up to 27% of hip revisions are re-revisions which are 3 times more likely to fail compared to a first acetabular revision. This downward spiral can be broken by personalized hip implants like Materialise aMace with an implant **survival rate of 98%.**

First, increased device performance can lead to improved patient outcomes, fewer complications, and increased long-term survival. The use of 3D-printed patient-specific implants to treat severe hip defects in re-revision cases leads to a high implant survival [9; 10]. Traditional approaches have had high failure rates and push patients towards worse outcomes and decreased satisfaction. A patient-specific implant, on the other hand, can effectively break the revision cycle and yield implant survival rates of up to 98% with two years of follow-up. Patient satisfaction mirrors this upward trend [9]. Similarly, personalization affects patient outcomes with cranio-maxillofacial implants, too. Patient satisfaction vastly improved when personalized guides and models are used during surgery. Using ProPlan CMF guides and models for mandibular reconstruction led to significantly higher satisfaction with their postoperative appearance compared to conventional "free hand" reconstruction; 87% of patients were satisfied with guided surgery results versus only 50% with conventional instrumentation. [11]

Other benefits of personalization include improving predictability and physician peace-of-mind. For complex scenarios (like a congenital heart defect), a 3D-printed anatomical model can be used to determine treatment objectives and techniques, often redefining the surgical approach [12].

Personalization optimizes medical device performance with operational efficiencies, by replacing a broad range of instrumentation with tailored versions. This makes surgery more efficient, but also lowers the cost of operational steps like sterilization. The use of personalized 3D-printed surgical guides for knee arthroplasty is but one example [13].

Economic advantages can be demonstrated from either a hospital or patient perspective. Capturing economic benefits, for example, stems from

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improved operations in logistics flow or supply chain, which in turn reveals hidden opportunities. Personalization can improve logistics and reduce waste. By creating devices only when required by–and specific to–an individual patient, the need to purchase and manage stock is reduced.

Clinical societies can often help in identifying sustainable solutions with the broadest chance of impact. The Special Interest Group for 3D Printing within the Radiological Society of North America (RSNA) advocates using "appropriateness criteria" when creating anatomical models for surgical planning at the point-of-care [14]. Bringing the community together to develop appropriateness criteria for a certain clinical indication accelerates innovation.

When 80 needs to be the new 65

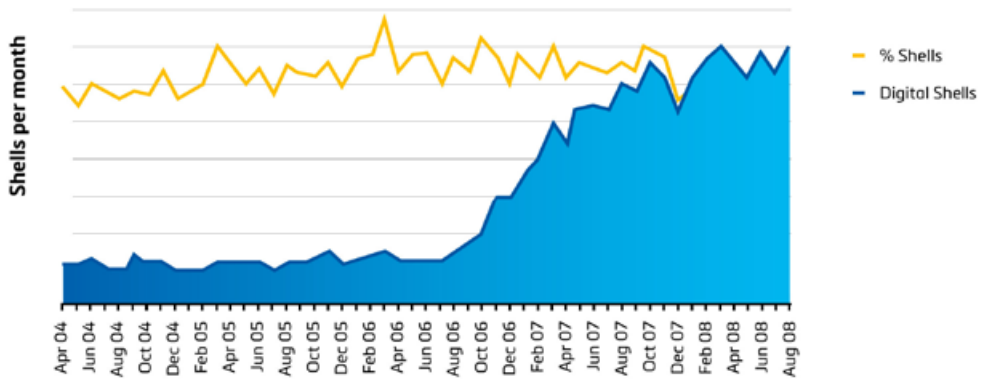

Figure 1:
The introduction of 3D printing pushed digital shell manufacturing for hearing aids to nearly 100% penetration in 2 years

Given the present slate of medical devices on today's market, the overwhelming majority of children born in the 21st century will likely benefit from a personalized treatment. Based on current trends and data, we foresee 75% of these children receiving a personalized medical device at some point during their lifetime [15]. Some device treatments, such as surgical guides or orthodontic aligners, have been widely adopted since their introduction less than 20 years ago. Others, such as 3D-printed hearing aids, took just under three years to transform an entire industry (see Figure 2). Other devices are experiencing consistently higher rates of adoption, such as cranio-maxillofacial implants. Many others, like sleep apnea devices, are still in the early stages of personalization. Figure 2 projects the cumulative chance that any age group will have had treatment with a personalized medical device by 2050.

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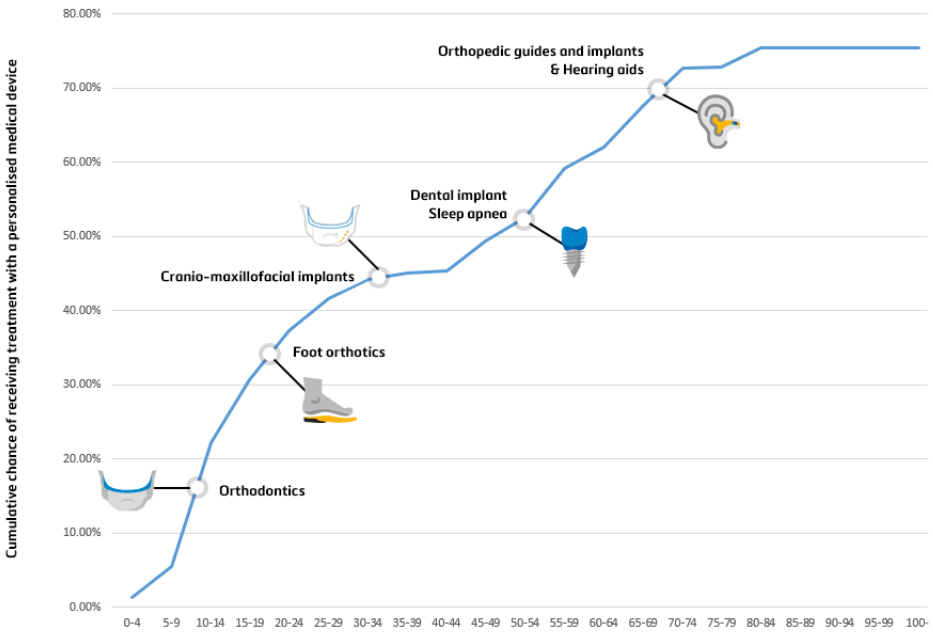
Figure 2:

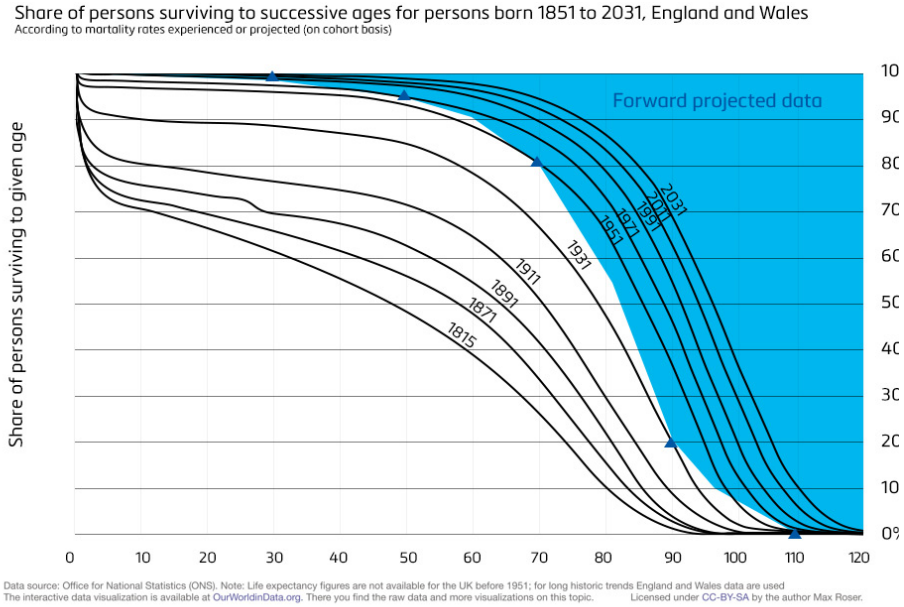
This graph represents the cumulative chance of receiving treatment with a personalized medical device over the course of a lifetime as it is expected to be in 2050 (this means a 20-year-old in 2050 will have a >30% chance, while an 80-year-old will have a >75% chance). Personalized medical devices that have been taken into account for this projection are taken in the field of **orthopedics** (orthotics, implants, guides), **dentistry** (aligners, implants, guides), **cranio-maxillofacial surgery** (implants, guides), **otorhinolaryngology** (hearing aids, sleep apnea), **oncology** (guides, implants), and **cardiology** (valves, stent grafts).



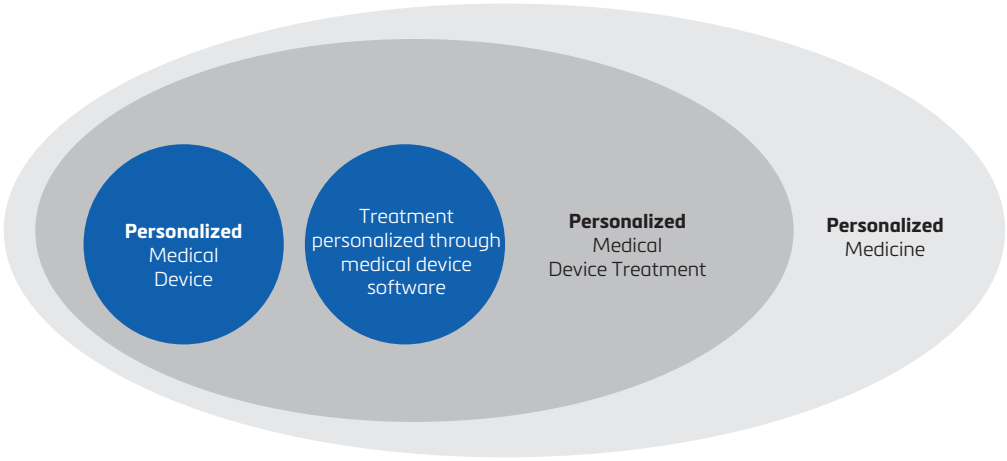
Changing demographics mean substantial barriers to healthcare economics. While it is a sign of progress that every child born after 2000 has a more than 80% chance of seeing their 80th birthday (see Figure 3), at the same time, the annual healthcare expenditure of an 80-year-old is roughly twice that of a 65-year-old [16]. With a healthcare system already under pressure, sustainable personalized healthcare solutions that are both performant and cost-effective are needed to support this shift.

Figure 3:

Projection of life expectancies from birth year. Based on measured data (white region) and projections (blue)[3]



Defining personalization in the medical device context



In "Council Conclusions on Personalized Medicine for Patients," [17] the EU ministers of health defined personalized medicine as:

"A medical model using characterization of individuals' phenotypes and genotypes (e.g. molecular profiling, medical imaging, lifestyle data) for tailoring the right therapeutic strategy for the right person at the right time, and/or to determine the predisposition to disease and/or to deliver timely and targeted prevention."

While there is no doubt that innovations in fundamental biology and biochemistry will continue to disrupt personalized medicine, one aspect often overlooked is the potential of personalization in medical devices. Treatment supported with medical devices has already been a key driver in the demographic growth of the older population, revolutionizing cardiovascular, orthopedic and oncology treatment, among many others.

Applying the broad understanding of personalized medicine to medical devices, we can, in general, define personalized medical device treatment as:

"Any medical device of which its geometry, location, function or material, is determined based on the individual phenotype as assessed based on personal data (medical images, clinical data ...) with the intention of improving the performance of the medical device for the patient."

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As defined below, personalized medical device covers the use of phenotype data to influence the performance of a standard medical device. Often medical device software, like with surgical planning, is used as the foundation of a personalized medical device treatment. Among the many examples are a pacemaker with settings configured based on cardiac measurements, a knee implant set by a surgical robot using intra-operatively acquired anatomical landmarks for planning, or a vascular stent that is deployed using intra-procedural imaging, to name but a few.

The International Medical Device Regulators Forum (IMRDF) has provided a clear definition for a personalized medical device– whether custom-made (fully patient-specific to a physician's prescription), patient-matched (within the design parameters set by the manufacturer), or adaptable (modified at the point-of-care) [18]. Examples include personalized hip implants, surgical knee guides, or cranial reconstruction implants that require thermoforming at the point-of-care.

The medical device can be personalized in a number of ways, usually in regards to form (but sometimes function), behavior, or material that can be tailored to the individual.

In the interest of clarity, we will use the terms personalized medicine, personalized medical device treatment, and personalized medical device throughout this publication as defined above.

Regulation Creates Economic Advantage

By adopting regulatory frameworks, product quality becomes clear to customers. Innovation in regulatory frameworks have allowed to create a more sustainable future for personalized medical devices. For example, Materialise chose to CE mark their patient-specific devices (models, guides and implants) for cranio-maxillofacial surgery. Adoption rates are thus further motivated by operational efficiencies. The CE mark eliminates the need for a written prescription form required for custom-made devices without CE label, and thus reduces the administration and overhead that come with device procurement. Mapping a forward-thinking regulatory strategy will inspire confidence in personalized medical devices inside and outside of health organizations. Choosing tools that are consistent with regulatory process requirements simplifies compliance, too.

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Next Generation 3D-Printed Devices

How to focus your efforts and set your priorities to enable personalization

Developing next generation 3D printed devices starts by identifying suitable applications and technology developments to expand the scope of opportunities.

Three points should be considered in determining appropriate target applications:

1

Compare applications to ascertain which application will make the most difference. It is an exercise that helps pinpoint **WHAT** needs to be personalized and is crucial to identifying unmet clinical needs and the corresponding links to personalization. Patient selection or stratification to narrow the scope of who benefits from the personalized solution will further guide decisions. Patients with severe bone defects who receive a personalized shoulder implant might gain greater limb mobility than a comparable patient who undergoes artificial knee surgery, for example.

2

Understanding **HOW** to personalize so that the final device performance improves patient outcome is also important. This is relatively straightforward in some instances. For example, straightening a bone according to its mirrored counterpart to correct trauma treatment complications. It is much less straightforward in other, more complex systems (e.g. personalizing the articulating surfaces of a knee implant to restore optimal function and eliminate pain).

3

Demonstrating the clinical benefits of the personalized versus standard solution helps people understand **WHY** personalization is needed.
For medical device companies, it is wise to build the infrastructure for personalization by investing in niche and high-value use cases and grow towards more high-volume applications in a later phase. Minimizing variables and confounding factors and ensuring the highest possible gain are two ways the clinical benefits can be more apparent.

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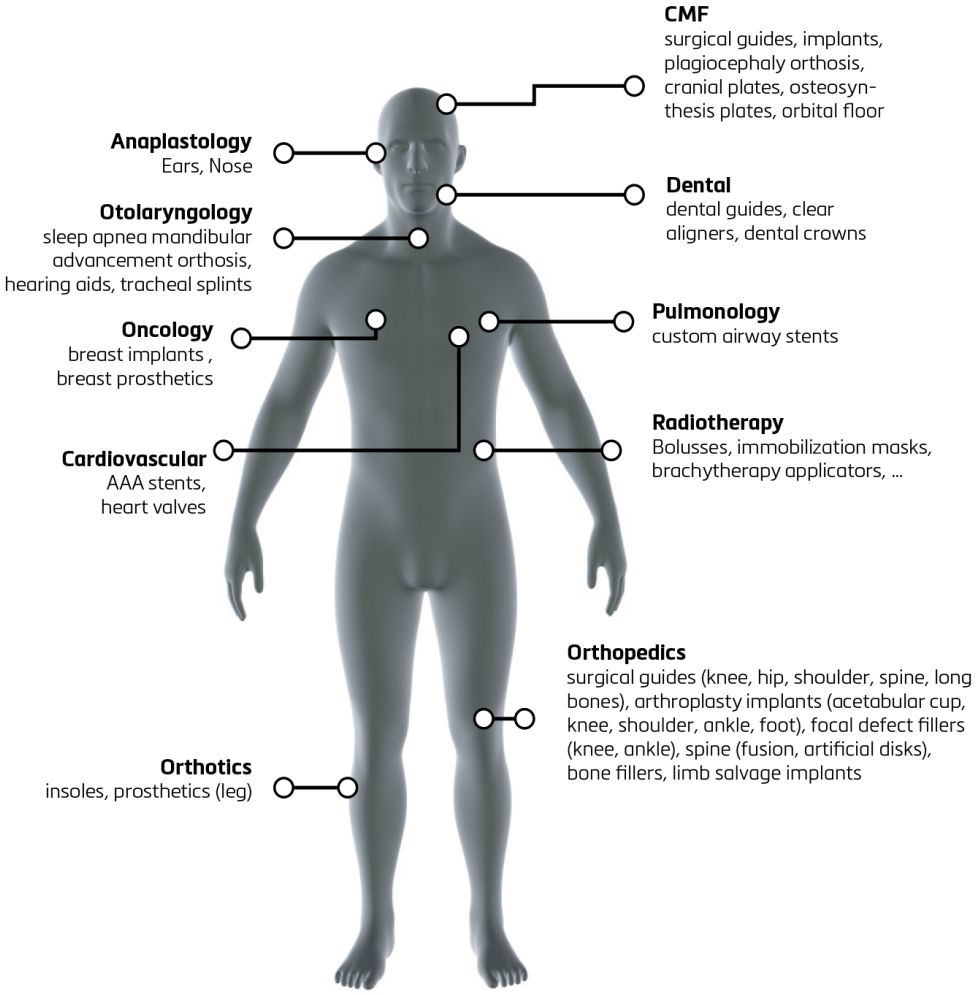
Figure 4:

Examples of medical devices that are personalized today or where we expect them to become personalized in the near future "



Next-generation 3D printing technologies will accelerate manufacturing of personalized devices, with even more advancements. Smaller devices, with embedded mechanisms and functionalities may become possible through technologies that allow printing to micrometer or even nanometer scale.

Material properties will have variables that can be activated and adjusted according to the patient or application. These characteristics are evident in 3D-printed bioresorbable medical devices entering the market, for example in tracheal splints or for long bone graft cages. As knowledge of biologics, tissue engineering and cell regeneration improves, so will the number of developed applications. The impact will be seen in the resulting capacity to treat larger defects, support soft-tissue regeneration, or enable loadbearing applications.
At one point, 3D printing with live cells will become feasible, changing the way we think about implants, organ donation, or tissue regeneration.

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Cost-Effective and Scalable Operations

Cost-effectiveness has three components: the delivered value, the immediate cost encountered and any expected future savings. A personalized approach is not without cost—but that does not mean the expense outweighs the value. The immediate gains of the cost-effective nature of personalized solutions can also be validated over the long-term by building and compiling cases that warrant the cost of a personalized approach.

Nonetheless, the notion that personalization is expensive persists in terms of both time and cost. Companies that have been successful in bringing scalable personalized medical device products to market have demonstrated that there are crucial steps to go from individualized personalization to mass personalization, especially as case volumes grow.

The four key drivers to scale personalization and profit:

1 **Automation** will further the reach of personalized applications by making them more scalable and improving operational cost-effectiveness from the hospital point-of-view. Introducing front-end and back-end systems to process and keep track of cases, supported with AI technologies such as machine learning for data analysis will simplify operations. This will enhance segmentation of medical images, surgical (pre-) planning or QA. Choosing intuitive and powerful tools for data and image handling, process control and manufacturing makes the operational backend for each case efficient and cost-effective.

2 Embrace platforms that **facilitate efficient physician interaction** on personalized patient cases. This means implementing easy-to-use clinical applications which capture physicians' input, as well as provide intuitive ways to communicate, track patients' devices, and monitor their cases. Reducing physicians' barriers to selecting a personalized device or treatment for their patients improves adoption.

3 Create an approach to **streamline data transfer and ensure data quality** at the source. By reducing processing times for personalization workflows, lead times can be kept low and missing cases becomes avoidable. It also helps ensure personalized devices are not competitively disadvantageous with standard devices.

4 Set up **close collaborations** with other medical device companies, hospitals, physicians, technology providers, payers, and regulators. Existing platforms for personalization of medical devices based on medical images will allow medical device developers to deliver their products or services more cost-efficiently, which helps the overall sustainability of the health care system. The right partnerships offer economies of scale, such as with mass personalization. Operational back-end partnerships boost expanding your portfolio with an increasing number of personalized medical devices.

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How to Personalize a Medical Device?

For custom-made and patient-matched medical devices, the approach to personalize a medical device is well understood and is similar across most applications.

First, a treatment objective (final teeth or jaw alignment, foot position, anatomical joint restoration, re-create post-operative kinematics, etc.) needs to be identified based on patient data. The aim should be to achieve better patient outcomes as evidenced by clinical data. Second, the treatment objective is translated into a personalized plan that outlines the steps to achieve the desired outcome. Finally, the personalized plan needs to be converted into a personalized medical device, whether used on a **temporary basis** by a physician (surgical guides, anatomical models, or radiotherapy boluses) or **for extended use** by a patient (orthopedic implants or orthotics).

Medical image data is often the basis for personalization, possibly in combination with other patient data sources. Medical image data can be augmented with computational modeling or AI-based analyses to determine how the personalized device's features might influence device performance.

3D printing is a key technology for manufacturing personalized medical devices because of its inherent quality, design flexibility, and ability to produce unique parts.

Predictive Planning

Predictive planning helps identify how best to personalize a medical device or medical device treatment with data driven technologies (like artificial intelligence, simulation, or modeling). For example, by using population-shape modeling for quantifying patient-specific defects in the shoulder, the broader data assists the physician in determining the optimal resulting implant position. Similarly, by using planning algorithms trained with AI on retrospective behavior, we can learn best practices from expert physicians and propose plans that require much less effort to modify and approve.

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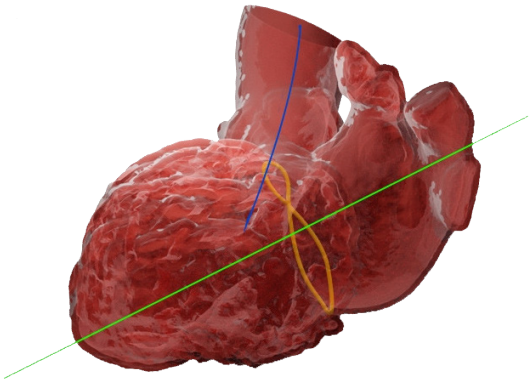
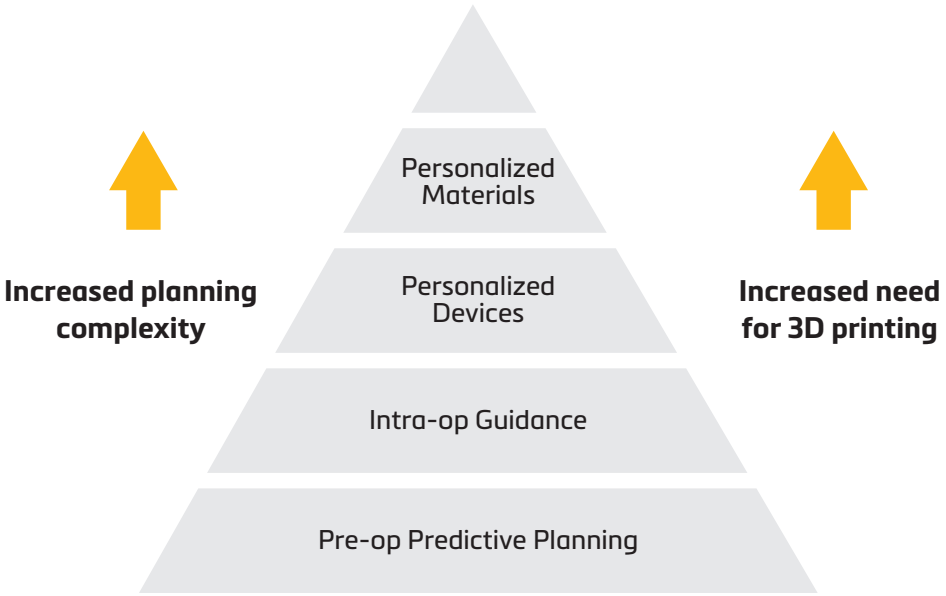
Figure 5:
3D model created from a CT image, superimposed with annotations that drive predictive planning for a trancatheter mitral valve replacement



Clinical metrics play a role in planning, as well. Treatment of aortic outflow tract obstruction is improved by using additional data-driven methods in the mitral valve therapy device planning to optimize the implant location.

Today, predictive planning frequently does not lead to producing a personalized medical device but rather supports personalization of standard medical devices. Outcome data is predicted to be the source of real patient impact in the planning phase. Data will not only change the way a device is positioned in a patient, but will shape the way a device is designed for an individual.



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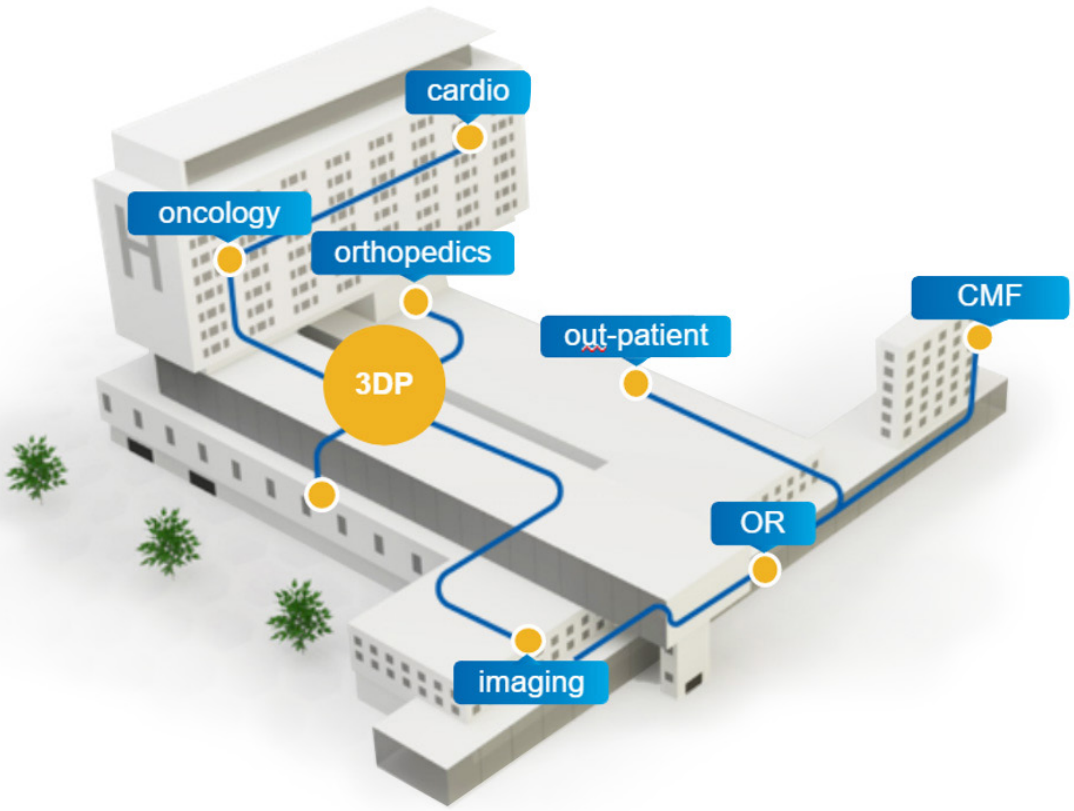
Personalization at the Point-of-Care

Discover the full potential of Point-of-Care 3D Printing

Point-of-care 3D printing is a relatively recent trend where hospitals are bringing 3D printing inside their facilities. Leveraging the intrinsic capabilities of 3D printing to manufacture on-site must be paired with certified workflows to ensure quality—independent of where devices are produced. At Materialise, we are evolving from a personalized medical device being adapted at the point-of-care (adaptable medical devices) to the actual manufacture of a custom-made or patient-matched device at the point-of-care. The latter must take into account the distributed expertise (e.g. for surgical planning) or case logistics (e.g. for lead times).

Digital technologies, such as virtual or augmented reality or robotics, will complement 3D-printed devices (like visualization or navigation after surgical planning). The foundational software technology (3D modeling or planning) used in personalized medical devices will easily transform that data into a digital flow. The scope of personalization can thus be enlarged. One example: adapting surgical planning and navigation using real-time intra-operative data.



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Conclusion

Since sustainable solutions in health care are a crucial step to solving the ever-changing industry demands–from growing populations to stricter regulations and higher expectations–Materialise remains committed to pioneering new personalized medical devices and medical device treatments in the market, driven by a profound understanding of 3D planning and 3D printing technologies. While we design new applications ourselves, we are also developing a supporting software infrastructure that allows our partners and customers to scale personalized applications to the market. We are innovating in domains like automation and predictive planning (with technologies like artificial intelligence) and continue to integrate these developments into our core 3D planning and 3D printing suites. When appropriate, we co-create with our partners to allow these new innovations to expand their product or services offerings. We do all this because we believe that mass personalization enables better, more predictable treatment, which can be made accessible to everyone. We hope that the perspective offered in this paper will help you prepare for this new reality and that you will join us in this journey.

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About Materialise

Materialise is a global 3D printing software and services company whose medical division is dedicated to enabling researchers, engineers and clinicians to revolutionize patient-specific treatment that improves and saves lives. Our open and flexible platform, Materialise Mimics, forms the foundation of certified Medical 3D Printing and incorporates a comprehensive range of software solutions and 3D printing services. With over 30 years of excellence, we work alongside our customers in healthcare, automotive, aerospace, consumer goods, art and design, to build groundbreaking 3D printing applications that make the world a better and healthier place.

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