Dear friends and colleagues,

Thank you very much for attending the "3D+ Heart United (3DHU) Workshop" today.

Two years ago, I participated in the "8th World Congress of Pediatric Cardiology and Cardiac Surgery (WCPCCS)" held in Washington, D.C. During its educational session, I was deeply impressed by Dr. Diane Spicer instructing with physical specimens in hand, while Dr. Andrew Cook conducted morphology education in a virtual reality space, wearing a head-mounted display. This was my first experience observing congenital heart disease models through VR, and during the social gathering, I had the opportunity to meet domestic and international colleagues interested in VR and 3D printing.

Since then, we have continued to strengthen our connections through regular web meetings, sharing applications of advanced imaging technology and case studies. Furthermore, Dr. Shiraishi has joined this group upon their suggestion, enriching our discussions significantly.

This workshop, "3D+ Heart United (3DHU)," was realized following Dr. Ryan Moore from Cincinnati Children's Hospital's proposal last autumn to organize a workshop on congenital heart disease utilizing VR technology during his visit to Japan for the Star Wars fan event in Makuhari scheduled for April 2025. Unfortunately, due to reductions in subsidies for universities and pediatric hospitals under the current U.S. administration, Dr. Moore will not be able to attend in person this time but will join us online.

This workshop focuses on the application of "3D+ technologies" (VR: virtual reality, AR: augmented reality) for diagnosing, preoperative simulations, educating, and researching congenital heart diseases. We will introduce actual use cases from countries such as the U.S., Israel, India, and Colombia through lectures, and the workshops will allow participants to experience these technologies firsthand. Additionally, a social gathering will be held on the night of the 26th to deepen exchanges with domestic and international experts.

I sincerely hope that this workshop will contribute not only to the treatment of congenital heart diseases in Japan but also to the broader promotion of VR, 3D printing, and AR technologies in the medical field.

Yours sincerely,

Masaki Kodaira (Keio University)

Isao Shiraishi (National Cerebral and Cardiovascular Center)

Fusion of Real and Virtual: A Novel Supporting System for Congenital Heart Disease Surgery using 3D Replicas and Computer Simulations

Shiraishi I[1)], Kurosaki K[1)], Iwai S[1)], Washio T[2)], Sugiura S[2)], Hisada T[2)].

National Cerebral and Cardiovascular Center, Suita, Japan[1)].

The university of Tokyo Graduate School of Frontier Sciences, Kashiwa, Japan[2)].

Accurate understanding of the 3D anatomical structure is critical for successful surgical intervention in complicated congenital heart disease (CHD). We have developed precise and super-flexible polyurethane replicas of CHD by using the stereolithography 3D printing followed by vacuum casting. As a result, the heart replicas were approved as medical devices in Japan. We then conducted a physician-led clinical trial. The criteria of the primary endpoints were fully met, and the super-flexible 3D heart model will be covered by the national insurance system this year. The effectiveness of the support system was then further enhanced by adding a functional analysis capability. Namely, a novel computer simulation system exclusively for pediatric CHD called "ped UT-Heart" was developed, in which hemodynamics, wall motion and valve motion, and electrophysiology are simulated by a patient-specific finite element heart model to compare different types of surgical procedures before real surgery. We are now preparing a multicenter clinical trial to prove its usefulness and efficacy. In conclusion, a fusion system of real simulation (super-flexible 3D heart replicas) and virtual simulation (ped UT-Heart) could be a promising and ideal supporting medical device for surgery of intractable complicated CHD.

Takumi Washio (The University of Tokyo Graduate School of Medical Frontiers)

The development of these devices was carried out in collaboration with crossMedical Co. Ltd, Japan Medical Device Corp, UT-Heart Inc, and Q'sfix Corp.

Advancing Pediatric Cardiology Through Multimodal Imaging and 3D+ Technologies

In this talk, we present an overview of the ped UT-Heart simulator, focusing on both pre-processing and heartbeat calculation. In the pre-processing stage, predicting the twisted fiber structure and the parameters of blood circulations outside the heart is essential for accurately assessing cardiac outputs. To calculate the heartbeat, we simulate the cooperative stochastic behavior of motor proteins to reproduce the relationship between mechanical stress and muscle contraction velocity, resulting in accurate time transients for blood pressure and volume in individual patients. We will discuss how we use the simulator to enhance both clinical treatments and our fundamental understanding of heart function.

Mahesh Kappanayil (AIMS, Kochi, India)

I shall speak about how we established South Asia's first POC 3D Lab at Amrita Institute, Kochi, India, almost 10 years ago. I will describe the challenges, rewards, and impact through case studies. This talk will cover our pioneering journey through 3D printing and how it eventually led to the establishment of the Extended Reality Lab.

https://www.amritahospitals.org/kochi

Hirofumi Seo (SCIEMENT, Inc.)

Does ultrafast, ultra-beautiful 3DCG reconstruction from medical images change anything?

3DCG reconstruction from CT and MRI images is already widely used in clinical practice. However, while AI-driven imaging techniques receive much attention, most 3DCG seen in hospitals still appears outdated and difficult to interpret. Unlike game graphics, these models cannot be freely manipulated in real time and are often limited to pre-rendered sequences.

To address this, I developed Viewtify®, a software that intentionally avoids advanced image processing, focusing instead on generating extremely fast and visually appealing 3DCG from medical images. It lacks features like volume calculation or simulation but allows real-time interaction with even 4DCT data.

Moreover, Viewtify supports commercial glasses-free stereoscopic displays, enabling users to experience anatomically accurate models with a real sense of depth—like having a moving organ model in front of them.

This presentation explores what may change when 3DCG becomes “ultrafast” and “ultra-beautiful,” using real pediatric cardiac CT cases as examples.

David Buyck (University of Minnesota)

This talk presents our work at the University of Minnesota's Visible Heart Lab, where we are reshaping cardiac education through free virtual reality (VR), augmented reality (AR), and mobile applications. Built from high-resolution anatomical imaging—including micro-CT and structured light scans—our applications provide globally accessible, clinically relevant, and anatomically accurate 3D heart models. These tools bridge theoretical understanding and real-world practice by simulating both healthy and diseased cardiac states, integrating interactive features such as blood flow visualizations, medical devices, and layered anatomy. Used in over 100 countries, including underserved regions, this technology enables scalable, interdisciplinary education for medical students, physicians, device professionals, and patients. This session will highlight the software innovations behind these tools, demonstrate global use cases, and outline the future potential of immersive medical education.

Yoshie Ochiai (JCHO Kyushu Hospital, Department of Pediatric Cardiovascular Surgery)

We report a case of double outlet right ventricle (DORV) of the transposition type with subpulmonary ventricular septal defect (VSD) following pulmonary artery banding, in which a preoperative 3D-printed model based on CT imaging was used to visualize the VSD patch closure line, the arterial switch procedure, and coronary artery transfer prior to the intracardiac repair. The patient was an 11-month-old boy weighing 7.15 kg. Surgery was performed according to the preoperative simulation using the 3D model, including intraventricular rerouting (IVR), so called large VSD closure, arterial switch operation (ASO), and coronary transfer. Following weaning from cardiopulmonary bypass, the patient developed respiratory and circulatory failure necessitating emergent extracorporeal membrane oxygenation (ECMO) support. The cardiac catheterization under ECMO revealed functional mitral stenosis (MS) unexpectedly. To save this patient, mitral valve replacement was performed successfully. We speculate that the sudden reduction in left ventricular volume after ASO and IVR resulted in the development of functional MS. Although the 3D model was very useful for preoperative planning of the intracardiac repair for DORV, unexpected postoperative functional MS occurred.

<u>Carlos Eduardo Guerrero-Chalela (Congenital Heart Disease Institute, Fundación Cardioinfantil – Instituto de Cardiología, Bogotá, Colombia)</u>

Title: 3D+ Experience in a Resource-Limited Setting: Impact on Care

Speaker: Carlos Eduardo Guerrero-Chalela, MD[2]

Authors: Camilo E. Pérez-Cualtán, PhD (c),[1,2], MD[2], Camila Castro-Páez, MSc,[1,2], Juan Manuel Pérez, MD[2,4], Carlos Eduardo Guerrero-Chalela, MD[2,3], Juan Carlos Briceño, PhD,[1,2], Javier Navarro-Rueda, PhD,[2,5].

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Integrating Three-Dimensional Plus (3 D +) technologies into healthcare transforms the landscape of education, diagnosis, and intervention, particularly in complex fields such as congenital heart disease (CHD). We present the experience of establishing a pioneering 3D+Center in Latin America, focusing on the structured implementation process, its educational impact on healthcare professionals, real-world clinical applications, and a comprehensive cost analysis. Establishing a 3 D + Center involved strategic planning, infrastructure development, and interdisciplinary collaboration among engineers, physicians, and educators. Key steps included acquiring advanced imaging and modeling software, training staff, and establishing workflows for converting medical images into high- fidelity 3 D- printed and virtual models. In education, the 3D+ Center developed tailored programs for cardiologists, surgeons, and medical students, enhancing their understanding of complex CHD anatomy and improving communication within multidisciplinary teams. Over 60 professionals have been trained through hands-on sessions and digital simulations using patient-specific models. Clinical applications included more than 30 CHD cases where 3D+ models guided surgical planning, interventional cardiology procedures, and patient-family counseling. Notably, these models contributed to changes in surgical strategy in 50% of cases; the 3D models changed the procedure's plan and/or approach. More than 90% of participants agreed that 3D models could better predict complications or unexpected findings before the procedure than 2D imaging. A cost analysis with 3D+ assisted approaches showed a significant reduction in operative time and intraoperative decision-making, with a 61% reduction in medical and surgical materials costs, a 5% reduction in hospital stay costs, and reduced surgical times and hospital stays. This experience highlights the feasibility and clinical value of implementing 3 D + Centers in resource-limited settings, supporting a broader vision of precision medicine and advanced education in Latin America.

Workshop: "Use of 3D Printing Models for Surgical Planning:

Title: 3D Printing in South America: Integrating Patient-Specific Planning, Realistic Simulation, and Device Innovation

Speaker: Carlos Eduardo Guerrero-Chalela, MD[2]

Authors: Camilo E. Pérez-Cualtán, PhD (c), MD[12], Camila Castro-Páez, MSc[12], Juan Manuel Pérez, MD[24], Carlos Eduardo Guerrero-Chalela, MD[23], Javier Navarro-Rueda, PhD[25], Juan Carlos Briceño, PhD[12]

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Abstract:

Three-dimensional (3D) printing technologies are transforming the diagnosis, planning, and innovation in congenital heart disease. This abstract outline our experience with 3D printing for three distinct case series and introduces two technological innovations derived from clinical needs.

First, we developed a patient-specific descending aortic printed model using high-resolution imaging and anatomical segmentation for treating a complex abdominal aorta aneurysm requiring a patient-specific prosthetic graft. The model was printed with a composite flexible-rigid material to optimize sizing, orientation, and prosthetic anchoring, enabling a tailored solution for complex aortic reconstruction.

Second, we explored the feasibility of 3D printing coronary arteries in a cohort of 26 patients. Of them, 19 had anatomical features amenable to 3D modeling. The printed models evaluated vessel course, external compression, and preoperative simulation. This study provided insights into coronary artery segmentation's limitations and clinical thresholds, especially in smaller, tortuous vessels.

Third, a simulation protocol that compares porcine right ventricular outflow tract (RVOT) models, chosen for their anatomical and mechanical similarity to human tissue, evaluates the circumferential strength of the pulmonary annulus against different types of commercially available digital 3D printing materials. This simulation aids in understanding the interaction between RVOT models and pre-procedural balloon sizing, fit testing, and valve selection. Finally, a finite element model is being developed to assess frame-tissue interaction during valve deployment, providing a predictive tool for procedural success and potential complications.

In parallel, two innovations emerged from our 3D printing center. The first was designing and patenting a novel catheter specifically tailored for cannulating a patent ductus arteriosus (PDA). This innovation was tested using a custom-printed aorta-pulmonary-PDA model made of flexible material mimicking vascular compliance. The second innovation involved creating in-hospital 3D-printed solutions to address urgent needs for non-clinical devices, paving the way for a manufacturing hospital and aiding in cost savings.

These cases and innovations demonstrate the versatility and growing clinical relevance of 3D printing in an in-hospital resource-limited setting, offering a unique bridge between patient-specific planning, realistic simulation, and device innovation.

Workshop: "Different Use of VR: From Medical Simulators to Education"

Title: Initial Experience with a Multi-user Educational Tool for Cardiac Anatomy and Congenital Heart Disease Utilizing Virtual Reality

Speaker: Carlos Eduardo Guerrero-Chalela, MD[2]

David Buyck, MS[1], Camilo E. Pérez-Cualtán, PhD (c)[23], Camila Castro-Páez, MSc[23], Kevin Muñeton, MD[1], Juan Manuel Pérez, MD[35], Javier Navarro-Rueda, PhD[36], Juan Carlos Briceño, PhD[23], Paul Iaizo, PhD[1], Maski Kodaira, MD[7], Carlos Eduardo Guerrero-Chalela, MD[34]

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Virtual reality (VR) is emerging as a "sandbox"-type controlled environment that allows for the manipulation of complex cardiovascular pathologies, such as congenital heart disease

(CHD), in a safe setting. This approach facilitates interaction with three-dimensional anatomical structures without directly intervening with the patient or altering diagnostic outcomes, ensuring practical and risk-free learning. Understanding the three-dimensional anatomy of CHD can be challenging using two-dimensional images alone, making VR a promising tool to enhance medical education in this field.

This study evaluated the effectiveness of VR compared to traditional 2D imaging methods for teaching CHD. 3D models were reconstructed from computed tomography (CT), cardiovascular magnetic resonance imaging, and micro-CT data using Mimics and 3-Matic software. Expert radiologists reviewed the models and adapted them for use on Oculus Quest 2 VR headsets via Unity. Three academic courses involved general practitioners, sonographers, pediatric intensivists, cardiologists, anesthesiologists, and residents. Each course included 2D images and VR sessions, Likert scale surveys, and knowledge tests.

A total of 64 participants completed the Likert scale surveys. Statistical analyses indicated significant differences in participants' perceptions between 2D and VR methods:

- Morphological identification: Significant improvement with VR ($r = 16.5$, $p = 1.215\times10^{-6}$).

- Defect understanding: Although statistically significant ($p = 1.056\times10^{-9}$), the practical improvement was limited ($r = 2.5$).

- Spatial relationships: Moderate increase with VR ($r = 1.125$, $p = 1.948\times10^{-9}$).

- Proportions and measurements: Major improvement with VR ($r = 17.6875$, $p = 6.898\times10^{-7}$).

- Communication of findings: Moderate to large improvement ($r = 12.0625$, $p = 1.524\times10^{-6}$).

Kruskal-Wallis analysis showed no significant differences in perception between specialties, except for communication of 3D findings ($p = 0.01787$).

A total of 30 participants completed the knowledge tests. In these assessments ($n = 30$), participants demonstrated significant improvement after the VR session ($p < 2.2\times10^{-16}$), with an average score increase of 4.37 points.

Virtual reality significantly enhances the understanding of congenital heart disease, particularly in morphological identification, anatomical measurements, and communication of findings. These results support VR as an effective complementary educational tool compared to traditional methods of medical teaching.

Shai Tejman-Yarden (Sheba Medical Center, Israel)

Dr. Shai Tejman Yarden is a pediatric cardiologist form Sheba Medical Center in Tel Aviv. He has degrees in both the medical field and bioengineering, and he heads the Engineering in Medicine lab in the ARC Innovation Center in Sheba. His Lecture will focus on the different studies his crew has performed using virtual reality for cardiac anatomy and the various innovations coming out of the collaborations with the industry and the academic institutions regarding augmented reality for medical use other than cardiology.

Ben M. Maoz (Department of Biomedical Engineering, Sagol School of Neuroscience Head of the Drimmer-Fishler Core for Personalized Medicine, Tel Aviv University)

Title: New tools for studying human physiology

Between 60 to 90% of the drugs that successfully pass animal trials fail in human clinical trials. This poor statistic demonstrates the urgent need for a human-relevant model. Micro-engineered cell culture models, termed Organs-on-Chips, have emerged as a new tool to recapitulate human physiology and drug responses. Multiple studies and research programs have shown that Organs-on-Chips can capture the multicellular architectures, vascular-parenchymal tissue interfaces, chemical gradients, mechanical cues, and vascular perfusion of the body. Accordingly, these models can reproduce tissue and organ functionality and mimic human disease states to an extent thus far unattainable with conventional 2D or 3D culture systems. In this talk, we will present a number of physiological insights that can be achieved using this technology and to correlate it with clinical data.

Title: **Future of 3D printing**

3D bioprinting is redefining regenerative medicine with innovations that blend engineering precision and biological complexity. Cutting-edge advances in this field have dramatically improved print resolution, material versatility, and multi-cellular integration. New bioinks – from tunable hydrogels to decellularized matrix composites – allow the printing of tissue scaffolds that closely mimic the native heart tissue environment. High-resolution techniques like light-based bioprinting and micro-extrusion enable cell-level precision, placing living cells with microscale accuracy. These breakthroughs now make it possible to fabricate multi-layer, multi-cellular structures (e.g. myocardium with pre-formed vascular networks) that were once science fiction.

On the clinical front, bioprinted cardiac tissues and vascular constructs are rapidly progressing from lab prototypes to applications in cardiology. Engineered heart tissue patches, printed with patient-derived cells, show promise for repairing damaged myocardium after a heart attack, beating in sync with native tissue. Likewise, 3D-printed vascular grafts and valve implants tailored to patient-specific anatomy could revolutionize the treatment of heart disease, improving integration and reducing rejection. This talk will highlight how such bioprinting innovations are being translated from bench to bedside. By fusing cutting-edge technology with clinical insight, 3D bioprinting stands poised to transform cardiovascular care, heralding a new era in regenerative medicine and translational cardiology.

Agenda

Day 1: April 25th, 2025

9:00 Opening remarks by Masaki Kodaira

9:00 - 09:25 Opening lecture

"Building the Congenital Heart Surgical Mediverse with Multiplayer Gaming Networking & Real-Time 3D Engines"

- Moderator: Naritaka Kimura (Keio University, Japan)
- Virtual Speaker: Ryan Moore (Cincinnati Children's Hospital, USA)

9:25-9:50

Keynote Presentation: "Use of Advanced Imaging for Congenital Heart Disease Surgery"

- Moderator: Naritaka Kimura (Keio University, Japan)
- Virtual Speaker: David Hoganson (Boston Children's Hospital, USA)

9:50 - 10:30 Keynote Presentation:

"Cardiac 3D from start to the beginning "

- Moderator: Masaki Kodaira (Keio University, Japan)
- Speaker: Shai Tejman-Yarden (Sheba Medical Center, Israel)

10:30 - 11:15

Lecture: "Advancing Pediatric Cardiology Through Multimodal Imaging and 3D+ Technologies"

- Keynote speaker: Isao Shiraishi (National Cerebral and Cardiovascular Center, Osaka, Japan) 20min
- Keynote speaker: Takumi Washio (The University of Tokyo Graduate School of Medical Frontiers) 20min

11:15 - 12:00

Workshop: "From CT to 3D print"

- Speaker: Netanel Nager
- Panelists:
    - Mahesh Kappanayil (AIMS, Kochi, India)
    - Carlos-Eduardo Guerrero-Chalela (FCI-LC, Bogotá, Colombia)
    - Shai Tejman-Yarden (Sheba Medical Center, Israel)

Main Hall

12:00 - 13:30 Lunch Break

Lounge room

12:30 - 13:30 Workshop: Advanced 3D Visualization and Planning in Congenital Heart Disease

Afternoon Session

Main Hall

13:30 - 14:15

Workshop: "Different Use of VR: From Medical Simulators to Education"

- Facilitator: Masaki Kodaira (Keio University, Japan) & Carlos-Eduardo Guerrero-Chalela (FCI-LC, Bogotá, Colombia)

14:15 - 15:00

Case Study Presentation: "Point-of-Care (POC) 3D+ Lab in a University Hospital in Asia - Real Life Case Studies - Challenges and Impact."

- Moderator: Hiroyuki Yamagishi (Keio University, Japan)

- Speaker: Mahesh Kappanayil (AIMS, Kochi, India)

15:00 - 15:45

Plenary Lecture: "3D+ experience in a resource limited settings: impact on care"

- Moderator: Terunobu Fukuda (Kobe University)
- Speaker: Carlos-Eduardo Guerrero-Chalela (FCI-LC, Bogotá, Colombia)

15:45 - 16:00

Coffee Break

16:00 - 16:45

Keynote Presentation: "New tools for studying human physiology"

- Moderator: Masaki Ieda (Keio University, Japan)
- Speaker: Ben Maoz (Tel Aviv University, Israel)

16:45-17:00

"Transforming Congenital Heart Disease Planning: Precise Decisions with Interactive 3D Insights?"

Speaker：Beatriz Dominguez Gonzalez

Day 2: April 26th, 2025

Main Hall

8:00 – 9:00 David VR workshop

Morning Session

Main Hall

9:00 - 09:20

Non-Clinical Virtual Speaker, the developer point of view: “Accelerating the Evolution of Medical Training: Pioneering Software Solutions for the Future.”

- Moderator: Carlos-Eduardo Guerrero-Chalela (FCI-LC, Bogotá, Colombia)
- Speaker: David R. Buyck (Minnesota, USA)

9:20-9:40

Keynote Presentation: "Emerging Trends in XR and 3D Printing for Cardiovascular Research"

- Moderator: Keisuke Sato (Shizuoka Children Hospital)
- Speaker: Mahesh Kappanayil (AIMS, Kochi, India)

09:40 - 10:30

"3D+ beyond reality MR, holograms and haptics."

- Moderator: Masaki Kodaira
- Speaker: Hirofumi Seo (SCIEMENT, Tokyo, Japan)
- Speaker: Shai Tejman-Yarden (Sheba Medical Center, Israel)
- Panelist: Mahesh Kappanayil (AIMS, Kochi, India), Keisuke Sato (Shizuoka Children Hospital)

10:30 - 11:00

Panel Discussion: "Future of 3D printing”

Speaker: Ben Maoz (Israel)

- Panelists: Mahesh Kappanayil (India), Keiichi Itatani (Japan), Yujiro Kawai (Japan)
- Moderator: Shai Tejman-Yarden (Israel)

11:00-11:30

Workshop: "Customizing 3D Models for Patient-Specific Care"

- Moderator: Keisuke Sato (Shizuoka Children Hospital)
- Facilitator: Mahesh Kappanayil (India)

Main Hall 11:30-13:00 Lunch Break

Lounge room 12:00 -13:00 Workshop: Advanced 3D Visualization and Planning in Congenital Heart Disease

Afternoon Session

Main Hall

13:00 - 13:35

Workshop: "Use of 3D Printing Models for Surgical Planning: Cases in Japan"

- Speaker: Isao Shiraishi (Japan)

13:35 - 13:50

Workshop: "Use of 3D Printing Models: Cases in South America"

- Speaker: Carlos-Eduardo Guerrero-Chalela (FCI-LC, Bogotá, Colombia)

13:50-14:10

Workshop: "Use of 3D Printing Models for Surgical Planning: Cases in Israel"

- Speaker: Shai Tejman-Yarden (Israel)

14:10 - 14:50

Interactive Lecture: "Innovations in Interaction Design for Cardiac Simulations"

- Moderator: Isao Shiraishi (Japan)
- Speaker: Keiichi Itatani (Japan)

14:50 - 15:00

Coffee Break

15:00 - 15:15

Co-hosted Session with Canon:

Lecture “CT Imaging for VR and 3D Printing.”

15:35 - 15:50

“4D Imaging for The Management of Congenital Heart Disease”

- Moderator: Masaki Kodaira
- Speaker: Satoshi Asano (Nagano Children Hospital, Japan)

15:50 - 16:20

"A case of intracardiac DORV repair in which the preoperative 3D model was useful for surgical planning"

- Moderator: Isao Shiraishi
- Speaker: Yoshie Ochiai

16:20 - 16:50

Closing Panel: "Uniting Global Efforts: The Role of 3D+ in Transforming Cardiac Healthcare."

- Panelists:
    - Mahesh Kappanayil (AIMS, Kochi, India)
    - Isao Shiraishi (Japan)
    - Keiichi Itatani (Japan)
    - Carlos-Eduardo Guerrero-Chalela (Colombia)
    - Shai Tejman-Yarden (Sheba Medical Center, Israel)
- Moderator: Masaki Kodaira (Japan)

17:00 Closing remarks by Masaki Kodaira