In an average lifespan of 80 years, the heart beats ≥2.5 billion times and ejects ≈200 million liters of blood into the circulation. This amazing performance is slowly, but progressively reduced with age because of a concurrent loss of cardiomyocytes without meaningful regeneration. Pathological events, most dramatically presenting as myocardial infarction, expedite cardiomyocyte loss and consequently cause contractile dysfunction leading to heart failure.

Common treatment includes pharmacological protection from neurohumoral overstimulation and mechanical circulatory support; neither is addressing the underlying problem of cardiomyocyte loss. In end-stage heart failure and only in a stringently selected patient population, that is ≈2500 patients in the United States, heart transplantation is performed with excellent results. Despite the urgent need for a broader application leading to heart failure, there is little reason to assume that these numbers will increase in the future. Hence, there is a clear unmet need for alternative strategies to advance the present state-of-the-art in the clinical management of patients with end-stage heart failure.

Therapies aiming at the biological regeneration of the heart by remuscularization address the underlying cause of the disease in a straight forward; however, clinically not yet accomplished way by (Figure) (1) implantation of cardiomyocytes, cardiac progenitor cells, or other cells with cardioprotective paracrine activity,1–5 (2) changing the fate of the myocardial scar’s stroma cells toward a cardiomyocyte lineage by in situ reprogramming,6 or (3) tissue engineered heart repair with the aim to create structurally and functionally defined surrogate heart muscle in vitro for precise applications in vivo.7

Cell sheet and hydrogel-based tissue engineering modalities are undoubtedly most advanced toward clinical application. The arguably most comprehensive variant of tissue engineered heart repair was originally proposed by Ott et al10 in 2008, that is the recreation of a full heart transplant by the recellularization of a decellularized donor heart; proof-of-concept was provided in a rat model. In the present study, Guyette et al12 retrieved 73 nontransplantable human hearts from the New England Organ Bank and subjected 40 of them to a SDS/Triton-X100 decellularization protocol for subsequent recellularization. Together with an earlier study by Sánchez et al,13 which included 52 human hearts from the Spanish National Transplant Organization, there is now compelling evidence from 2 independent laboratories for the feasibility of effective decellularization of human hearts under defined conditions. Although Sanchez et al13 demonstrated partial recellularization with c-kit+ cardiac progenitor cells, bone marrow–derived mesenchymal stem cells, human umbilical cord endothelial cells, H9c2 rat cardiomyocytes, and mouse HL-1–derived myocytes, the study by Guyette et al12 demonstrated for the first time the applicability of bona fide human cardiomyocytes derived from induced pluripotent stem cells. By a rigorous experimental study design, Guyette et al12 demonstrated that these cardiomyocytes would adhere to the decellularized myocardium, form force-generating muscle, and in case of whole heart recellularization with 500 million cardiomyocyte contribute to left ventricular compression. Despite the low pressures generated by the recellularized left ventricle (2.4±0.1 mm Hg), Guyette et al12 succeeded in demonstrating that remuscularization of the decellularized human heart is feasible. However, these results also suggest low cell retention, which would be in line with studies on direct cell injection into the beating heart and suboptimal functional organization. Considering that the human heart contains ≈4 billion cardiomyocytes,14 structurally organized to overcome diastolic pressures of at least 80 mm Hg, Guyette et al12 are facing a paramount challenge in the re-engineering of hemodynamically relevant function. Additional challenges include (1) the decoration of the denuded vascular bed, including large vessels and most importantly capillaries, with the appropriate surface lining by endothelial cells and in case of the larger arteries and arterioles smooth muscle cells, (2) recreation of a conduction system for coordinated electrical activation, and (3) development of pliable heart valves with documented longevity under the physiologically relevant hemodynamic load.

Taken together, it seems fair to conclude that stripping the human heart off its cellular components is a relatively easy task, whereas recellularization in a tissue-specific context with appropriate function is less trivial. The Ott laboratory will without doubt continue to pioneer the field of organ decellularization followed by recellularization to overcome the above-mentioned caveats. Not only the tissue engineering community will be looking forward with interest and excitement to the solutions, addressing the fundamental challenges on the way to a fully remuscularized heart transplant. Whether this has to involve the decellularization and recellularization...
of a human heart or may alternatively involve readily accessible large animal hearts to meet the increasing clinical demand remains to be elucidated. In addition, the suggestion of an autologous therapy will likely have to be reconsidered for an allogeneic approach because of the anticipated, and recently documented, attrition in the development of autologous induced pluripotent stem cells for myocardial repair from within and outside. Circ Res. 2013;113:922–932. doi: 10.1161/CIRCRESAHA.113.300216.


References


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It was recently noticed that the first sentence of the *Circulation Research* editorial by Wolfram-Hubertus Zimmermann (Strip and Dress the Human Heart. *Circ Res*. 2016;118:12–13) contained an error. The correct sentence is as follows:

“In an average lifespan of 80 years, the heart beats >2.5 billion times and ejects ≈200 million liters of blood into the circulation.”

The error has been corrected in the online version of the article, which is available at http://circres.ahajournals.org/content/118/1/12.full