Cardiac Assistance From Skeletal Muscle: Therapeutic Electrical Stimulation In The Management Of Heart Failure

Cardiovascular disease is the major cause of mortality and morbidity in the industrialized world. Although death rates from coronary heart disease have been declining, heart failure, which is usually the consequence of obstruction of the coronary arteries, is on the increase. Heart failure is a progressive, debilitating condition that accounts for a high proportion of hospital admissions and readmissions. For some years the only surgical option for treating heart failure has been cardiac transplantation. Unfortunately fewer donor hearts are becoming available, and the number of transplantation operations performed has therefore been falling year by year, despite rising demand. Many patients cannot meet the strict age and other criteria for transplant surgery. Of those who are placed on the waiting list, 25–30% die before a suitable donor is found. Even for those who receive the operation, transplantation may not be a perfect solution. Transplanted hearts often fail through rejection or accelerated narrowing of the coronary arteries. Lifelong use of immunosuppressive drugs is expensive and not without side-effects, which include susceptibility to infection. Xenotransplantation—the use of donor hearts from other species, such as genetically modified pigs—could relieve the problem of donor shortage but poses risks of porcine virus infection and would call for massive immunosuppression. Total artificial hearts and left ventricular assist devices carry a risk of thrombus formation, suffer from a high infection rate, and depend on external power supplies; they are therefore used only as a bridge-to-transplant. Thus there is a growing need for a viable alternative to current surgical approaches to heart failure.

The idea of using muscle from a patient's own body to assist his failing heart is far from new. However, early attempts failed because skeletal muscle could not be made to work incessantly without becoming fatigued. The discovery of the adaptive capabilities of skeletal muscle [1, 2] has now made this approach feasible. Skeletal muscle that has been transformed (or 'conditioned') by stimulation, is so fatigue-resistant that it can perform cardiac levels of work on a continuous basis [3].

The surgical procedure known as cardiomyoplasty [4-7] uses the latissimus dorsi muscle. This thin, flat sheet of muscle from the back is often chosen by plastic reconstructive surgeons, partly because moving it does not leave the patient with a serious functional or cosmetic deficit. It must be detached from the pelvis, ribs and spine but the nerve and blood vessels that enter at its upper end are carefully preserved. Electrodes are placed close to the nerve, and connected to an implantable electrical stimulator that is triggered by the electrical activity of the patient's heart. The muscle is then transferred into the chest, and wrapped around the heart. After a delay to allow for revascularization, the grafted muscle is conditioned and finally stimulated, usually on alternate beats, at the appropriate point in the cardiac cycle. The clinical benefits of this procedure, which has now been carried out on some 1500 patients worldwide, are due mainly to the reinforcing effect of the wrap, which reduces ventricular wall stress and restricts enlargement [8, 9]. About 85% of patients show symptomatic improvement. Many of the patients who are candidates for cardiomyoplasty are prone to arrhythmias, and outcomes have been improved by selecting patients carefully, and in some cases by implanting a defibrillator at the time of surgery. In an alternative procedure, known as aortomyoplasty, the muscle is wrapped around the ascending or descending aorta. Experience with aortomyoplasty is limited as yet, in terms of the number of patients (only about 20 worldwide) and the duration of follow-up [10].

In the procedures just described, the latissimus dorsi muscle is wrapped around existing structures: the ventricles of the heart in cardiomyoplasty, and the aorta in aortomyoplasty. Other configurations are being investigated that could harness muscle power more effectively [11]. In particular, the latissimus dorsi muscle can be formed into a separate auxiliary pump, or Skeletal Muscle Ventricle (SMV) [12, 13]. Such a device can be connected to the aorta and stimulated to contract during the filling phase of the patient's own heart cycle. This unloads the heart, boosts the blood supply around the body, and enhances the blood flow in the coronary arteries that supply the muscular wall of the heart (myocardium). In another configuration it is connected in parallel with the left heart, rather like a mechanical left ventricular assist device [14, 15]. SMVs constructed in experimental dogs have pumped in circulation for months and years, and in one case for over 4 years [16, 17]. In terms of pumping power, SMVs could rival the best mechanical artificial ventricles, but—unlike those devices—every component can be implanted, so they offer no psychological challenge to the patient [18]. However, the procedure is less conservative than cardiomyoplasty, because it places a new surface in the bloodstream, and although rapid progress is being made, it is not yet ready for use in patients.

In all its forms, cardiac assistance from skeletal muscle has the great advantage that patients do not have to wait for a donor heart. Because the procedure makes use of their own tissue, there is no need for immunosuppression, with its attendant costs and undesirable side-effects. The patient's own heart is not discarded, so it can still respond to the neural and hormonal signals that regulate its function in response to physical activity. And because the skeletal muscle graft shares the workload of the heart the conditions are created for at least a partial recovery of the weakened myocardium.

Much of the early clinical development of cardiomyoplasty was supported by Medtronic Inc., who made the special stimulators needed for the procedure. Their withdrawal from the field has, for the moment, denied patients access to this form of treatment. However, new stimulators are becoming available through another company, Illini Group Ltd. of Chicago. Because of the regulatory environment in North America these are being used at the moment by surgeons in other parts of the world. There is a positive aspect to this hiatus in the access to treatment. Since the introduction of cardiomyoplasty 15 years ago there have been major advances in our understanding of the relevant basic science. We have a better idea of how the procedure benefits the heart. We know more about the conditioning process, and how this should be modified to give the muscle the required combination of power and endurance. We have a more accurate picture of the blood supply to the latissimus dorsi muscle, how it is affected when the muscle is mobilised, and how best to maintain graft viability. These and other issues have been the subject of recent reviews [19, 20]. There is now an opportunity to incorporate these important advances into the surgical protocols for cardiomyoplasty, with the prospect that both the benefits to the individual patient and the success rate of the procedure will be improved.

Transplantation, mechanical pumps, cardiomyoplasty and SMVs are not in competition. Rather they will form part of an enlarged armamentarium available to the cardiothoracic surgeon. By taking less severely affected heart failure patients off the transplant waiting list, techniques based on skeletal muscle assistance can help to ensure that scarce donor hearts are available to those for whom transplantation remains the only option.

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Contributor:

Stanley Salmons, Ph.D., 2001

See:

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