What pacemakers can teach us about the ethics of maintaining artificial organs

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Abstract:

This paper offers an initial survey of the ethical issues posed by the need to maintain and service the artificial organs currently being developed for implantation into patients by medical laboratories around the world. Drawing on lessons from the history of the cardiac pacemaker, we argue that five features in particular will generate ethical issues associated with the maintenance and servicing of artificial organs: (1) the location of the devices inside the human body; (2) the complexity of the devices; (3) the role of software; (4) the impact of continual improvement of artificial organs; and, (5) the influence of the commercial interests of manufacturers. We suggest a framework to help policymakers, device manufacturers, and physicians anticipate and address these ethical issues.

Keywords: artificial organs; ethics; pacemakers; maintenance; medical devices; enhancement; surgery; tissue engineering.

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Introduction

One day soon it may be possible to replace a failing heart, liver or kidney with a long lasting mechanical replacement or perhaps even with a 3D printed version based on the patient's own tissue. Such artificial organs could make transplant waiting lists and immunosuppression a thing of the past. Supposing that this happens, what will the ongoing care of people with these implants involve? In particular, how will the need to maintain the functioning of artificial organs over an extended period impact on patients and their doctors and on the responsibilities of those who manufacture such devices? Drawing on lessons from the history of the cardiac pacemaker, this paper offers an initial survey of the ethical issues posed by the need to maintain and service artificial organs.

In §1 we explain what we mean by "artificial organs" and briefly describe a number of proposed devices that would meet our definition. We observe that such devices will require ongoing service and maintenance, especially as they improve and remain inside the human body for longer periods. To inform our analysis of the ethical issues raised by this requirement, we look to an established clinical device that is (in at least some key respects) a close analogy for artificial organs – the cardiac pacemaker. Thus, in the second section we briefly outline the nature and history of cardiac pacemakers, with a particular focus on the need for technical support, maintenance and replacement of these devices. In §3, drawing on the existing medical literature and on our conversations and correspondence with cardiologists, regulators, and manufacturers, we describe five sources of ethical issues associated with pacemaker maintenance: (1) the location of the devices inside the human body, such that maintenance generates surgical risks; (2) the complexity of the devices, which increases the risk of harms to patients as well as introducing potential injustices in access to treatment; (3) the role of software – particularly software that can be remotely accessed – in the functioning of the devices, which generates privacy and security issues; (4) the impact of continual development and improvement of the device; and, (5) the influence of commercial interests in the context of a medical device market in which there are several

competing products. Organising our discussion of the ethical issues in terms of their sources allows us to present, in §4, a table of questions that, we suggest, clinicians, researchers, hospitals, regulators and policy makers should ask to help to identify the ethical issues that might emerge for maintenance of artificial organs in the future. Finally, in §5, we offer some initial suggestions as to how these questions should be answered.

§1. Artificial organs

In what follows we will assume the following definition: artificial organs are manufactured fully implantable devices that are a destination therapy for organ failure, and fulfil the essential functions of the replaced organ for an extended period of time. The sorts of artificial organs we have in mind are an alternative to transplantation from a donor. In particular, in this paper, we are interested in artificial versions of the 'vital' organs, such as the heart, lung, kidneys, liver, et cetera. This is due to the vulnerability of patients when these organs (or their artificial replacements) fail or need repair or maintenance.

Of these criteria, the requirement that the device is fully implantable is perhaps the most controversial, especially given the historical use of the term 'artificial organs' to refer to non-implanted technologies such as dialysis.[1] However, researchers are increasingly focusing their attention on implantable medical devices. As we argue below, devices sitting within the human body raise issues that are not posed by external devices, and these will be of increasing importance in the future as devices are miniaturised and implanted. As for the other criteria, if devices cannot fulfil the essential functions of the organs they are intended to replace then they will not be suitable as a destination therapy in cases of organ failure. Unless artificial organs can replace the function of failed organs for an extended period of time, they are unlikely to address the shortage of donor organs which is the stated rationale for their development; more prosaically, they are unlikely to require the service and maintenance that is the focus of our discussion in what follows.

To our knowledge there are as yet no devices on the market that fulfil this definition, however there are a number of devices in development that may do so if successful. These include fully mechanical artificial organs, tissue-based implants, and hybrid implants with both tissue and mechanical dimensions.

Recent artificial heart prototypes such as the SmartHeart being developed by Cleveland Heart and Cleveland Clinic and the BiVACOR being developed at the Texas Heart Institute provide an example of emerging mechanical artificial organs. Both these prototypes have reimagined the design of the heart, pumping the blood around the body through a rotary pump that delivers pulseless flow.[2] The designs of these two implants bring the quest for an artificial heart closer than ever before to meeting the definition we have proposed. They are expected to deliver a breakthrough in device longevity, sufficient that they might to serve as a destination therapy for heart failure. They are also closer to being completely implantable than earlier prototypes by virtue of being smaller and lighter.[3] Nevertheless, even the most promising artificial hearts on the horizon remain externally powered, with the option of a wearable power pack with batteries to enable the patient to move away from the power supply.[4]

An artificial kidney under development at the University of California San Francisco (UCSF) will, if successfully brought to market, combine mechanical parts with human tissues to deliver the first fully implantable artificial kidney.[5] The proposed device would comprise a hemofilter – a mechanical filtration system akin to dialysis – and tissue-based "cell bioreactor" with tissue engineered kidney tubule cells that help to regulate blood pressure and produce vitamins such as vitamin D.[6] Functionally, this means that the implant would deliver all the essential functions of a kidney, including blood pressure regulation and vitamin production, neither of which is achieved by dialysis. The developers claim that the device will be long lasting in the body.[7] If they can deliver on their proposal the device seems likely to meet our definition.

Another frontier for artificial organs is synthesis from living tissue. While the public imagination has been particularly captured by the idea of personalised organs seeded from the patient's own cells,[8] there are no solid tissue-based artificial organs available at present. However Organovo Holdings Inc. in San Diego have brought 3D printed liver tissue to market, for liver toxicity testing, and the company foresees therapeutic applications for this technology in the future.[9] If tissue based whole organs are eventually brought to market, it seems likely that they will meet our definition. In terms of understanding the ethical issues associated with tissue-based artificial organs, it is important to note that these are likely to incorporate non-tissue components. For example, artificial bladders engineered from bladder cells by Anthony Atala's team at Wake Forest Institute for Regenerative Medicine comprised

a composite collagen and polymer scaffold seeded with cells derived from the patient's own defective bladder.[10]

A number of difficult ethical and policy questions will arise as artificial organs are developed and come into use, including: how the conceptual schemas governing existing regimes of regulation for medical products apply to artificial organs;[11] how we should evaluate their cost-effectiveness;[12] the appropriate standards and methods for preclinical[13] and clinical testing of artificial organs;[14] whether compassionate-use exemptions are appropriate for artificial organs before they are clinically proven;[15] what patients should understand in order to provide informed consent to implantation of an artificial organ;[16] and, the moral significance of the therapy/enhancement distinction.[17]

However, in this paper we focus on the ethical questions that will arise as a result of the need to provide maintenance to artificial organs, which to date have received almost no consideration. The more sophisticated these devices become, the more likely it is that they will need to be tuned, serviced, and repaired if they are to function inside the patient for any length of time, especially as the patient's condition changes. As we shall argue below these seem likely to generate a number of important and difficult ethical questions.

Given the importance of incorporating clinical experience into the development of ethical frameworks to govern future developments in medical technology, we looked for an example of a contemporary implantable device that could function as a guide to the ethical issues that might arise as a result of the need for service and maintenance of artificial organs — and settled on the pacemaker.

Pacemakers share a number of relevant features with artificial organs: they are implanted electronic devices which support a vital organ; they are a destination therapy for the arrhythmias that they are implanted to treat; and, they may function in patients for a number of decades. As we shall see, over the period in which they support the health of the patient, they may require significant amounts of service and maintenance. Because pacemakers have been in clinical use for over half a century, there is a large body of evidence regarding the ethical issues they raise. We believe that they serve as a useful guide to the issues that may arise surrounding artificial organs in the future.

§2. Cardiac Pacemakers

Pacemakers help control arrhythmias by sending electrical signals to regulate the contractions of the heart. A pacemaker comprises a pulse generator and battery in a shielded, hermetically sealed case, which is implanted just below the skin in the chest. The pacemaker attaches to one, two or three leads, which are fed along a vein into one or more of the chambers of the heart. The precise functioning of the pacemaker depends on the nature of the arrhythmia. In some cases they monitor the heart and administer an impulse when things go wrong, whereas in other cases they emit regular impulses. As well as hardware components, pacemakers include software, which monitors and records the heart rhythms of the patient, drives the pulse generator, monitors the status of the battery, and also stores a history of pacemaker activity. This information can be accessed by a cardiologist or device technician using an external device programmer, which is typically specific to the pacemaker brand and sometimes model.

Despite the relative simplicity of pacemakers — at least compared to the artificial organs being developed in laboratories around the world — patients fitted with pacemakers require regular monitoring and the device itself requires regular maintenance.

Because heart function alters over time, with age, the progress of disease, or other metabolic changes, patients fitted with pacemakers must visit their cardiologists regularly to ensure that the functioning of their pacemaker is adjusted appropriately to their condition. Increasingly, however, new pacemaker models are equipped with wireless access functionality, which enables remote monitoring of patient parameters and device function: as we discuss below, this has generated predictable concerns about privacy and security. Occasionally, cardiologists will need to update the software and/or firmware of particular models of pacemaker where problems with the existing software and/or firmware have been identified.[1]

Moreover, pacemakers must be replaced when the battery runs low – usually between 5 – 14 years after implantation, depending on the model and usage patterns.[18] Cardiologists are

[1] For example there was a recent case involving Medtronics' *EnRhythm* pacemakers in which the battery life estimate when cardiologists interrogated the device was different to that measured by the inbuilt battery replacement notification system. This issue was fixed by a software update that patients had to have installed via their cardiologist. T. Samsel, "Important: Medical Device Correction – Enrhythm Pacemakers," (*Physician Letter*), 2010, http://www.medtronic.com/enrhythm-advisory/downloads/enrhythm-battery-issues_physician-letter.pdf.

responsible for monitoring battery life, and advising when a replacement is needed. At that time, the old pacemaker is disconnected from the leads and completely replaced, often with an updated model. The device cannot be fitted with new batteries as it is hermetically sealed. The leads are tested when the pacemaker unit is replaced, but they are not usually replaced unless there is a fault.

Whereas replacement of the pacemaker is a very low risk procedure, replacement of pacemaker leads is riskier.[19] The leads are more invasive and scar tissue can develop around them while they are in the body, meaning that there is a risk of damaging the blood vessels or heart during removal.[20] Sometimes clinicians will judge that it is too risky to remove a lead that is damaged or no longer required, and the lead will be abandoned inside the patient.[21]

Finally it is worth noting that, as with any medical condition or device, complications may occur outside the regular schedule of visits with the cardiologist, and patients will sometimes present at the emergency department for treatment. As we discuss below, maintenance of pacemakers raises different issues in the context of the emergency department compared with scheduled appointments in the cardiology clinic.[22]

§3. Sources of ethical issues associated with the maintenance of cardiac pacemakers

The requirements of the pacemaker for ongoing support and maintenance generate a number of ethical issues, some of which have received little attention in the literature to date. In this section, we enumerate and explore these with an eye to their implications for future artificial organs. We have organised our discussion under five headings, according to the features of the pacemaker and its context of use that give rise to them: (1) the fact that pacemakers are implanted; (2) the complexity of maintaining pacemakers; (3) issues associated with software, especially remotely accessible software; (4) the cycle of device improvement; and finally (5) the influence of commercial interests.

3.1. Implantation

The fact that pacemakers are implanted inflects all, and exacerbates many, of the issues we discuss below. In particular, it contributes to the nature and likely extent of harm associated

with maintenance, due to the need for surgery, which has inherent harms and risks, including surgical wounds, loss of blood, risk of infection, risk of complications associated with anaesthesia, and the inconvenience of hospitalisation.

The location of the pacemaker inside the patient's body also poses challenges in the context of emergency medicine and surgery.[23] In order to avoid procedures — and especially MRIs — interfering with the operations of a pacemaker or even causing burns to the patient, it is important that physicians be able to determine whether or not patients have pacemakers and to be able to correctly identify the make and model if they do. Pacemaker patients generally carry a pacemaker card, which identifies them as carrying a pacemaker and provides details about its make and model, but this may be unavailable in emergency contexts. In its absence, various factors can reveal that an unconscious patient is implanted with a pacemaker. For example the pulse generators are palpable below the skin, and pacemaker activity is visible on a cardiac trace, although this may be subtle.[24] Where the emergency concerns the pacemaker, correct identification of make and model are essential to provide treatment, whilst delays in identification can lead to delays in treatment. To address this, national regulatory bodies have introduced requirements for pacemakers to be inscribed with make and model information on the outside of the pulse generator, such that they can be identified from a chest x-ray. This largely addresses the issue of identification, although in practice the x-rays can be difficult to decipher, and misidentification sometimes occurs.[25]

The fact that pacemakers sit inside the human body and sustain an organ as vital as the heart also means that they have begun to blur the boundary between bodies and machines and between organs and devices. The ambiguous status of the pacemaker is most obvious in the debate about the ethics of withdrawal of treatment. Those who think of pacemakers as devices, analogous to external means of life support, such as ventilation, will typically believe that is acceptable to "withdraw treatment" by switching off a pacemaker. However, the more we think of pacemakers as replacement electrical systems for hearts, the more it seems troubling to interfere with the functioning of a patient's heart by switching off its electrical system. Research with those involved in deactivation suggests that their intuitions about when it is morally acceptable track the level of patient dependence on the device, with health professionals reluctant to disable devices that act constantly to keep the patient alive, but more willing to deactivate devices that intervene intermittently to restore function.[26] The ambiguous status of the pacemaker is also revealed in conflicting intuitions about the extent

to which it should be thought of as property. Outside of the body, pacemakers are clearly property and may be bought and sold on the medical devices market. Once inside the human body, though, they seem to become parts of the body. In our conversations with cardiologists, health lawyers and administrators we have encountered a remarkable diversity of opinions regarding whether patients own their pacemakers and about their rights to dispose of them as they wish or demand deactivation, which attests to the ambiguous status of the pacemaker between organ and machine.

Correspondingly, there are two distinct ways to think about pacemaker failure – as a clinical issue of patient health and treatment, to be managed primarily by clinicians, or as a technical issue of device failure and repair, to be managed primarily by technicians.

People with pacemakers needing maintenance present to health professionals as patients seeking medical treatment for clinical symptoms. It is therefore natural to suppose that the technical dimensions of maintenance are subsumed under, and answerable to the clinical. Nevertheless, as we discuss further below, in the context of pacemaker maintenance technicians take on a significant responsibility. They often participate in patients' regular biannual check-ups, driving the programmer and providing technical advice to the cardiologist. For example, a workforce study across several European countries found that internally employed technicians attended 27% of visits for implantable cardiac devices, and externally employed technicians attended 18% of visits.[27] They are also 'on call' to emergency departments, where they will present with pacemaker programmers to interrogate the devices of patients and work with healthcare professionals on their management. Some of these technicians are employed by the device manufacturer, which may create conflicts of interest (discussed below), but even technicians employed by hospitals may focus on technical issues associated with the device, rather than taking a holistic approach to the well-being of the patient.

Importantly, clinicians and technicians receive different training, and thus may engage differently with patients. In particular, health professionals are usually introduced to clinical ethics in their training – at least to basic ethical ideals such as the principle of beneficence, respect for patient autonomy, and the Hippocratic Oath. In contrast, although some device technicians have a nursing or other clinical background, such a background is not required and many have an engineering or medical sciences background where they may not have

been instilled with even the most basic ethical principles associated with care for patients. Whether or not it is necessary for all those involved in the care of patients to have some familiarity with medical ethics is itself an ethical issue.

3.2. Complexity

The pacemaker is a fairly simple device compared to the sorts of artificial organs already under development. Even so, maintenance can require complex interactions between cardiologists, radiologists, and technicians and involves attention to both software and hardware components. The complexity of the pacemaker is one of the main factors contributing to risks of harm to patients.

Although natural hearts are complex, and there can be anatomical variation, a cardiologist should be able to apply his or her expertise to any patient. However, the multiplication of different brands and models of pacemakers has effectively made it impossible for cardiologists to have an expert knowledge of all the different devices a patient may be fitted with. For this reason, the support of specialist technicians who are employed and provided by the manufacturer is increasingly important in cardiac care[28]. [2] Cardiac nurses and hospital employed technicians are also involved in provision of care associated with pacemaker maintenance. Furthermore, sub-specialisaton can mean that different cardiologists are responsible for implantation and follow-up. Given this complexity, the way the various health professionals work together and communicate can have a significant impact on patient experience and outcomes.

While effective communication between clinicians remains vital, the need to access specialist technical support and coordinate the actions of various health professionals does not usually create inconvenience or risk of harms to patients for routine check-ups and maintenance, as cardiologists know which devices their patients have, and schedule these appointments in

[2] The pacemaker is no outlier amongst current implantable devices in this respect – many vascular devices, including arterial grafts and stents, as well as cardiac implants such as left ventricular assist devices, and orthopaedics implants such as spinal kits are supported by technicians who become members of the surgical team during implantation procedures and are also sometimes involved in follow-up. Indeed, recent research with surgeons and surgical teams suggests that company reps are playing an increasing role in clinical encounters across a range of interventions. Furthermore, surgeons increasingly rely upon technicians when implanting devices (manufacturer technicians will often be in the operating suite assisting with selection of e.g. stents and making recommendations about placement).

advance when they know the relevant staff will be available. However, it can lead to delays (and associated harms) in emergency settings, when non-specialist emergency staff need to stabilise the patient while they wait on the arrival of specialists and possibly a manufacturer-employed technician with the relevant programmer. Some patients might require external pacing, which can be uncomfortable and distressing to patients, and might require sedation.[29] In other circumstances emergency staff might cut the leads of a 'runaway' pacemaker.[30] Because this destroys the leads, it risks the harms associated with lead removal and replacement.

Another implication of the complexity of pacemakers is that geographical location of patients is likely to impact on the speed and quality of treatment they receive. Patients who live near the large hospitals that have in-house cardiac technicians, and programmers for many different models of pacemaker on site are likely to receive speedy diagnoses in an emergency context, whereas patients who are more remotely located will have their geographical disadvantages amplified due to the need to source an appropriate programmer and a technician for their pacemaker.

3.3. Software as a source of ethical issues

The fact that pacemakers contain software, which records, stores and now often even transmits, information relevant to the patient's health generates a number of ethical issues.

The data that pacemakers generate allows cardiologists an unprecedented level of knowledge of the functioning of their patients' hearts. In contrast, this information is not readily accessible to patients: patients cannot even keep track of the remaining battery life on their device, but rely upon clinicians and/or device technicians to do so.[31] They are also unlikely to be privy to cardiologists' prognostications about their health and life expectancy on the basis of their cardiac trace, except insofar as these prompt the cardiologist to make changes to the way the device is programmed, or to make other recommendations to the patient about their healthcare. The precise extent of patient's rights regarding information about their own health care status is, of course, an ethical question.

Recently, technological advances have enabled the remote monitoring of battery, pacemaker function, and patient cardiac function for many pacemaker models. This in turn has given rise to a set of privacy and security issues. Whenever information is transmitted there exists the

chance it will be intercepted or will go astray. Whenever information is stored, questions arise about who has — and should have — access to this information. In private communication with cardiologists, we have been told that while it is typically impossible to draw conclusions about specific activities (e.g. sexual activities) from a patient's cardiac trace, it *is* possible to get a fair idea of their overall health. Moreover, manufacturers collect and use data provided by pacemakers for purposes of quality control and to inform the design of future models. While this has no negative clinical impact on patients, it raises ethical issues around patient control over their health-related data, and the right of companies to profit from such information. Furthermore, in 2012, 'ethical hacker' Barnaby Jack demonstrated that some remotely accessible pacemaker models could be hacked and made to deliver a lethal electric jolt to the person with the device implanted.[32] Notoriously, concerns about the risk of such an attack prompted a decision to disable the wireless functionality of former US Vice President Dick Cheney's cardiac implant while he was Vice President in order to protect him against this 'credible threat'.[33] Measures to improve the privacy and security of pacemakers are challenging, as the device must remain accessible to health professionals in emergency situations.[34]

3.4. Continuing improvement of the technology

Pacemakers have developed considerably since they were invented in the 1960s and they continue to evolve, with companies today releasing new models of pacemaker pulse generators approximately every 6-12 months.[35] While improvements have delivered many benefits for patients, the continuous dynamic of technological progress can also generate problems.[36]

Patients typically have their pacemakers replaced every 5-14 years when the battery runs down.[37] This means that by the time a patient needs a replacement device, it is likely that the existing device will have become obsolete. Given that pacemaker leads are often not replaced when the pacemaker is replaced, and that replacing them is higher risk than replacing the pulse generator, it is important that new pacemakers be able to attach to existing implanted leads. For the first two decades of the pacemaker's use, patients were at risk of harm if newer devices were not compatible with older leads.[38] Removing old pacemaker leads places patients at risk of damage to the heart and blood vessels, while abandoning old leads inside the patient increases the chance of blood clots, scarring or calcification in the veins in which

they sit. In the 1980s concerns about the incompatibility between implanted leads and replacement pacemakers led to the establishment of a voluntary code for pacemaker leads and later to an ISO standard for pacemaker leads and lead attachments (ISO standard 5841-3), which has most recently been updated in 2013.[39]

The continuing development of pacemakers also makes demands on clinicians, as they must ensure that they are able to treat patients effectively using the latest model of the pacemaker. While it seems plausible that replacement of patients' expired pacemakers with new models would reduce the need for cardiologists to maintain expertise regarding the operations of obsolete and "legacy" devices, the evidence on this is ambiguous. There are recent reports of two different lithium ion battery powered pacemakers lasting 26 years[40] and 31 years[41] in patients. Another exception here — which is noteworthy for what it suggests about other implantable medical devices — concerns the small number of patients who are still fitted with early pacemakers that were manufactured with plutonium batteries. At least one of these patients was still alive and fitted with their original pacemaker 31 years after it was implanted, and a comparative study found nuclear pacemakers lasted more than three times as long as lithium ion powered devices.[42] Thus cardiologists treating these patients must maintain knowledge of the specifications and functioning of a device manufactured some 30 or more years ago. Ensuring that the technical documentation of each and every device that is manufactured remains available for three decades itself poses significant challenges.

3.5. Commercial Interests

The success of pacemakers as a therapy for arrhythmias has led to the development of a multi-million-dollar market in which manufacturers compete for sales and market share. This competition drives the rapid development of pacemakers and has produced many benefits for patients. However, the dynamics of this market, as well as the multiplicity of devices it has produced, have also generated a number of ethical issues.

The number of different devices on this market can sometimes be bewildering for patients and even for their physicians. Both the number of different brands of devices and the short production life-cycle of each model means that it can be extremely difficult to source good published data on any particular model let alone on a comparison between models.

The diversity of products and the rate at which they appear and become obsolete also has more concrete implications for patients. We noted above the problems that used to arise when new models of pacemakers were not compatible with the patient's leads. The same issue of compatibility has also arisen between pacemakers and leads manufactured by different companies. Thus, in the past even a patient who had a pacemaker removed shortly after implantation and replaced with a different brand would sometimes discover that their new pacemaker was not compatible with the leads with which they had been implanted. The adoption of an ISO standard for pacemaker leads has at least partially addressed this issue, as most pulse generators will now connect to most leads either directly or with adapters that meet the ISO standard. However, this standard risks constituting an impediment to further innovation of both pacemakers and leads. Moreover, increasingly the presence of proprietary software in the pacemaker generates similar problems with compatibility between pacemakers and the tools used to capture and represent their data across different brands.

Built in obsolescence of devices also works to encourage — or even force — patients and physicians to purchase new and more expensive devices rather than just replace the existing pacemaker. The use of proprietary software can help ensure a steady income stream by effectively locking patients and cardiologists into ongoing relationships with a particular manufacturer. Indeed, many of the problems described above are exacerbated by the proprietary hardware and software components of devices.

The commercial interests of manufacturers may also generate conflicts of interest for technicians employed by device manufacturers, who play a significant role in the maintenance of pacemakers, including in clinical contexts with patients. Their attendance at appointments and role in ensuring the safe and effective operation of the device is likely to give patients the sense that the technician — and by implication the device manufacturer — is looking after them. To the extent that patients and/or clinicians form an emotional attachment to, or develop good working relationships with particular manufacturer-employed technicians this is likely to increase their loyalty to those brands. Often the interests of manufacturers and patients will align, but sometimes it may be in the interest of the manufacturer rather than the patient to recommend replacement or upgrade of a part that will cost either the patient or health system money. It is also worth observing that, as many of these technicians will not have had any training in clinical ethics, even if they intend to do the

right thing and to flag conflicts of interest whenever they occur, they may be poorly equipped to do so.

Finally, potential conflicts of interest may also arise in other interactions between clinicians and companies. Training for cardiac surgeons and cardiologists relating to each new model of the pacemaker or leads is provided by the device manufacturer. The line between clinical education and sales is often blurry — to say the least — in this context.[43] The pacemaker programmers are proprietary and expensive, so that most hospitals and cardiologists do not own programmers for the various pacemaker brands they implant. Anecdotal evidence suggests that some manufacturers lend a programmer to cardiology clinics that regularly use their devices, and this could influence patterns of device choice by the cardiologist, potentially to the detriment of particular patients.

§4. Summary of results

In light of our discussion of pacemakers, we have developed a set of questions that we believe should be asked about artificial organs as they start to be developed in order to foreground the ethical issues that the need to maintain and service these devices may raise (table 1).[3] Indeed, these questions are relevant to any implantable medical device. Together, they form a framework that we hope will help developers, policy makers and institutions to identify and anticipate these issues. We also expect that this list will be useful to patients and clinicians when assessing the suitability of particular devices for individual patients.

[INSERT HERE **Table 1: Ethics framework for artificial organ maintenance**]

§5. Further remarks

Although our primary purpose here has been to identify the right questions to ask about the maintenance and servicing of artificial organs, we believe that all the ethical issues identified

[3] Again we should emphasise that these issues are themselves only a subset of the larger set of ethical issues raised by the development of artificial organs. However, they are subset that has been largely neglected to date.

with pacemakers *are* likely to arise with artificial organs — and some of them with a vengeance.

In most cases, the implantation and removal of artificial organs — and perhaps also the maintenance of artificial organs — will require major surgery. Furthermore, whereas the opportunity costs associated with the implantation of pacemakers (such as the possibility that implanted leads turn out to be incompatible with later devices) are small, implantation of artificial organs might involve much greater opportunity costs for the patient (for example if removal or replacement is going to be more risky than the initial implantation, or impossible). Where this is the case, despite the convenience and apparent benefits of fully implantable artificial organs in terms of making patients' lives closer to 'normal', it might nevertheless sometimes be better to support patients with external devices, which are more easily serviced, maintained and upgraded, than devices that are entirely implanted.[44]

As artificial organs become more common in the community, health professionals will need to be cognizant of the possibility that patients have an implant upon which their life depends and to develop procedures to identify when patients have an artificial organ and which make and model of the organ it is. Tissue engineered artificial organs are likely to be particularly difficult to detect.

Similarly, the issue as to how maintenance of implanted devices is conceived – as clinical or technical – will become increasingly important as artificial organs emerge, as will questions of who performs maintenance and how they are paid. Decisions about withdrawal of treatment/device deactivation are likely to be especially vexed, as deactivation of the device may require active intervention of the treating physician and because the consequences of deactivation will be immediate and devastating to the patient. This is likely to remain true *even if* deactivation is requested by the patient, and the task is officially viewed as a form of technical support for a device the patient owns.

It should be expected that most artificial organs will be much more complex than the pacemaker, and the sorts of teams required to support them may be more extensive. Effective communication between the members of these teams will be important to ensure efficient treatment and good outcomes for patients. Furthermore, the provision of artificial organs and support and maintenance for them is more likely to be concentrated in large teaching

hospitals in wealthy countries. These observations in turn have implications for patient access to these treatments.[45]

We also suspect that issues related to cross-platform and backwards compatibility will become increasingly important as more and better artificial organs come onto the market. A challenge here is for regulators and policy makers to anticipate these at the development stage, given that they will not arise until there are multiple generations of device and/or more than one company marketing devices in the same category. Planning for issues associated with (in)compatibility is particularly important in the case of artificial organs, as the associated harms to patients could be serious. The issue is not only the compatibility of spare parts, but also the training and credentialing challenges associated with ensuring that health professionals have the skills to support and maintain devices.

Most medical devices on the market today are commercially developed by for-profit device companies. It is likely that this will also be true of artificial organs. These companies might have commercial incentives to engage in practices that give rise to harms, or unfair or less than optimal treatment. Such practices can be as simple as using proprietary software, or changing the specifications of connectors to force 'customers' to upgrade otherwise working components. One issue that may arise, with significant implications for those responsible for funding access to healthcare, including governments, insurance companies and perhaps even individual patients, relates to the distribution of costs between the initial implantation of the artificial organ and the service procedures to service it. Those responsible for purchasing artificial organs would be wise to ensure that they do so on the basis of an accurate assessment of the lifetime costs of the device and that they are able to enforce any agreements relating to the distribution of costs so as to reduce the risks of cost blowouts when patients need service procedures for their artificial organs that have suddenly become extremely expensive. The involvement of device companies in training and maintenance may also generate conflicts of interest for people involved in clinical care, including company employees who provide technical support in clinical contexts.

Conclusion

The development of artificial organs holds out the promise of significant medical benefits for the large number of patients who are currently unable to secure a donor organ for transplant.

As has been the case with other advances in medicine, it will also raise new ethical questions as well as exacerbate more familiar ethical problems. We have focused our discussion here on the ethical issues that might arise out of the requirement to service and maintain artificial organs as they remain in patients for longer and longer periods. By asking the right questions those involved in the development, implementation, and regulation of artificial organs can be better prepared to confront these issues as and when — or even before — they arise.

Thus, it is our recommendation that the issues we have identified here be taken up by at least three different communities.

Researchers and clinicians involved in the pre-clinical development of artificial organs should be aware of the potential for these issues to arise. Rather than waiting for poor outcomes to drive policy (as was the case with the introduction of a standard for pacemaker leads) it is possible for many issues that might arise to be anticipated at the research and development stage, and for measures to be adopted to mitigate likely harms. This could include simple amendments to the design of products to e.g. ensure that the make and model and other important information about a device is identifiable from an x-ray, or that the presence of the device can be detected in the course of routine observations that would be undertaken on most patients presenting to a clinician.

As new artificial organs come into clinical use, *hospitals* (or relevant institutional administrators) should be thinking about the potential ethical challenges posed by maintenance, and exploring how these can be avoided or ameliorated by local processes and outcomes. Two sets of issues in particular stand out as relevant at the institutional level. One is the importance of systems that will ensure safe management of patients with implantable devices in emergency. The second is the need for institutions to examine the nature and extent of their interactions with device companies, including reliance on industry technicians in clinical care.

Finally, *policy makers and regulators*, too, should be considering the potential ethical challenges posed by the service requirements of artificial organs. Regulatory frameworks influence the behaviour of commercial entitles at all stages of the development and commercialisation of products, and recent regulatory theories note the ability of well-designed regulatory frameworks to avoid reaching the point where punitive measures apply.[46]

Realising the full potential of artificial organs will require all three of these groups to work together to confront the many ethical – as well as scientific —questions that will arise as these devices are developed and adopted. We hope that our attempt here to foreground the ethical issues arising out the need to service and maintain such devices will serve as a small contribution to this important task.

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Table 1: Ethics framework for artificial organ maintenance

1. Given that the device is implanted in the human body, what is the impact of this on:	
• Physical experience of maintenance for patients	e.g. Does maintenance require surgery and/or hospitalisation? Will it be painful, inconvenient, disabling for the patient?
• Psychological experience of maintenance for patient	e.g. Is maintenance more like clinical care or technical support? Does bedside manner matter? Will it be distressing for the patient?
• Ancillary risks associated with maintenance	e.g. If a procedure is required, what are the risks? What are the anaesthesia and wound care protocols? Do learning curves or low centre volumes apply?
• Emergency care	e.g. Is the device easily identified? What are the risks if it is identified incorrectly? What are the options for emergency intervention?
• Withdrawal of treatment	e.g. Is it regarded as 'part of the body'? What would be required to remove or deactivate it? Under what circumstances can it be deactivated?
• Rights and ownership	e.g. Is the artificial organ part of the patient's body or a piece of property that they have purchased? Does anyone own the device after implantation, or have rights over it?
2. How complex is the device? What is the impact of complexity on:	
• Communication between health professionals	e.g. Who are the health professionals involved in care and maintenance, and what communication systems are in place?
• Patient access to maintenance	e.g. Are patients in regional or remote areas disadvantaged? Does this compound other disadvantages e.g. socio-economic?
• Timeliness of maintenance	e.g. Is complexity likely to cause delays to maintenance that might harm patients?
3. Does the device rely on software? If so, what is the impact on:	
• Security of the device	e.g. Is it remotely accessible? Can it be hacked? Will this put the patient at risk?
• Privacy of patient data	e.g. Does the device collect patient data? Who has access and what can they use it for?
4. What is the likely cycle of continuing improvement for the device? How will this impact on:	
• Clinician training and skill maintenance	e.g. How many 'versions' of the device will clinicians encounter? Who provides training and certification?
• Longevity of the device	e.g. Might the device require spare parts? How unique are these to the model? Is there any risk of obsolescence and what would the implications be for the patient?
5. Are there commercial interests at play? If so, what is the impact on:	
• Hardware maintenance	e.g. Backwards compatibility, cross-platform compatibility, availability of parts. How are costs distributed between the initial implantation of the device and service and maintenance?
• Software maintenance	e.g. What equipment/expertise is needed to update, reprogram or deactivate device? Who controls access to this?
• Responsibility for maintenance	e.g. When a fault emerges, what happens? Who employs maintenance personnel, what is their role and where are they located?
• Objectivity of clinical decision-making	e.g. Do conflicts of interest affect surgeons, technicians or institutions?

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