PAPER

The case for cryonics

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ABSTRACT

Cryonics is the low temperature preservation of people who can no longer be sustained by contemporary medicine in the hope that future medicine will make it possible to revive them and restore their health. A speculative practice at the outer edge of science, cryonics is often viewed with suspicion. In this paper I defend two theses. I first argue that there is a small, yet non-negligible, chance that cryonics is technically feasible. I make the case for this by reference to what we know about death and cryobiology, and what we can expect of future nanorobotics. I further argue that insofar as the alternatives to cryonics are burial or cremation, and thus certain, irreversible death, even small chances for success can be sufficient to make opting for cryonics a rational choice. Finally, I reply to five objections.

What will happen when contemporary medicine can no longer keep you alive? While most people opt for burial or cremation, some opt for cryonics, hoping that one day, medical advancements will make it possible to revive them and restore their health. Currently around 250 people are cryopreserved in the USA, and around 1500 more have made arrangements for cryopreservation upon their eventual deaths.[1 2]

Since its inception in the 1960s, cryonics has been practiced outside of mainstream medicine, and the number of peer-reviewed papers on the topic is limited. This is unfortunate, or so I suggest, and in this paper I present the basic case for cryonics.

TECHNICAL FEASIBILITY

How does cryonics work? Under ideal conditions a patient dies in the hands of medical personnel, who—immediately after legal death has been pronounced—start the cryopreservation process. The body is rapidly cooled to just above 0°C while respiration and heartbeat are artificially maintained and heparin is injected to avoid coagulation. This way cells are protected from the ischaemic damage that would otherwise occur shortly after death. The patient is then perfused with a cryoprotectant, an antifreeze solution, to prevent ice-crystal formation and subsequent fracturing when the body is further cooled to below 0°C. When the body's cell fluids are partially replaced with cryoprotectant, then rather than freezing and fracturing, the fluids become gradually more viscous until a glassy state is reached at around −120°C. This process is called vitrification, after *vitrum*, the Latin word for glass. The body is then submerged in liquid nitrogen, at −196°C, and stored in the hope that one day medical technology will have advanced sufficiently to make it possible to repair the freezing damage and to cure the patient of the condition from which he or she died.

Might cryonics be technically feasible? Let us start by considering an intuitive argument against the practice:

P1: A cryopreserved person is dead.
P2: A dead person cannot be revived.
C: A cryopreserved person cannot be revived.

This argument appears sound: Both P1 and P2 seem to be true and the conclusion seems to follow from the premises. A problem, however, is that it is unclear if P1 and P2 employ the term 'dead' in the same sense. In a strong sense of the term, we call a person dead only when revival is impossible. In this sense, P2 is clearly true. If death occurs only when revival is impossible, however, it is no longer so clear that P1 is true. Although cryopreserved people are legally dead, it is an open question whether they are dead in the strong, irreversible sense.

Whether or not a given person is irreversibly dead depends on what medical technologies are available. Only a few decades ago, a person with a cardiac arrest was rightfully considered irreversibly dead, as there was nothing medical doctors could do to bring the person back to life. Today many are brought back to life after cardiac arrest, so in cases where there is doubt, the criterion for death is no longer cardiac arrest, but rather the shutdown of brain activity (brain death). This, however, is not an unproblematic criterion either, since, under favourable conditions, it is possible to survive a complete shutdown of brain activity. As early as 1955, James Lovelock reanimated a rat that had been cooled to just above 0°C, and whose brain activity had fully stopped.[3] Similar experiments have more recently been carried out successfully with pigs.[4] This year, moreover, UPMC Presbyterian Hospital has started stabilising victims of severe trauma by replacing their blood with a cold saline solution that rapidly cools the body and stops virtually all cellular activity, including brain activity.[5] This buys surgeons more time to treat the damages, after which the patient's blood is transferred back and the body is reheated. The same principles apply in cold drowning cases: When humans drown in cold water, brain activity stops, but due to the rapid cooling, the damage is much less severe than would otherwise be observed. Humans have been restored to life and normal functioning after being completely submerged in cold water for up to 66 min.[6]

Death, accordingly, is not as simple and singular as we might assume, and in the context of cryonics, the notion of death that is most commonly employed is *information-theoretical death*. Information-theoretical death occurs when the

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neural structures that encode personality, thoughts, memories, etc, are damaged to such an extent that restoration is in principle impossible.[7] It is plain that people whose brain activity stops in cold drowning cases need not be information-theoretically dead; otherwise, we would not have seen cases where they were brought back to life and where their personality, thoughts, memories, etc, were intact. But are cryopreserved people information-theoretically dead? Considering this, we must keep in mind, first, that the cooling in favourable cryonics cases is at least as fast as that in submersion in cold water, and since respiration and heartbeat are artificially maintained during the initial cooling, the cellular damage is almost certainly less severe. Second, concerning further cooling, ultimately down to nitrogen temperature, we know that biological structures can survive such cooling. Human sperm, eggs and tissues are routinely cryopreserved, thawed and recovered. The vitrification procedures used in cryonics, moreover, closely resemble those used in mainstream cryobiology.[8] From this perspective, cryonics is not a radically new practice, but an extension—albeit a speculative one—of a practice that is well established.

The central additional challenge in cryopreserving whole bodies, or larger organs, is that they do not cool uniformly. When cooled, moreover, biological materials contract, and when different parts contract at different rates, they easily fracture. Though there are ways to minimise fracturing (slow cooling is beneficial and so is slight reheating before the vitrification stage), even the best cryopreservation techniques are likely to result in at least some fracturing.[8] It is worth pointing out, however, that even though fracturing can be a serious form of damage, fracturing does not, by itself, cause information loss. When biological materials fracture, different parts are located differently relative to each other, but the materials themselves remain intact.

Even if we grant that cryopreserved people might therefore not be dead in the information-theoretical sense, we still face the question of whether it will ever be possible to repair the damages that do occur. There are, however, some reasons for optimism. The most compelling reason is the development of repair technologies such as nanorobotics. Though only simple nanobots, or nanomachines, have been made so far, it might well be possible—when nanotechnology is developed further and nanobots can be supplied with significant computational power—for nanobots to penetrate a cryopreserved person's body, identify the fracturing damage, infer the structure prior to the damage, and help restore the body to its precryonic state.[9] [i] If an area of the body is too damaged for repair (due, for instance, to local information loss), new tissue or whole new organs can in principle be either 3D printed or laboratory grown. 3D printing of biological materials and laboratory growing of organs are now part of established medicine.[10] [11] As such, reviving cryopreserved persons, though it cannot be done today, does not require the development of *radically* new technologies; it requires further refinement and convergence of technologies that already exist.

How should we estimate the probability that an individual who is cryopreserved today will, at some point in the future, be reanimated? Though it is hard to set a numerical probability, we can say something about the factors that are relevant in determining that probability. One factor is the circumstances surrounding the cryopreservation process. In the least ideal circumstances, a cryonicist dies unexpectedly and must be kept in cold storage at a hospital or a mortuary for hours, or days, before cryopreservation. In these cases, severe damage is likely. In the better cases, as described above, cryopreservation can begin immediately after legal death has been pronounced. Even if the cryopreservation is successful, however, and information-theoretical death is avoided, we must also count in the probability that the relevant technologies, though they can *in principle* be developed, will *in fact* be developed. It should be noted, though, that once a person is cryopreserved, she can remain in storage for centuries without further deterioration, so even if it takes a long time for the relevant technologies to develop, she is not in a hurry. The only way in which a long storage time is a problem is that it increases the probability of interfering factors such as natural disasters, political unrest or bankruptcy of the cryonics provider. Finally, we must consider the possibility that even if the cryopreservation is successful and the relevant technologies become available, reanimation might in fact never take place. Although many cryonicists have funds to pay for reanimation, such procedures will also depend on good intentions of those of the future who would carry it out, and such good intentions might not exist.

Still, it seems that if a person is cryopreserved under favourable circumstances, and if we take for granted a level of political stability and technological development that is consistent with the stability and development over the last centuries, there is a non-negligible, even if small, chance for success.

RATIONALITY

If there is a non-negligible, even if small, chance that cryonics is technically feasible: What conclusions should we draw about the rationality of opting for cryonics? One point to keep in mind in determining its rationality is that insofar as the alternative to cryonics is burial or cremation, the alternative is—for all practical purposes—a 1.0 probability of irreversible death. If we further grant that it is bad to die and good to survive (more on this below), cryonics, though it is uncertain and speculative, almost certainly offers a higher expected utility than the alternatives.

As such, even if the probability of successful revival through cryonics might be far below 0.5, opting for cryonics might still be a rational choice. By analogy, if you are trapped in a burning house, and your only chance of being saved is with help from firefighters, you have good reason to call 911 even if you think the probability of the firefighters arriving in time is lower than 0.5. A small chance for survival is better than none, and a small chance is precisely what cryonics offers. David Shaw has presented an argument along the same lines. Shaw draws a parallel to Pascal's Wager, and defends cryonics by arguing that it is rational to opt for a small chance of receiving *infinite* benefits.[12] I think it is sufficient, however, to argue that it is rational to opt for a small chance of survival when the alternative is no chance at all.

An important disanalogy between opting for cryonics and calling 911, however, is that whereas calling 911 costs nothing, cryonics comes with a significant price tag. Cryonics requires a stand-by team before, and intensive surgery after, legal death has been pronounced. It also requires long-term storage, and since there is no known end to the storage time, a patient's funds must be sufficient for the interests alone to pay for continual storage. (The funds themselves can be spent on the reanimation procedure, since from that point onwards, further storage will not be needed.) Currently, the major cryonics organisations

[i]For an overview of the medical potential of nanobots, see Patel GM, *et al*.[9]

charge from $28 000 to $200 000 for cryopreservation, including indefinite storage.[13] Though these are both significant sums, they are made affordable to many cryonicists through life insurance. People who want to be cryopreserved need the cryopreservation only in case they are legally dead, and a life insurance that pays $200 000 upon legal death need only cost a few dollars per day. An insurance that pays $28 000 might cost less than a dollar per day.

Whether it is rational to opt for cryonics in an individual case seems to hinge on what has the highest expected utility: spending the required money on cryonics or spending it on something else. If one is poor, and needs all one's money to meet one's basic needs, spending the required money on cryonics might well have a comparatively lower expected utility. If, however, the money that could be spent on cryonics would otherwise be spent on luxury goods, it seems that cryonics might be an attractive alternative. While luxury goods often contribute little to long-term well-being, cryonics gives one a non-negligible opportunity to have a significantly longer life. If this is attainable for only a few dollars per day, it seems that for many it is at least prima facie rational to opt for cryonics.

OBJECTIONS

Even if the above argument is sound, and does render it at least prima facie rational for many to opt for cryonics, there might still be reasons that detract from cryonics' desirability or that override it completely.[ii]

According to one argument, the personal identity argument, cryonics is undesirable because the person who is reanimated might not be the same person as the one who is cryopreserved. If this is correct, cryonics does not ensure survival; it is an expensive way to create new people in the future.

Personal identity is a difficult issue, but as long as we grant that persons can survive drowning in cold water, it is unclear why they could not also survive cryonics. Cryonics differs from cold drowning cases by being monitored rather than accidental, and by involving a longer storage time, a lower storage temperature, and some fracturing damage to the central nervous system. The only differing factor that seems directly relevant to personal identity is the fracturing damage. Insofar as cryoprotectants render the damage modest, however, and insofar as people regularly survive neurosurgery, it is not clear why people could not survive the kinds of damages involved in cryonics. It is also important to keep in mind that although cryonics is a radical procedure in one sense, a reanimated person will consist of the same particles as the person who was cryopreserved and those particles will be arranged in virtually the same pattern. Since we know that cryopreservation can render fine biological materials (including neurons) intact, chances are good that it can also render intact the neural structures that encode personality, thoughts and memories. Even if we think that neither particles nor patterns of particles are directly relevant to personal identity (perhaps we hold a psychological continuity theory or we believe in a soul), it is unclear what more, on a physical, and thus medically relevant, level we can require for survival than the same particles being arranged in the same pattern.

Another argument against cryonics is that life after reanimation might be very bad. Reanimated people might have old and deteriorated bodies, be left without friends and family, feel alienated in a radically transformed society, and find that their work skills are dated. These factors, in turn, arguably lower the expected utility of opting for cryonics by virtue of lowering the value of successful reanimation.

A number of things should be pointed out in response. First, whether one will have an old and deteriorated body depends on a number of factors, most obviously the age at which one dies. Many people die at a young age, and for all I argue here, it might well be that cryonics should primarily be used as a means to give these people the chance of having a normal life span. Even if one dies at old age, however, it is possible that in a future where nanobots can heal damage from freezing, they can also heal damage from aging. Aging is a physical process, and like other physical processes, it can, in principle, be reversed.

As for the absence of family and friends, David Shaw has pointed out that there is nothing about cryonics that prevents family and friends from also being cryopreserved. Even without family and friends, however, it might still be better to have a future than not to have one.[ii] When people left Europe for America, they often left their families for good, and though this must have been sad, the settlers formed new personal bonds and, presumably, had lives worth living. We must also keep in mind that in this respect, cryonics is not different from any other life-saving technologies. If other life-saving technologies are employed only on isolated individuals while their families and friends are left to die, they might not always be worth employing. That, however, is neither an argument against developing life-saving technologies nor an argument against employing such technologies in cases where life afterwards will in fact be worthwhile.

As for future societal and technological changes, we might ask how bad it would be for people from the past to be reanimated today. Would Aristotle, for example, if he were reanimated today, have a life worth living or would he be better off dead? Though it is, of course, difficult to tell, I am inclined to think that a reanimated Aristotle would be deeply intrigued by contemporary science, technology and philosophy, and that his life would be very much worth living. Aristotle, moreover, lived 2500 years ago, and presumably, the time gap for postcryonic reanimation would be significantly shorter.

As for work skills, there seem to be two main options. One option is that in the postcryonic future, work will no longer be necessary in order to create wealth.[14] In that case, reanimated cryonicists will not need to work. The other option is that work will still be needed. In that case, while some reanimated people might do roughly what they did before they were cryopreserved, others might need to change their career paths. Changing career paths, though it might be challenging, does not seem to be so bad that death is preferable, and it is common even today. Here it might be objected that in the future, people might to be so radically enhanced that the gap between reanimated cryonicists and others will be too huge to bridge through education. If this is what we fear, however, we must ask why, in a society where others are radically enhanced, reanimated cryonicists could not be enhanced in a similar manner. Of course, there is a real possibility that reanimated cryonicists will not be enhanced, that they will be so maladjusted that they will not find work, and that no welfare state or charity will help them. If they would just be left to die, however, it is puzzling why a future society would go through the trouble of reanimating them. It is also worth noting that if life after reanimation is intolerable, reanimated cryonicists can presumably commit suicide and thus put themselves back in the position of non-cryonicists.

[ii]Shaw discusses and rebuts a number of other objections to cryonics. See ref. 12, pages 516–19.

Even if we expect postcryonic life to be tolerably good, however, it might be further argued that it is bad for us not to die, and accordingly, bad for us to be cryopreserved. There are two versions of this argument: that dying is good for us as individuals and that it is good for society.

What concerns dying and individual welfare, a defender of cryonics might respond in two different ways. One is to deny that dying is beneficial. Though this debate is too complex to be dealt with here, denying that dying is beneficial for the individual who dies is at least prima facie reasonable, for dying is, after all, something that most of us struggle to avoid, and virtually all of medicine is founded on this premise. Another way to respond is to point out that cryonics offers the prospect of a longer life, not immortality. In this sense, there is no deep difference between cryonics and other life-saving technologies.

On a societal level, the central benefit of death is presumably the avoidance of overpopulation. Here again a defender of cryonics might respond in two different ways. One is to argue that overpopulation is unlikely to become a significant problem. This reply has some merit, for historically, the more developed a country becomes, the lower its birth rate, and as this trend continues, the world's population curve is flattening.[15] Second, even if the world's population will increase, it is not clear that a larger population is, in sum, a bad thing. Though a larger population brings many challenges, it also brings more specialisation and trade, and thus more wealth.[16] Predictions about the future should take into account the historic trend that the larger the world's population has become so far, the more wealth *per inhabitant* we have had.[17] If, in the future, we can 3D print most commodities, grow food in skyscrapers, and cheaply convert salt water to fresh water, it is not clear that a larger population is, in sum, negative.

The other way to respond is to argue that even if overpopulation will become a significant problem, this is insufficient to reject cryonics. Cryonics is a matter of life and death, and it might well be that an individual is not morally required to sacrifice his whole future for the sake of not burdening society with one additional life. What concerns public policy, it seems that even if overpopulation really becomes a pressing issue, we should not reject cryonics, but tax it so as to internalise the negative externalities that cryonicists (*ex hypothesi*) inflict on others by continuing to live. If we should tax cryonicists for contributing to overpopulation, however, we should presumably also tax others who contribute as much or more to overpopulation. Families that have three or more children are likely to contribute much more to the size of the human population three or four generations ahead than what individual cryonicists do.

A fourth argument against cryonics is that it will create a significant class difference between those who can afford it and those who cannot. We might get an upper class that lives for centuries while the lower classes die natural deaths as they do today. This argument is not convincing. First, cryonics is usually financed through life insurance, so it commonly costs only a few dollars per day. As such, cryonics is not a luxury good available only to a small elite. Second, the objection is not really an objection to cryonics at all, but an objection to a certain *distribution* of cryonics. To the extent that one takes this objection to be decisive, one should not reject cryonics, but rather promote general redistribution of wealth and perhaps seek to introduce cryonics into governmental healthcare programmes. Finally, the objection, rather than undermining the value of cryonics, rests on the very premise that cryonics is a significant good, for if it were not a significant good, why would it matter that only the rich had access to it?

A final objection is that cryonics is selfish: In a world with as much poverty as ours, the argument goes, it is morally problematic to spend significant resources on cryonics. In assessing this objection, two things must be kept in mind. First, the aim of cryonics is to preserve life, and it is not common to judge people as unduly selfish for trying to save their lives. If a woman (or her insurance provider) pays $150 000 for a double bypass surgery, we would usually not blame her. Typically, we do not even blame people for spending significant sums on houses, cars, clothes, books and vacations beyond what they need to live comfortable lives. Given this, why should we blame people for spending money on cryonics? Of course, a strict utilitarian might object to cryonics, as well as to nice houses, cars, vacations, books and even bypass surgeries, but as long as we think that we may cut ourselves at least *some* slack, and spend at least a portion of our money on ourselves, we might just as well spend that money on cryonics as on any other good—and since cryonics is potentially life-saving, we seem even more justified in spending it on cryonics. As such, the selfishness argument, like the previous one, does not really tell us much about cryonics. Rather, it is a reminder of the general fact that all the money that we spend could potentially have been given to a charity.

CONCLUSION

Cryonics is costly. It is also unproven, for it relies on the development of technologies that are not yet available and thus cannot be clinically tested. Neither its cost nor the fact that it is unproven, however, constitutes a knockdown argument, for though the chances that cryonics will work might be low, the potential value that it might help realise is very big, and the alternatives—burial and cremation—offer no potential value at all.

It is unfortunate, therefore, that cryonics receives minuscule attention. It is unfortunate, first and foremost, since if cryonics is in fact technically feasible, it has the potential to save millions of lives. Little public and academic attention, moreover, leads to little research and development, and though cryonics is carried forward by general research in cryobiology (especially whole organ cryopreservation[18]), more specialised research on cryonics would be beneficial, and would make cryonics available faster and to more people.

Cryonics also gives rise to a range of intriguing philosophical and legal questions that deserve more attention. What should be the legal status of cryopreserved people? Should they, for example, be allowed to retain property rights? Another question is whether patients with terminal illness should be allowed to undergo what we might call 'cryocide', cryopreservation before legal death. This would probably be technically advantageous, since when people are cryopreserved only after they have died natural deaths, their bodies are already damaged. It is also worth noting that some of the central ethical arguments against euthanasia or assisted suicide would not apply to cryocide, for the aim of cryocide would not be to end life, but to preserve it. Finally, since a lot of medical expenses are spent on the last few months of our lives, cryocide might make economic sense. Perhaps the resources that are currently spent on preserving a low quality life for a few extra weeks or months would be better spent on cryonics.

Finally, cryonics is psychologically interesting. For one, it might be interesting to explore if cryonics is widely rejected, not so much because of the weight of the reasons against it, but rather, because of a number of psychological factors. These might include status quo bias, the disgust elicited by imagining frozen bodies, our reluctance to confront our own mortality, and a failure to grasp that although an option that is *both* expensive *and* has a low probability for success should almost always be rejected in everyday life, when the alternative is certain death, it might well be the best option that we have. It might also be interesting to explore the potential psychological benefits of cryonics. For some, fear of death is a significant evil. With the prospect of being cryopreserved, facing death might feel less like being dragged to the execution chamber and more like embarking on a dangerous journey.

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