J. Cell. Mol. Med. Vol 12, No 5B, 2008 pp. 1785-1793

ETHICAL ISSUES IN CELLULAR AND MOLECULAR MEDICINE AND TISSUE ENGINEERING

Department of Plastic and Hand Surgery, University Hospital Erlangen, University of Erlangen-Nuernberg, Krankenhausstrasse 12, D-91054 Erlangen, Germany

Email: raymund.horch@uk-erlangen.de

Raymund E. Horch

Department of Cellular and Molecular Medicine, 'Carol Davila' University of Medicine and Pharmacy, 'V. Babes' National Institute of Pathology, Bucharest, Romania

Email: LMP@jcmm.org

L. M. Popescu

Department of Anesthesia at the Brigham and Women's Hospital Brigham and Women's Hospital, 75 Francis Street, Harvard Medical School, Boston, MA 02115, USA

Email: cvacanti@partners.org

Charles Vacanti

Institute for Bioethics and History of Medicine, University of Freiburg, Stefan-Meier-Str. 26, D- 79104 Freiburg, Germany

Email: giovanni.maio@uniklinik-freiburg.de

Giovanni Maio

All theory, dear friend, is gray,
but the golden tree of life springs ever green.

Johann Wolfgang Goethe

Motto

"omnis cellula e(x) cellula"
("Every cell is derived only from a preexisting cell").

Rudolf Virchow

Introduction

The objective of tissue engineering is to create or recreate living body parts or organs that will fully integrate with the recipient's body. The advent of tissue engineering as a new field of research with a high potential towards the clinical care of patients from bench to bedside has involved numerous different scientists in various fields of cellular and molecular medicine, material research, engineering, physics, chemistry, computational research and allied disciplines [1–5]. Due to a potentially enormous impact on the health of our society – that is as a whole continuously becoming older – tissue-engineered solutions to circumvent natural degenerative processes have become of great interest. They may aid to maintain a high quality of life in the elderly. This issue has been widely acknowledged, but has created numerous debates also. Many of the techniques applied in research and in practical applications of nowadays tissue engineering approaches [3] with direct or indirect relation to the care of human beings seem to be straight forward and do not offer a sufficient potential for ethical debates [6–8].

Nevertheless, innovative medical research and new technologies always raise ethical and policy concerns. In biomedical research, these issues include the ethical conduct of basic and

*Correspondence to: Prof. Dr. R. E. HORCH, M.D., Department of Plastic and Hand Surgery and Laboratory of Tissue Engineering and Regenerative Medicine, University Hospital Erlangen, Friedrich-Alexander -University of Erlangen-Nuernberg, Krankenhausstrasse 12, D-91054 Erlangen, Germany. E-mail: raymund.horch@uk-erlangen.de

doi:10.1111/j.1582-4934.2008.00460.x

clinical research as well as the equitable distribution of new therapies [7]. While questions of intellectual property have been widely published in this context, there is limited literature on ethics in cellular and molecular medicine and for the field of tissue engineering [6, 9, 10].

With respect to the ethics of tissue engineering, Derksen and Horstman [11] have suggested that one can roughly distinguish two perspectives. On the one hand, this technology could be considered morally good because tissue engineering is 'copying nature'. On the other hand, tissue engineering could be considered morally dangerous because it defies nature: bodies constructed in the laboratory are seen as unnatural. The tremendous public attraction that the implantation of cultured chondrocytes in the form of a human ear cartilage (which was implanted under the skin of a nude mouse and that was eventually called auriculosaurus [1]) gained rapidly all over the world is a vivid testimony to the perception of people when confronted with such spectacular and obvious research efforts. Based on the discussion of the engineering of heart valves, authors have proposed that the ethics of tissue engineering should be framed not in terms of 'natural' or 'unnatural' but in terms of 'good embodied life' and 'lived integrity' [11].

Historical aspects

While research with stem cells from the very beginning has evoked many controversial debates worldwide not only within the recent years (especially when those cells are derived from embryos), there is comparatively little public debate on ethical issues in cellular and molecular research, when it is not directly correlated to clinical applications.

A survey of the literature reveals that the term 'ethics' in cellular and molecular medicine is not covered in a database such as PubMed, while the term ethics and cellular medicine offers 608 papers published between 1967 and 2008. Decades ago, early papers such as Vogels report on: 'Can we count on the possibility of manipulation in the field of human genetics? May we and are we permitted to breed people?' [12] or Hirschhorn's comment on 're-doing man' [13] were discussing the principle question and the fear of any manipulation of the human genetic information at all. At that time even reproductive medicine was in its childhood as Ramsey's considerations on the medical ethics of *in vitro* fertilization show [14, 15]. However, it has to be remembered that at the same time the first successful clinical heart transplantation was made public in 1967. The public confusion of transplanting organs from one human being into another – especially the human heart – was considerable. It is widely recognized that despite better knowing about the function of the brain even nowadays feelings are literally more associated with the heart than the brain. The famous quotation of Antoine De Saint Exupery *'It is only with the heart that one can see rightly; what is essential is invisible to the eye'* may serve as a vivid example of this phenomenon. Looking back into this field of scientific publication nowadays such questions seem to have been more or less answered over the time, although it is clear that they cannot be definitely solved for every opinion and for all times.

For instance, the field of *in vitro* fertilization to overcome human infertility has become a clinical routine worldwide and is currently being financed by many social security systems in developed countries.

Genetic manipulation of the human genome seems nothing spectacular today. The human genome has been decoded in many aspects and DNA fingerprint tests are popular practice in many fields of our daily life. This demonstrates that parallel to any progress in cellular and molecular research the debates also are subject to changing perceptions over time. Issues that have been extremely controversial decades ago have become less critical in the public perception today and new challenges arise with the ever-progressing efforts in cellular and molecular research. Ethically of course the acclimatization to habits that have become daily practice does not mean that they are ethically unobjectionable by themselves. However, an ethical reflection should not be addicted to fashions and should keep in thinking critically.

Nevertheless, due to the translational character of cellular and molecular medicine [16–19] many critical questions can arise from this field of research that may pose ethical problems.

Stem cell research in cellular and molecular medicine and tissue engineering

It is always difficult to estimate the true benefits to individuals and to society that are gained by the introduction of new drugs or medical technologies. As an example it may be recognized that the introduction of antibiotics and vaccines has enormously increased our life spans and improved the health conditions of people all over the world. Nevertheless still major illnesses such as cancer, diabetes mellitus, Alzheimer's disease, heart disease are ongoing and challenging conditions, which desire continuous research on a cellular and molecular basis. Research in human developmental biology has led to the discovery of human stem cells that have been described for many decades and that have been subject to multiple investigations. Human stem cells are precursor cells that can give rise to multiple tissue types, including embryonic stem (ES) cells, embryonic germ (EG) cells, and adult stem cells. The discovery of techniques for the *in vitro* culture of stem cells has provided unprecedented opportunities for studying and understanding more about human biology [20]. In human beings, transplants of haematopoietic stem cells following chemotherapeutic treatments for cancer, for example, have been routinely administered for many years now.

It has been proposed by scientific communities that persons considering donating their excess embryos for research purposes should be afforded the highest standards of protection for the

informed consent and voluntariness of their decision [21]. But if the human embryo is seen as a human being – and there are a lot of reasons to do this – there remains the question why medicine does not prevent supernumary embryos at all from the ethicist's standpoint. In view of the moral concerns surrounding the uses of embryonic and foetal tissue voiced by a segment of the American population, it has been proposed by the *AAAS* (*American Association for the Advancement of Science*, *Science* magazine) that strengthening federally and privately funded research into alternative sources and/or methods for the derivation of stem cells, including further initiatives on adult stem cells, should be encouraged [21]. According to their statements human stem cell research can be conducted in a fully ethical manner, but it is considered to be true that the extraction of embryonic stem cells from the inner mass of blastocysts raises ethical questions for all those who consider the intentional loss of embryonic life by intentional means to be morally wrong. Also, the derivation of embryonic germ cells from the gonadal tissue of aborted foetuses is problematic for those who oppose abortion [21]. From an ethical point of view there are enough objections at the moment to the process of deriving stem cells to consider AAAS recommending against its public funding.

In contrast, adult stem cell research is more broadly acceptable to the population. Generally there seems to be no discussion in the media about the so-called adult stem cells, since the potential benefit appears to be very high and the utilization of the patient's own cells poses no serious ethical conflict.

Although it is impossible to predict the potential outcome, momentarily worldwide many experiments carried out that aim towards the determination of the mechanisms underlying the conversion of a single, undifferentiated cell into the different cells comprising the tissues and organs and of the human body. A high potential of therapeutic effects has been claimed for this field of research, but is still not sufficiently understood or proven. Given the widely unsolved ethical, legal, religious and policy questions, the potential use of stem cells to generate replacement human tissues and, perhaps, whole human organs, remains a subject of ongoing public debate. For the majority of problems arising from embryonal stem cell research, we want to refer to the pertinent literature that is ample and multidimensional [21–27].

There is already preliminary existing evidence from animal studies that stem cells could potentially differentiate into cells of choice, and it is hoped that these cells then would act properly in their transplanted environment. Further, somewhat cruder experiments (*e.g.* the transplantation of foetal tissue into the brains of Parkinson's patients) could indicate that the expectation that stem cell therapies could possibly provide robust treatments for many human diseases may be a reasonable one, although this has not been definitely proven today. It is only through controlled scientific research that the true promise will be understood.

Recent publications on the re-programming of adult cells into embryonal-like cells (gPS, "germline derived pluripotent stem cells") that behave similar to stem cells [28] may well bridge the gap between current controversial stand points. The different ways to reprogram adult cells might offer the possibility to produce customized stem cells with the genetic material of the individual patient [27]. This method would not need the harvest of stem cells from embryos that then necessarily have to be destroyed – an act that is forbidden by law in many countries, such as Germany for instance.

For the moment, in tissue engineering the application of embryonic stem cells is not a commonly accepted practice, while human adult stem cells are the object of frequent investigations [29, 30].

Ethical aspects of mixing human and animal tissues

Many experiments in various fields of research in cellular and molecular medicine are performed worldwide on a daily routine without a thorough discussion of ethical implications. In tissue engineering, it is common practice to seed human cells on biomaterials. Cultured or non-cultured human cells are frequently seeded onto experimental animals [4, 31–34]. Ethically this creates a combined human-animal being, also called chimera. Such chimeras are commonly perceived as individuals, organs, or parts of an organism consisting of tissues of diverse genetic constitution [35]. However, it remains controversial how much diverse genetic constitution is needed to be allowed to call it chimera. The question has been brought up by the ethical committee of first author's former University how it has to be considered if chimeric animals with incorporated human cells are still alive and subject to experimental studies while the original cell donor may have deceased due to any reason. Although this question seems to be artificial there is no clear answer how such a chimera has to be considered, since it carries tissues or stromal cells from a former human being and may potentially reproduce itself and theoretically propagate the parts of the initial cell donator. In the current literature, this issue has not been addressed so far [36].

With regard to tissue engineering such models have been and are used frequently for experimental purposes and have been reviewed by numerous ethical committees to be unproblematic. This holds true as long as confidentiality and patient privacy is secured when working with tissues or cells in such models and ensuring appropriate use of the material for scientific reasons only.

If stem cells are applied in this way, a plethora of ethical questions arise immediately. Karpowicz *et al.* [22] addressed the question if it is ethical to transplant human stem cells into non-human embryos. They postulated that in the future human or non-human stem cell chimeras will be increasingly applied to study human cells in developing non-human animals. Such experiments raise a number of issues that may create further controversy in the stem cell field. These authors tried to outline the scientific value and ethical ramifications of such studies. In addition, they try to give suggestions how such experiments may be conducted ethically. It is proposed that the transplantation of human stem cells into prenatal non-human animals would allow researchers to

study human cell development without directly using human embryos. Intrinsic value and animal integrity are two key concepts in the debate on the ethics of the genetic engineering of laboratory animals. These concepts have, on the one hand, a theoretical origin and are, on the other hand, based on the moral beliefs of people not directly involved in the genetic modification of animals [35]. In a study comparing the moral experiences and opinions of people directly involved in the creation or use of transgenic laboratory animals to people not directly involved in the genetic modification of animals it has been strongly suggested that these concepts would not have to be adjusted or extended in the light of the moral experiences and opinions from practice [35]. Nevertheless from the ethicist's point of view it remains a question whether such chimeric organisms have to be created at all. Even the aim to create chimeras could theoretically be seen as an ethical assault.

In order to regenerate dysfunctional human tissues, the observation of large-scale human cell actions in comparative animal models is deemed necessary to advance future research. This may help to investigate human stem cell plasticity. Because embryonic stem cell transplants have been reported to form tumours in postnatal rats [24], researchers have successfully begun to assay human embryonic stem cell function using prenatal chimeras [37]. As an example, retinal stem cells (RSC) found in the adult mammalian eye [38] form an adult somatic cell population that represents a potentially valuable therapeutic tool. RSC transplants are believed to eventually restore sight, and perhaps treat otherwise intractable diseases, such as macular degeneration and retinitis pigmentosa. Understanding the specification of retinal fate during human development, from embryonic cell to early neuroectoderm and later retinal lineages, is useful and necessary before replacing large areas of the human eye becomes possible [22, 23].

According to Karpowicz *et al.* [22] for molecular biologists, chimeric DNA refers to sequences derived from two sources and combined into one; for cell biologists, there are nucleocytoplasmic hybrids involving somatic cell nuclear transfers (cloning) within or between species; for embryologists, chimeras are prenatal combinations of cells derived from different zygotes, either intraspecies or interspecies; for geneticists, there are interspecies genetic hybrids such as the mule; and finally, there are interspecies xenografts of tissue into postnatal hosts. When we use the term 'chimera' here, we mean transplants of human stem cells into prenatal non-human animals, although more broadly speaking, any of the above combinations can use this analysis [22, 23].

It has been formulated that two hypothetical human/non-human RSC chimera experiments could be undertaken: (*i*) transplants of adult human RSCs into early embryonic mice at the blastocyst stage, or (*ii*) transplants of adult human RSCs into the eye and brain of foetal monkeys. The first of these would be a preanatomic chimera assay, a test of whether human cells can participate in the morphogenesis of non-retinal mouse tissues. The second would be a late chimera assay, a restricted and postanatomic analysis of human RSC contributions to preformed tissue types [22]. These authors have referred to the Aristotelian teleological philosophy, which maintains that all living things have an inner tendency to reach their appropriate ends or goals, and that their biological functions enable them to achieve this. Contemporary proponents of this approach argue that although the proper ends of humans may differ radically from that of mice or monkeys, the intentional alignment of each with their respective ends is a moral good. According to this view, it would be wrong to tamper with nature in ways that prevent living beings from achieving their natural ends or pursuing their natural way of flourishing [39, 40]. If the merger of human and non-human tissues within chimeras frustrates the ends of the beings involved, it would be unnatural and therefore wrong.

Interestingly it can also be objected that, in principle, teleological guidance may also leave us to speculate endlessly about the 'natural' purposes of virtually all living things. On the other hand, it can offer only few clues as to what decisions are right [22]. Thus purely teleological arguments do not give a clear-cut answer to the question if it is ethically right to prohibit or to support the making of chimeras as ethically acceptable with any assurance.

Accordingly, there has been reasonable dispute in the past about limits of medical actions when we do interfere with the dysfunctioning human organism by surgery, medical interventions and transplantations for instance. Therefore, it cannot be generally regarded to be wrong to intervene into these functions or keep them from reaching certain ends. The context in which such interventions are carried out, not just the biological function of the organism and its components, has import on assessing whether that intervention is considered right or wrong [22].

Although it is doubtful, for example, whether human functions could ever arise in an embryonic mouse host, the entire prenatal development time of which is a mere fifteenth of a human being's, Karpowicz and co-authors have proposed some limits to chimeric experiments [22]. They suggested that the number of human cells transferred should be limited, that the choice of host animals for early blastocyst chimeras be deliberate, and that dissociation of human cells, rather than postanatomical tissue transplants should be applied for later embryonic chimeras. According to these suggestions, fewer human cells, in principle, would reduce the degree of 'humanization' in early chimeric experiments, as the host cells would outnumber the human cells. To ensure any potential psychological impact of neuronal alterations in chimeric organisms, the use of non-human animals that are closely functionally or morphologically related to humans should be only attempted during later embryonic development, when the host's unique neural networks have already formed to the point that human incursion could not occur. Dissociation of human stem cell xenografts into early or later embryonic hosts could be regulated if necessary, to guard against the possibility of human characteristic pattern formation and development [22].

The mixing of genes, human and animal cells or tissues from humans with those of animals has been studied for many years. In reality, techniques involving human-animal combinations have been used in the laboratories for decades. For instance, the utilization of animal cells (irradiated mouse fibroblasts) as carriers for the culture of human keratinocytes has been common practice for decades by now. The transplantation of cultured human keratinocytes propagated on animal cell feeder layers has also been published to be life saving in extensively burned patients

[41–46]. Serum-free culture techniques and utilization of biomaterials have been introduced to circumvent animal influences on cultured human cells [43, 44, 46]. Suggestions that animal eggs should, for example, be used to create hybrid human-animal embryos have elicited some strong reactions in the international news. Guidelines and regulations have to be discussed freely in the scientific community and should be brought on their way with the help of ethicists.

Gene therapy in cell science and tissue engineering

It is quite obvious that the potential market for gene-specific pharmaceuticals is huge. Hence, research in cellular and molecular medicine involving alteration of the genome is one of the cornerstones of scientific progress. Ethically, the idea of gene therapy is to introduce or to alter genetic material to compensate for a genetic mistake that causes disease. By doing so, it is hoped that one day by means of gene therapy diseases can be treated or cured for which up to now no other effective treatments are available.

However, many unique technical and ethical considerations have been raised by this comparatively new form of treatment [47]. Consecutively several levels of regulatory committees have been established to review each gene therapy clinical trial prior to its initiation in human subjects. Ethical considerations include the decision which diseases and/or traits are eligible for gene therapy research, how gene therapy can be safely tested and evaluated in humans, which cell types should be used, what components are necessary for informed consent.

Several ethicists have argued that genes and genetically modified organisms should be considered part of the common heritage of all people. Other thinkers and advocates have raised equity issues about the role of patents in impeding development and access to beneficial technologies. The World Health Organization has reminded member states that 'justice demands equitable access to genetic services'. WHO has also stated that '*Genetic services for the prevention, diagnosis and treatment of disease should be available to all, without regard to ability to pay, and should be provided first to those whose needs are greatest.*' [48]

While the fascination of genetic information has rapidly come to be appreciated by societies at large, it is also narrowly perceived that only analyses involving nucleic acids (*i.e. DNA*, *RNA*) yield genetic information. The fact that superficially '*non-genetic*' analyses, *e.g.* of proteins, hormones, metabolites and even radiologic imaging may, in certain situations, be equally informative as genotyping appears to have escaped many [49]. This may explain the individual tendency to handle what is wrongly perceived to be '*non-genetic*' medical information with much less care and attention to bioethics concerns than overtly 'genetic' information. Given the relatively large corpus of medical information not derived from *DNA* or *RNA* analysis, this issue is by far more complex and continues to challenge items of privacy in cell and tissue research with regard to individual and epidemiological data acquired from such research [50].

Although a considerable discussion about gene therapy has been reported long before the first approved human gene therapy trial in 1990 was initiated on severe combined immune deficiency patients the debate remains controversial [26, 51–56].

Internationally, numerous policy statements on human genetic intervention have been published, all of which support the moral legitimacy of somatic-cell gene therapy for the cure of disease. The debate over the ethical issues related to somatic-cell gene therapy has evolved over a 10-year period [56]. When lay perceptions about gene-based therapy are explored there are differences in the perception in various countries and societies. A survey in Iceland, following an intensive public debate on the consequences of the Human Genome Project over the next 40 years, revealed that the lay public was relatively optimistic with regard to the future of drugs and gene-based therapy. Reasons for this optimism were considered to be found in a basic trust and belief in the welfare state and the health system of this country. These results are not consistent with studies carried out in other countries where the public appears to be focused on the negative effects of genetic research and the threats to privacy [55].

Since the hallmark of ethical medical research is *informed consent* it has been considered to be important that voluntary consent be imperative in this context. The dilemma can arise when gene therapy may be the only possible treatment, or the treatment of last resort, for some individuals. In such cases, it becomes questionable whether the patient can truly be said to make a voluntary decision to participate in the trial. These criteria do not apply when genetic alterations are performed in a strictly experimental laboratory setting and when there is no application to human beings [50].

Richter and Bacchetta [47] have proposed a three-dimensional framework for the ethical debate of gene therapy where they added the genomic type (*nDNA versus mtDNA*) as a third dimension to be considered beside the paradigmatic dimensions of target cell (somatic *versus* germ-line) and purpose (therapeutic *versus* enhancement). According to their considerations somatic gene therapy can be viewed today as generally accepted. They conclude that many of the supposed ethical questions of somatic gene therapy today were not new at all, but should be considered as rather well-known issues of research ethics.

Tissue banking for cellular and molecular science and tissue engineering

Although tissue banking in some form or another has been practised for well over a century, it is only in the last decade that tissue banking has come into the public limelight with the recent surge of interest in the new life sciences, and in particular, in the fields of human genetics and genomic research. Tissue banking as

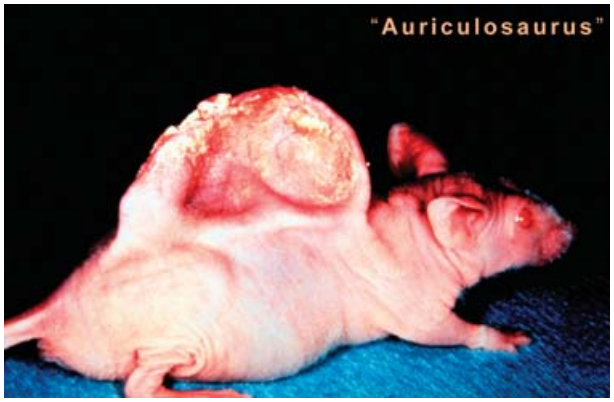


Fig. 1 Photograph of infamous mouse with the human ear, depicting new tissue-engineered cartilage generated in the shape of a human ear (C. A. Vacanti. Ref. [1]).

a means to provide material for medical research is by far not a new phenomenon. The German pathologist Rudolf Virchow [58] for instance initiated the first known repository in 1847. He eventually amassed more than 23,000 human tissue specimens. Ever since that time a large number of (mainly pathology or dermatology) departments in academic medical institutions and hospitals around the world is housing temporary or permanent collections of preserved human tissues and or organs. In his ground-breaking book 'Die Cellularpathologie in ihrer Begrundung auf physiologische und pathologische Gewebelehre...' ('Cellular Pathology in its foundation on physiological and pathological tissue science') (see Fig. 1), published in 1858, he set a cornerstone of modern medicine and biology based upon physiological and pathological histology with his postulate: *'omnis celula e(x) cellula' ('Every cell is derived only from a preexisting cell'*. He originated the idea that each cell in each living organism, both plant and animal, originates from another cell and that the origin of disease can only be located in the cell.

Essentially, it has to be reminded that Rudolf Virchow, with his book, changed abruptly the scientific thoughts and conceptions in the whole field of medicine and biology at his time.

Presumably, for the father (or founder) of pathology the (human) body is like a 'cell state' in which each cell acts as a 'citizen'! Accordingly, this could metaphorically be called a *'cell democracy'*. Virchow's assemblage of tissues was an invaluable tool for his research efforts.

There is no doubt that tissue samples in such collections that were originally sampled for patient-related diagnostic procedures now serve as an invaluable tool and resource for research purposes. Concurrent with the enormous advancement of genomic research it now seems very realistic that large-scale genotyping and the investigation of the human genome with new techniques for high capacity molecular characterization will yield a plethora of discoveries to both academia and industry. For instance, vital epidemiological information about the pattern and incidence of occurrence of various forms of diseases such as cancers has been (and continues to be) gained from human tissue research, and through the analysis of such information, important discoveries about the prevention, control and treatment of such diseases have been made for the benefit of humankind [49].

Currently, there are no clear guidelines as to whether referring or sending physicians have a right to demand the return of these tissue samples. At the Singapore University, it has been suggested that if non-institutional collections have to be made for any reason (for example, collections of a specific kind of tissue pursuant to a specific research project), such collections should only be assembled on the understanding that the human tissues collected will eventually be consolidated with the larger collections of institutions (for example, by a hospital, a university or a research institution) [49]. Institutional human tissue holdings should then set up a current database of all human tissue holdings within that institution. Such a database could be part of the institution's database of research projects, with information fields such as the research area, disease, human tissue collected, where they are stored within the institution, and the units and persons responsible for these human tissues. This is recommended because the size of holdings is also an important benefit of consolidation: a large-scale collection is believed to be more useful (particularly for population studies) than a small and limited collection [49].

Ethically one can discern the collection of tissues or cells in such banks into therapeutic/diagnostic tissue collections (samples are kept only as a part of the medical records of patients and are not applied towards research purposes) from the collection of cells and tissue for research purposes. If the latter aspect is pursued in combination with diagnostic/therapeutic sampling, adequate informed consent of the individual has to be obtained to fulfil ethical requirements.

There has also been a parallel trend towards the establishment of collections of human tissue in which the biological material remains viable or potentially viable, at least in some respects, at the cellular level. For instance, human tissue samples may be flash-frozen, and/or living cell lines may be propagated on culture media. This greatly increases the value of the samples for many lines of research. Institutions such as the Singapore University have taken the view that such purposed-assembled research banks are to be encouraged, provided that all appropriate ethical and legal considerations and concerns are appropriately met and addressed, as they promote and enhance research, which offers the promise of immense benefit in the future for humankind.

At the present time, there does not appear to be any uniform approach to the governance and regulation of tissue banking internationally. The Draft Discussion Document entitled *Data Storage and DNA Banking for Biomedical Research: Informed Consent, Confidentiality, Quality Issues, Ownership, Return of Benefits: A Professional Perspective* issued by the Public and Professional Policy Committee of the European Society of Human Genetics as part of the EUROGAPP Project 1999–2000 offers an illuminating survey of the gamut of existing opinions, legislation, guidelines and other policy statements applied in or issued by EC institutions, 18 European countries, the United States, and international organisations. Except in the case of the United States,

and possibly France, the majority of the jurisdictions surveyed are notable more for the absence of specific agreed national guidelines or legislation than by the presence of such in relation to storage of data derived from human tissue research and DNA banking. One of the prerequisites from an ethical standpoint seems to be that informed consent should be obtained from any potential donor of tissue or cell samples if there is any possibility that donated tissue samples may in the future be made available for commercial research with consequent financial benefit or gain to third parties, then this possibility must be made clear to donors at the very outset even if the arrangement is to be that the donors completely renounce their rights to any share of these gains or benefits [49].

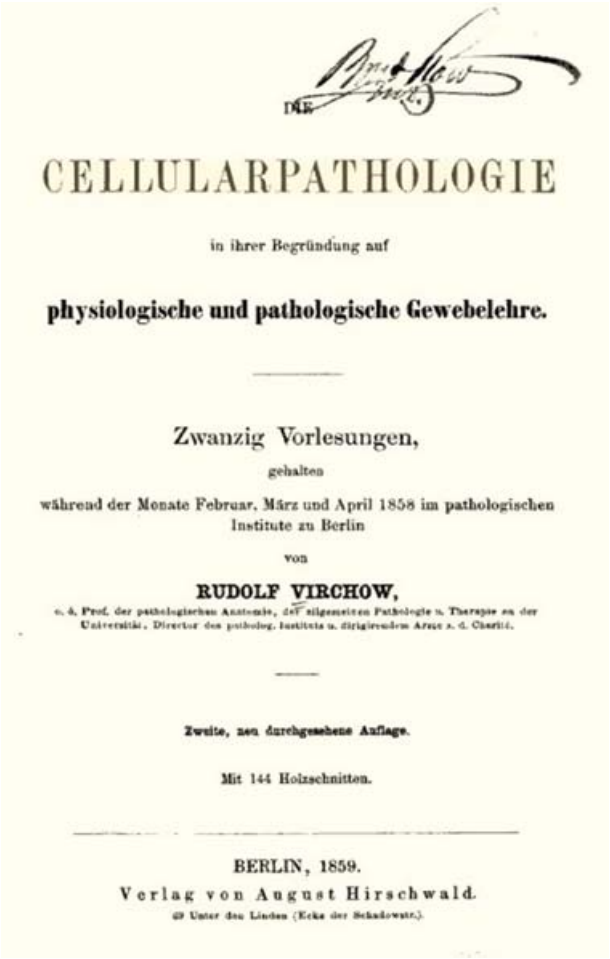
It can be also recommended that all research using human tissue samples should be approved by an appropriately constituted research ethics committee or institutional review board. In addition it should be common sense that researchers and all those involved in the conduct of tissue banking have an obligation to protect the confidentiality of the personal information of donors entrusted to them, as well as the privacy of donors.

Legal and intellectual property considerations

Ex vivo tissue-engineered products have been around for the last decade and are now increasingly entering clinical trials. Autonomous decision making on their participation is believed to be a prerequisite to allow prospective recipients of such tissue-engineered products to decide upon any legal and ethical aspects of such procedures. Compared to current practice in cell and tissue transplantation there are new elements in the transplantation of *ex vivo* tissue-engineered materials. These can be summarized into (*i*) the source and manipulation of the cells in the product, (*ii*) the implantation of the product and (*iii*) the additional risks and benefits due to the construction of the product and its activity in the body [9].

Thorough informed consent should be reached that takes the specific aspects of tissue engineering into account. The delicate nature of specific cell types and the various complexities of the tissue engineering process as well as its implications have to be made clear. When a clinical trial is conducted with such tissue-engineered products, any crucial issue, potential benefits and specific and general risks have to be made clear to the potential recipient according to his capacity to understand the whole procedure. The assistance of informed third parties has been proposed to help participants in their decision-making processes [9].

Attempts of governmental regulatory boards such as the European Commission to develop a directive to regulate all tissue-engineered products in a comprehensive yet flexible framework have been criticized from an ethical viewpoint [10]. It has been argued that there are shortcomings to such proposals because of disjunctures at various regulatory levels and because responsibilities of several authorities have not been clearly established.


DIE

CELLULARPATHOLOGIE

in ihrer Begründung auf

physiologische und pathologische Gewebelehre.

Zwanzig Vorlesungen,

gehalten

während der Monate Februar, März und April 1858 im pathologischen Institute zu Berlin

von

RUDOLF VIRCHOW,

Zweite, neu durchgesehene Auflage.

Mit 144 Holzschnitten.

BERLIN, 1859.

Verlag von August Hirschwald.

Fig. 2 With his publication of 'Die Cellularpathologie in ihrer Begruendung auf physiologische und pathologische Gewebelehre' in 1859, Rudolf Virchow (1821–1902) originated the idea that each cell in each living organism, both plant and animal, originates from another cell and that the origin of disease can only be located in the cell. This book is widely believed to have laid the foundations for cell pathology as a scientific discipline.

The appropriateness of patenting gene patterns, DNA sequences and life forms has been a source of considerable controversy. Generally before the advent of modern genomic research, until 1980, life forms were considered to be 'products of nature' and ineligible for patent protection. In the 20 years since the first biotechnology patents were granted, various critics have claimed that the patenting of living things promotes a reductionist conception of life that removes any distinction between living and non-living things. Some scientists and lawyers have questioned whether these patents promote the future biomedical research [48, 49].

Conclusion

There is no doubt that numerous advancements of science have transformed our lives in a way that would have been unthinkable of just a century ago. While many aspects seem to be common sense today, the field of embryonic or adult stem cell research raises a lot of severe ethical questions. It is unclear at the moment if results of stem cell research will have a similar effect than other scientific achievements, but the promise is so great that it seems wise to consider seriously how best to further such research in a manner that is sensitive to ethical objections. Public perceptions and conversations and ethical objections about research and use of human stem cells should be recognized and embedded into an ongoing dialogue. The authors want to bring to the public awareness that not always a clear-cut separation of the ethical problems and the pragmatic approach to biomedical decisions – including the field of molecular and cellular medical interventions – can be easily made.

Similar to others [49] we take the view that the vast majority of scientists and researchers in cellular and molecular medicine are responsible and are acutely aware of potential ethical concerns in the work that they do, and in that which they may propose to carry out. Scientists do not presume to know all the answers and ramifications of basic research in human cells. Most wish to do what is ethically right. Indeed, many may be inhibited from participating in some areas of research (which may in fact be entirely acceptable to the community, and in the public interest) by the lack of clear ethical direction or agreement on a given point, or by uncertainty generated by controversy in related areas.

Therefore, it is important to promote continued dialogue among all segments of society concerning the implications of cellular and molecular research. Ongoing educational processes fostered by public institutions and supported by researchers that informs such public dialogue seems desirable. As stated by the AAAS it should be recognized that science does not exist in isolation from the larger community that feels its effects, whether perceived as good or bad. The work of scientists is, and should be, conditioned and directed by consideration of broader human values. This means that the development of public policy, especially where highly controversial matters are involved, must take all interested sectors of the public into account. It is only through broad-based participation that the values of all stakeholders in the research enterprise can be carefully considered and weighed [21].

References

1. **Vacanti CA.** The history of tissue engineering. *J Cell Mol Med.* 2006; 10: 569–76.
2. **Vacanti JP.** Tissue engineering: from bench to bedside *via* commercialization. *Surgery*. 2008; 143: 181–3.
3. **Vacanti MP, Vacanti CA.** Composite tissue formation derived solely from a blood biological matrix: a preliminary study. *Transplant Proc.* 2008; 40: 1696–9.
4. **Horch RE.** Future perspectives in tissue engineering. *J Cell Mol Med.* 2006; 10: 4–6.
5. **Kneser U, Schaefer DJ, Polykandriotis E, Horch RE.** Tissue engineering of bone: the reconstructive surgeon's point of view. *J Cell Mol Med.* 2006; 10: 7–19.
6. **Merryman WD.** Development of a tissue engineered heart valve for pediatrics: a case study in bioengineering ethics. *Sci Eng Ethics.* 2008; 14: 93–101.
7. **Vallero DA.** Beyond responsible conduct in research: new pedagogies to address macroethics of nanobiotechnologies. *J Long Term Eff Med Implants.* 2007; 17: 1–12.
8. **Reed JA, Patarca R.** Regenerative dental medicine: stem cells and tissue engineering in dentistry. *J Environ Pathol Toxicol Oncol.* 2006; 25: 537–69.
9. **Trommelmans L, Selling J, Dierickx K.** Informing participants in clinical trials with *ex vivo* human tissue-engineered products: what to tell and how to tell it? *J Tissue Eng Regen Med.* 2008; 2: 236–41.
10. **Trommelmans L, Selling J, Dierickx K.** A critical assessment of the directive on tissue engineering of the European union. *Tissue Eng.* 2007; 13: 667–72.
11. **Derksen MH, Horstman K.** Engineering flesh: towards an ethics of lived integrity. *Med Health Care Philos.* 2008; 11: 269–83.
12. **Vogel F.** Can we count on the possibility of manipulation in the field of human genetics? May we and are we permitted to breed people?. *Hippokrates.* 1967; 38: 640–50.
13. **Hirschhorn K.** On re-doing man. *Ann N Y Acad Sci.* 1971; 184: 103–12.
14. **Ramsey P.** Shall we "reproduce"? II. Rejoinders and future forecast. *JAMA.* 1972; 220: 1480–5.
15. **Ramsey P.** Shall we "reproduce"? I. The medical ethics of *in vitro* fertilization. *JAMA.* 1972; 220: 1346–50.
16. **Popescu LM, Ciontea SM, Cretoiu D.** Interstitial Cajal-like cells in human uterus and fallopian tube. *Ann N Y Acad Sci.* 2007; 1101: 139–65.
17. **Radu E, Regalia T, Ceafalan L, Andrei F, Cretoiu D, Popescu LM.** Cajal-type cells from human mammary gland stroma: phenotype characteristics in cell culture. *J Cell Mol Med.* 2005; 9: 748–52.
18. **Suciu L, Popescu LM, Gherghiceanu M.** Human placenta: *de visu* demonstration of interstitial Cajal-like cells. *J Cell Mol Med.* 2007; 11: 590–7.
19. **Popescu LM, Gherghiceanu M, Hinescu ME, Cretoiu D, Ceafalan L, Regalia T, Popescu AC, Ardeleanu C, Mandache E.** Insights into the interstitium of ventricular myocardium: interstitial Cajal-like cells (ICLC). *J Cell Mol Med.* 2006; 10: 429–58.
20. **Hannig M, Figulla HR, Sauer H, Wartenberg M.** Control of leukocyte differentiation from embryonic stem cells upon vasculogenesis and confrontation with tumour tissue. *J Cell Mol Med.* 2008; 4.
21. **AaftAoSalfC Society.** Stem cell research and applications: monitoring the frontiers of biomedical research. The National Institutes of Health resource for stem cell research. 2007; National Institutes of Health, U.S. Department of Health and Human Services (Research Ethics and Stem Cells. In Stem Cell Information).
22. **Karpowicz P, Cohen CB, van der Kooy D.** It is ethical to transplant human stem cells into nonhuman embryos. *Nat Med.* 2004; 10: 331–5.
23. **Karpowicz P, Cohen CB, van der Kooy D.** Developing human-nonhuman chimeras in human stem cell research: ethical issues and boundaries. *Kennedy Inst Ethics J.* 2005; 15: 107–34.
24. **Bjorklund LM, Sanchez-Pernaute R, Chung S, Andersson T, Chen IY, McNaught KS, Brownell AL, Jenkins BG, Wahlestedt C, Kim KS, Isacson O.** Embryonic stem cells

develop into functional dopaminergic neurons after transplantation in a Parkinson rat model. *Proc Natl Acad Sci USA.* 2002; 99: 2344–9.

25. **Goldstein R, Drukker M, Reubinoff B, Benvenisty N.** Integration and differentiation of human embryonic stem cells transplanted to the chick embryo. *Dev Dyn.* 2002; 225: 80–6.
26. **Peters T.** "Playing God" and germline intervention. *J Med Philos.* 1995; 20: 365–86.
27. **Yamanaka S.** Induction of pluripotent stem cells from mouse fibroblasts by four transcription factors. *Cell Prolif.* 2008; 41 Suppl 1: 51–6.
28. **Yamanaka S.** Pluripotency and nuclear reprogramming. *Philos Trans R Soc Lond B Biol Sci.* 2008; 363: 2079–87.
29. **Vacanti V, Kong E, Suzuki G, Sato K, Canty JM, Lee T.** Phenotypic changes of adult porcine mesenchymal stem cells induced by prolonged passaging in culture. *J Cell Physiol.* 2005; 205: 194–201.
30. **Weinand C, Gupta R, Huang AY, Weinberg E, Madisch I, Qudsi RA, Neville CM, Pomerantseva I, Vacanti JP.** Comparison of hydrogels in the *in vivo* formation of tissue-engineered bone using mesenchymal stem cells and beta-tricalcium phosphate. *Tissue Eng.* 2007; 13: 757–65.
31. **Bach AD, Arkudas A, Tjiawi J, Polykandriotis E, Kneser U, Horch RE, Beier JP.** A new approach to tissue engineering of vascularized skeletal muscle. *J Cell Mol Med.* 2006; 10: 716–26.
32. **Fiegel HC, Kaufmann PM, Bruns H, Kluth D, Horch RE, Vacanti JP, Kneser U.** Hepatic tissue engineering: from transplantation to customized cell-based liver directed therapies from the laboratory. *J Cell Mol Med.* 2008; 12: 56–66.
33. **Fiegel HC, Pryymachuk G, Rath S, Bleiziffer O, Beier JP, Bruns H, Kluth D, Metzger R, Horch RE, Till H, Kneser U.** Fetal hepatocyte transplantation in a vascularized AV-loop transplantation model in the rat. *J Cell Mol Med.* 2008; 24.
34. **Horch RE, Kopp J, Kneser U, Beier J, Bach AD.** Tissue engineering of cultured skin substitutes. *J Cell Mol Med.* 2005; 9: 592–608.
35. **de Vries R.** Ethical concepts regarding the genetic engineering of laboratory animals: a confrontation with moral beliefs from the practice of biomedical research. *Med Health Care Philos.* 2006; 9: 211–25.
36. **Mirkes R.** Is it ethical to generate human-animal chimeras? *Natl Cathol Bioeth Q.* 2006; 6: 109–30.
37. **Goldstein RS DM, Reubinoff BE, Benvenisty N.** Integration and differentiation of human embryonic stem cells transplanted to the chick embryo. *Dev Dyn.* 2002; 225: 80–6.
38. **Tropepe V, Coles BL, Chiasson BJ, Horsford DJ, Elia AJ, McInnes RR, Vander Kooy D.** Retinal stem cells in the adult mammalian eye. *Science.* 2000; 287: 2032–6.
39. **Stout J.** The languages of morals and their discontents. In: Stout J, editor. Ethics after babel. Boston: Beacon Press; 1988; pp. 145–62.
40. **Kass L.** Biology and human affairs. Towards a more natural science. New York: The Free Press; 1985; pp. 249–75.
41. **Munster AM.** Cultured skin for massive burns. A prospective, controlled trial. *Ann Surg.* 1996; 224: 372–5; discussion 5–7.
42. **Bannasch H, Stark GB, Knam F, Horch RE, Fohn M.** Decellularized dermis in combination with cultivated keratinocytes in a short- and long-term animal experimental investigation. *J Eur Acad Dermatol Venereol.* 2008; 22: 41–9.
43. **Bannasch H, Unterberg T, Fohn M, Weyand B, Horch RE, Stark GB.** Cultured keratinocytes in fibrin with decellularised dermis close porcine full-thickness wounds in a single step. *Burns.* 2008; 4.
44. **Horch RE, Bannasch H, Kopp J, Andree C, Stark GB.** Single-cell suspensions of cultured human keratinocytes in fibrin-glue reconstitute the epidermis. *Cell Transplant.* 1998; 7: 309–17.
45. **Horch RE, Bannasch H, Stark GB.** Transplantation of cultured autologous keratinocytes in fibrin sealant biomatrix to resurface chronic wounds. *Transplant Proc.* 2001; 33: 642–4.
46. **Horch RE, Debus M, Wagner G, Stark GB.** Cultured human keratinocytes on type I collagen membranes to reconstitute the epidermis. *Tissue Eng.* 2000; 6: 53–67.
47. **Richter G, Bacchetta MD.** Interventions in the human genome: some moral and ethical considerations. *J Med Philos.* 1998; 23: 303–17.
48. **World Health Organization.** Proposed international guidelines on ethical issues in medical genetics. Geneva: WHO; 1997.
49. **BA Commitee.** Research involving human subjects: guidelines for IRBs. Singapore; 2004.
50. **Giarelli E, Jacobs LA.** Issues related to the use of genetic material and information. *Oncol Nurs Forum.* 2000; 27: 459–67.
51. **Cullen R, Marshall S.** Genetic research and genetic information: a health information professional's perspective on the benefits and risks. *Health Info Libr J.* 2006; 23: 275–82.
52. **Fuchs M.** Gene therapy. An ethical profile of a new medical territory. *J Gene Med.* 2006; 8: 1358–62.
53. **Rabino I.** Gene therapy: ethical issues. *Theor Med Bioeth.* 2003; 24: 31–58.
54. **Spink J, Geddes D.** Gene therapy progress and prospects: bringing gene therapy into medical practice: the evolution of international ethics and the regulatory environment. *Gene Ther.* 2004; 11: 1611–6.
55. **Traulsen JM, Bjornsdottir I, Almarsdottir AB.** 'I'm Happy if I Can Help'. Public views on future medicines and gene-based therapy in Iceland. *Community Genet.* 2008; 11: 2–10.
56. **Walters L.** Human gene therapy: ethics and public policy. *Hum Gene Ther.* 1991; 2: 115–22.
57. **Schmidt A, Weber OF.** In memoriam of Rudolf Virchow: a historical retrospective including aspects of inflammation, infection and neoplasia. *Contrib Microbiol.* 2006; 13: 1-15.
58. **Molenaar JC.** From the library of the Netherlands Journal of Medicine. Rudolf Virchow: Die Cellularpathologie in ihrer Begrundung auf physiologische und pathologische Gewebelehre; 1858. *Ned Tijdschr Geneeskd.* 2003; 147: 2236–44.