

A Decade After Dolly

It's been nearly a decade since the birth of Dolly the cloned sheep in the summer of 1996—followed by the announcement of her existence in February 1997—put the prospect of cloning human beings clearly before us.

Since then, a near consensus has emerged: Cloning human beings is a very bad idea, and should be prohibited. In the past ten years, more than forty countries have adopted prohibitions against human reproductive cloning. But the United States has not.

The past decade has seen the development of techniques that could produce not only cloned children, but also a “designer baby” world of genetically modified humans. Again, unlike many other countries, the US has not put in place binding regulations to prevent this.

This packet, prepared to assist writers and editors, summarizes what has happened—and what has not happened—in the areas of cloning and human biotechnology more generally during the decade since Dolly's birth and debut. It considers why the US has failed to adopt policies to regulate these technologies, and why this matters.

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Ten Years On: What Dolly Means Today

Ten years ago the world's first cloned mammal was born. The lamb named 6LL3—soon to become famous as “Dolly”—was created from the DNA of an adult sheep at the Roslin Institute in Scotland.

The team of veterinary researchers that cloned Dolly, led by Ian Wilmut and Keith Campbell, kept her existence under wraps for more than eight months after her birth on July 5, 1996. A newspaper headline revealed Dolly to the world on February 22, 1997, shortly before the Roslin team's scientific paper on the first cloning of an adult mammal was published in *Nature*.

The second paragraph of the *New York Times* front-page story on Dolly noted that “the achievement shocked leading researchers who had said it could not be done.” The third paragraph introduced the topic that has since dominated media coverage and public discussion of cloning: “In theory,” it said, “such techniques could be used to...create a genetically identical human—a time-delayed twin.”

Speculation about cloned human beings has continued both because of rogue efforts to produce cloned children and because cloning for research has become a contentious issue. Less noticed has been the link between cloning techniques and those that could be used to produce genetically modified “designer babies.”

Cloning policy since Dolly

The day after the announcement of Dolly's existence, President Bill Clinton called for a moratorium on human reproductive cloning. Though pro-cloning advocates began to organize—the “Clone Rights United Front,” for example, was founded that same week—it soon became clear that the public and policy makers around the world overwhelmingly rejected human reproductive cloning. Polls at the time showed it was opposed by 85 to 90 percent of Americans, and the number has not changed since. International bodies such as UNESCO, the World Health Organization, and the Council of Europe soon called for prohibitions against human cloning.

During the next few years, reproductive cloning was legally prohibited in dozens of countries, including almost all countries with significant biotechnology capabilities. But the United States remains, to this day, an exception. Fourteen states have laws that prohibit human reproductive cloning, but 36 states and the federal government have none. Why has Congress been unable to pass a bill to prohibit a practice opposed by nine out of ten Americans, by nearly every reputable scientist in the world, and indeed by every member of Congress?

The near-consensus in favor of banning human reproductive cloning has been complicated by divided opinion about using cloning techniques for research purposes. Many scientists support efforts to produce cloned embryos that can be used to derive stem cells, an approach referred to as *research cloning* or *somatic cell nuclear transfer (SCNT)*.

Cloning technology since Dolly

Almost each year since Dolly, more species have been cloned—at least twelve mammals by 2005. However, there has been little improvement in the efficiency of cloning. Dolly was the first successful birth after 277 cloning attempts, and cloning researchers have not been able to achieve much if any reduction in the number of eggs or attempts that are required.

Moreover, many cloned animals—some scientists say all of them—are born with anomalous conditions that undermine their health and longevity. Some of the female animals that carry the pregnancies also suffer, and some die in the process, due to the abnormally large size of many clones at birth. Cloning thus remains an expensive, resource-intensive process that poses great health risks to the clone and the mother.

Since the announcement of Dolly's birth, human cloning has periodically generated headlines—usually as scandal or fabrication. In 2001, a small company in Massachusetts, Advanced Cell Technology, claimed to have created the first clonal human embryos for research purposes. In fact, the embryos stopped dividing at the six-cell stage, and the company's claims were widely seen as a publicity move.

Over the next few years, fertility specialists Severino Antinori and Panos Zavos repeatedly asserted their progress towards the birth of a cloned human. The Raelians, a religious cult that believes life on Earth was created by extraterrestrials through genetic engineering, also made front-page headlines with even less believable claims of a cloned child. None ever produced any evidence.

In 2004 and 2005, a team led by Hwang Woo Suk of South Korea published papers in the world's top scientific journals asserting both the creation of cloned embryos and the derivation of stem cell lines from them. Hwang and several of his associates have now been indicted on felony charges related to fraud, embezzlement, and illegal procurement of women's eggs; their research papers have been withdrawn. Their lead American collaborator, University of Pittsburgh scientist Gerald Schatten, was cleared of research fraud but censured by his university, in particular for his financial relationships with Hwang and the Korean government.

Where to from here?

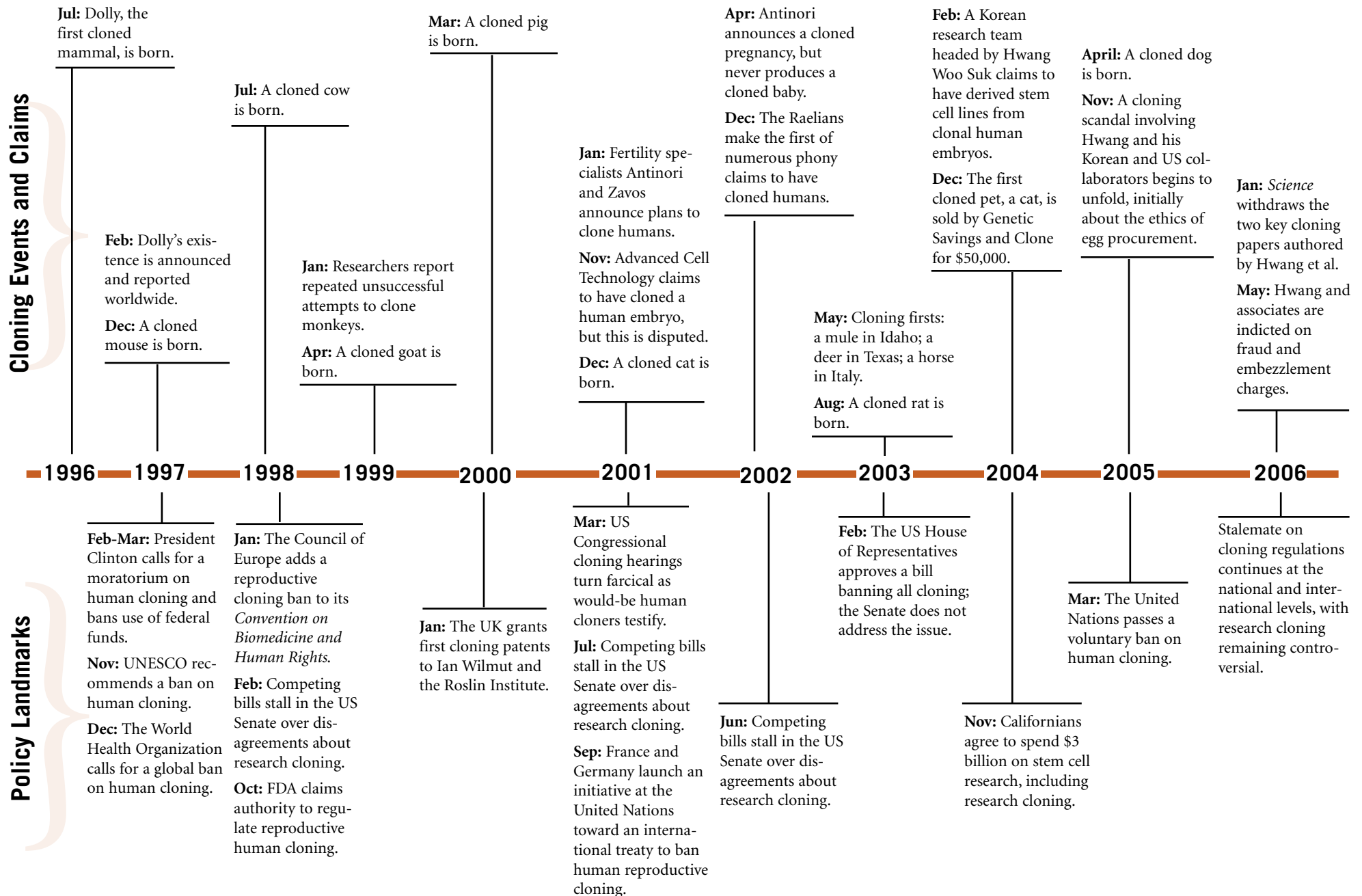
The “dual use” aspect of cloning technique is understood by researchers, but has received little attention from the media or policy makers. In their book about cloning Dolly, *The Second Creation*, Ian Wilmut and his co-authors wrote, “Cloning and [inheritable] genetic engineering are conceptually linked because they are technically linked.”

The Genetics and Public Policy Center at Johns Hopkins University has warned that “rapid advances in stem cell research and other genetic technologies make the possibility of successful permanent modification of the human genome... much more likely... and as a society, we are running out of time to plan sensible policies.”

The ten-year anniversary of Dolly's birth is an opportunity to reflect on what needs to be done if we are to realize any benefits that cloning technology offers, and avoid the real risks that it poses.

This will require leadership from all sides. Those who oppose research cloning need to recognize that the majority of Americans are willing to support some forms of embryo research, as long as the need is clear. And scientists need to recognize that most Americans are willing to support cloning research only if it is subject to strong social oversight and control.

Many nations, including Canada, Australia and most of Europe, have adopted comprehensive policies that ban reproductive cloning and inheritable human genetic manipulation, while allowing carefully regulated stem cell research to proceed. We need similar comprehensive enforceable policies in the United States and all countries.



A Cloning Chronology

- 1996 July 5:** The first cloned mammal, a lamb, is born at the Roslin Intsitute in Scotland. Officially called 6LL3, she is nicknamed Dolly by one of the stockmen who acted as midwives
- 1997 February 24:** Dolly's existence is announced by Ian Wilmut and colleagues at Roslin, a day after a newspaper scooped the official publication in *Nature*. President Clinton calls for a moratorium on human cloning.
- Late February:** "Clone Rights United Front" is founded by Randolfe Wicker. Billionaire John Sperling has the idea of cloning his girlfriend's dog, which eventually develops into the pet cloning company Genetic Savings and Clone.
- March:** President Clinton bans the use of federal funds for human cloning.
- June:** The US National Bioethics Advisory Commission recommends a ban on human reproductive cloning.
- November:** UNESCO adopts the *Universal Declaration on the Human Genome and Human Rights*, recommending a ban on human cloning.
- December:** The World Health Organization calls for a global ban on human cloning. Fertility researcher and Harvard-educated physicist Richard Seed announces his intention to set up human cloning clinics. A cloned mouse is born in Honolulu.
- 1998 January:** The Council of Europe adds a reproductive cloning ban to its *Convention on Biomedicine and Human Rights*.
- February:** Competing bills about human cloning stall in the US Senate due to disagreements about cloning for research.
- July:** A cloned cow is born in Japan.
- October:** The FDA claims authority to regulate reproductive human cloning.
- 1999 January:** Researchers in Oregon report repeated unsuccessful attempts to clone monkeys.
- May:** Dolly is found to have shortened telomeres (a part of each cell's DNA), leading to speculation that clones are "born old."
- April:** A cloned goat is born in Canada.
- 2000 January:** The UK grants the first patents for cloning to Ian Wilmut and the Roslin Institute, which had been purchased by Geron Corporation. A monkey created by embryo splitting is widely but incorrectly reported as a clone.
- March:** A cloned pig is born in Virginia.
- September:** The Raelians, a cult focused on extra-terrestrials, announce plans to clone a human.
- 2001 January:** Fertility specialists Severino Antinori and Panayiotis Zavos announce plans to clone humans for a fee of about \$50,000. They later part acrimoniously.
- March:** US Congressional hearings on human cloning turn farcical as the would-be cloners testify.
- July:** A ban on both reproductive and research cloning passes the House but stalls in the Senate.

September: France and Germany launch an initiative at the United Nations toward an international treaty to ban human reproductive cloning.

November: Advanced Cell Technology claims to have cloned a human embryo but most scientists consider the experiment a failure since it stopped developing at six cells.

December: A cloned cat is born in Texas.

2002 April: Antinori makes one of several announcements that a cloned pregnancy is underway, but never produces a cloned baby.

June: A second series of anti-cloning bills stalls in Congress because of polarization over research cloning, though support for a ban on reproductive cloning is unanimous.

December: Clonaid, the company formed by the Raelians, makes the first of numerous phony claims to have cloned humans.

2003 February: The US House of Representatives approves a bill banning all cloning; the Senate does not address the issue. Dolly is euthanized; it is never clear if cloning affected her health.

May: Cloning firsts: a mule in Idaho; a deer in Texas; a horse in Italy.

November: FDA suggests that food from cloned animals is safe but maintains a moratorium to conduct further risk assessment.

2004 January: Zavos announces that he has implanted a cloned embryo into a woman, but two weeks later says that she did not become pregnant.

February: South Korean researcher Hwang Woo Suk and his team at Seoul National University claim to have derived stem cell lines from clonal human embryos. This is later disproved.

November: Californians pass Proposition 71, allocating \$3 billion to fund human embryonic stem cell research, including research cloning.

December: The first cloned pet, a cat, is sold by Genetic Savings and Clone for \$50,000.

2005 March: The United Nations passes a voluntary ban on human reproductive and research cloning.

April: A cloned dog is born in South Korea.

May: Hwang and team announce dramatic improvements in cloning efficiency, and the creation of customized stem cell lines. These claims are later found to be fraudulent.

November: A cloning scandal involving the team headed by Hwang Woo Suk begins to unfold in Korea, initially about the ethics of egg procurement.

2006 January: *Science* withdraws the two key cloning papers authored by Hwang et al. The Hwang scandal grows into what some call the biggest scientific fraud in living memory.

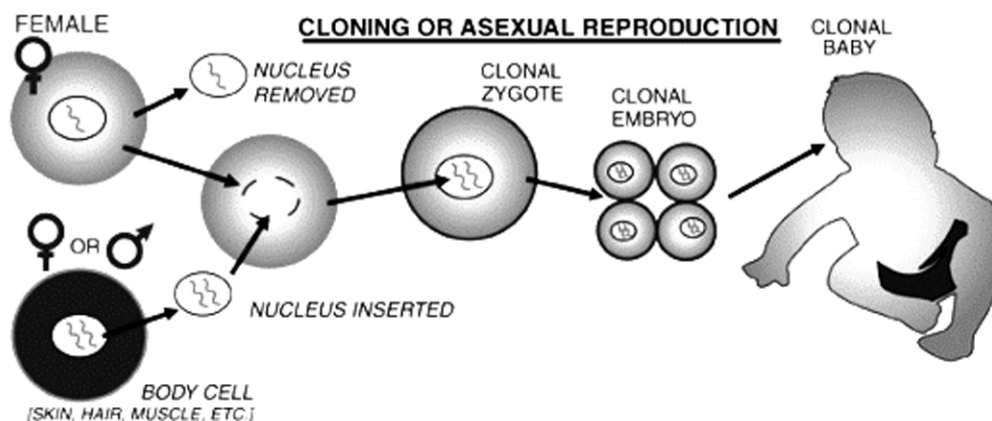
May: Hwang and five associates are indicted on fraud and embezzlement charges, and for illegally purchasing human eggs. If convicted, Hwang could serve up to 10 years in jail.

June: Stalemate on cloning regulations continues at the national and international levels, with research cloning remaining controversial.

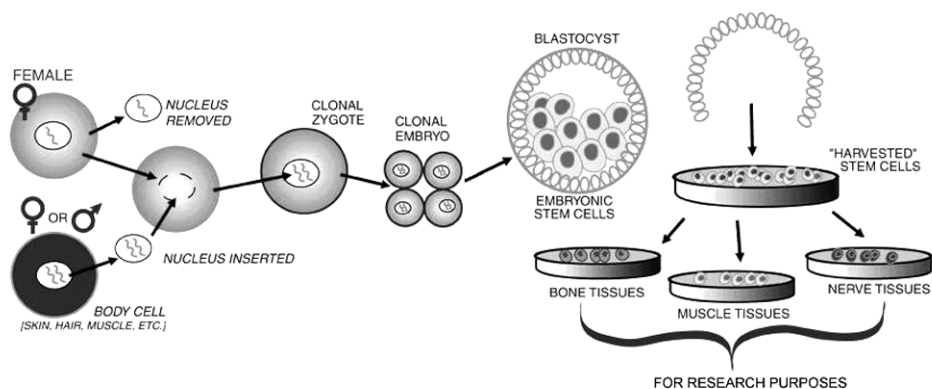
Reproductive Cloning, Research Cloning, and Designer Babies: What are the connections? How do they work?

The techniques of cloning, stem cell research, and genetic modification are interrelated. A basic understanding of these technical connections sheds light on the continuing inability of US lawmakers to successfully adopt a ban on human reproductive cloning, in spite of overwhelming support for one. The connections also suggest the importance of establishing procedures to prevent the unauthorized misuse of clonal embryos in efforts to produce cloned or genetically modified children.

Reproductive cloning. *Cloning* means creating a genetic duplicate of an existing organism. In sexual reproduction, a child's genes come from the parents' egg and sperm. A cloned child's genes would come from a body cell of a single individual. In cloning, the nucleus from a body cell is put into an egg from which the nucleus has been removed in a process called somatic cell nuclear transfer (SCNT). The resulting entity is triggered by chemicals and/or electricity to begin developing into an embryo. If that embryo were placed into a woman's uterus and successfully brought to term, it would develop into a child that would be the genetic duplicate of the person from whom the original body cell nucleus was taken—a clone.



Research cloning. Clonal human embryos created with SCNT may also be useful for research purposes. Many scientists hope that if *embryonic stem cells* can be derived from clonal embryos, they will prove useful for biomedical research or to produce stem cell lines with the same genetic composition as a particular patient.



In order to differentiate between the two purposes of SCNT, many people talk of *reproductive cloning* in contrast to *research cloning*, *therapeutic cloning*, or simply SCNT.

Concerns about research cloning are based on two very different sets of considerations, and held by people with two very different moral and political perspectives. Many religious conservatives, who oppose not only research cloning but embryonic stem cell research in general, believe that the destruction of embryos is morally reprehensible.

The other set of reasons for concern about research cloning has nothing to do with the status of embryos. It is based on concerns about health equity, the well-being of women who would be required to provide eggs for research cloning, and preventing the misuse of cloned embryos in efforts to produce cloned or genetically modified human beings. This position is taken by liberals and progressives who support stem cell research using embryos that were created but not used for fertility purposes.

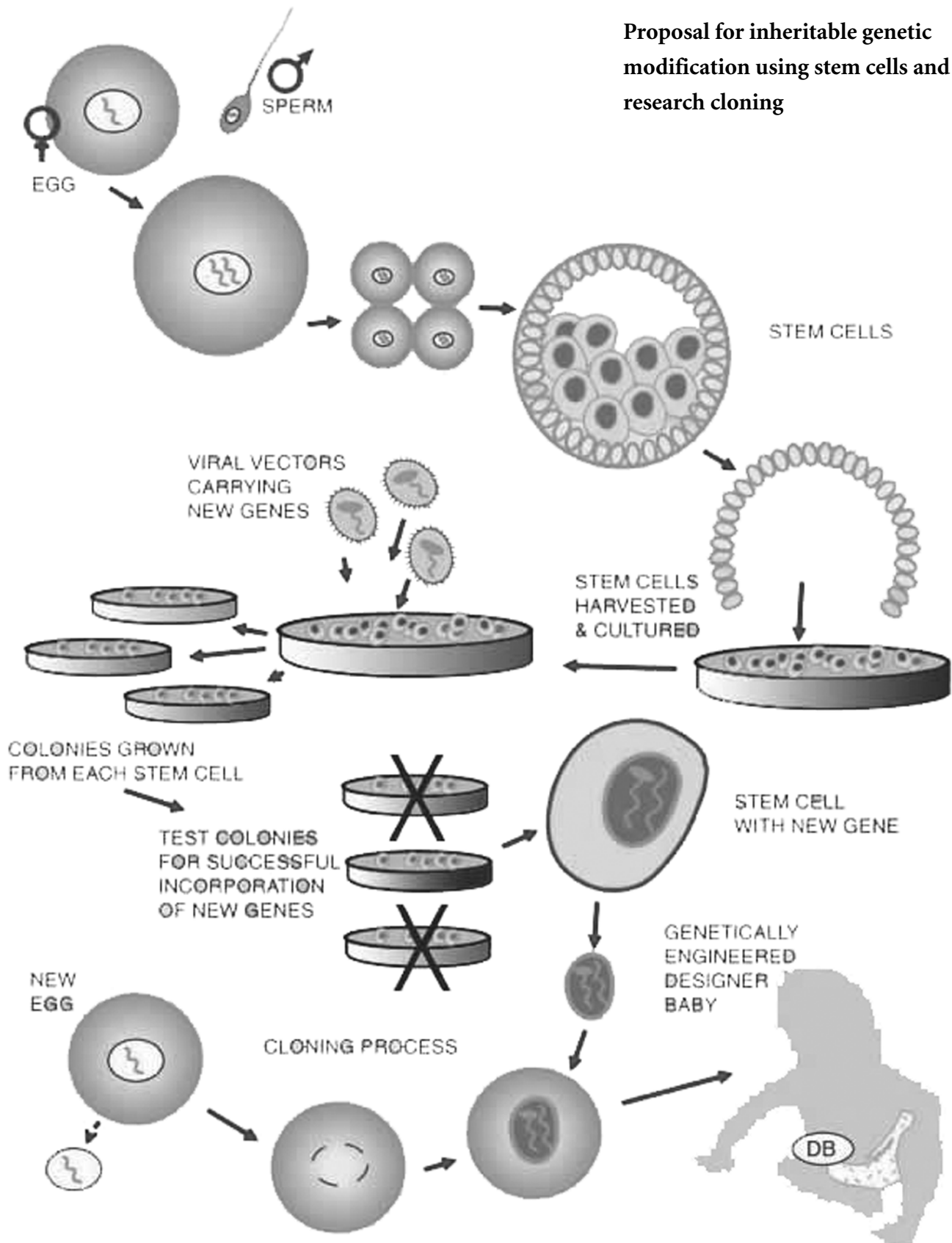
Inheritable genetic modification or “designer babies.” Embryonic stem cell research and SCNT make *inheritable genetic modification*—the production of genetically redesigned children, and altering the genes that are passed down to all future generations—technically more feasible. Proposals for inheritable genetic modification in humans combine techniques involving *in vitro* fertilization, gene transfer, stem cells and cloning. Here’s how it could work:

- Use IVF to create an embryo
- Remove embryonic stem cells
- Alter these stem cells: add or modify genes
- Grow colonies and test for successful gene transfer
- Use cloning techniques to transfer a modified stem cell nucleus into an enucleated egg
- Implant the resulting embryo into a woman’s uterus and bring to term
- The child born would be a genetically modified human

This “dual use” aspect of SCNT has received little attention from the media or policy makers. Some researchers have acknowledged it. In their book about cloning Dolly, *The Second Creation*, Ian Wilmut, Keith Campbell, and Colin Tudge wrote, “The true significance of cloning is to enhance genetic engineering in animals—to make it...routine and reliable...Cloning and [inheritable] genetic engineering are conceptually linked because they are technically linked.”

And according the Genetics and Public Policy Center at Johns Hopkins University, “[R]apid advances in stem cell research and other genetic technologies make the possibility of successful permanent modification of the human genome... much more likely.”

Proposal for inheritable genetic modification using stem cells and research cloning



Cloning Policy Around the World

Several major international organizations have recommended bans on human reproductive cloning:

- ▶ United Nations: *Declaration on Human Cloning*
- ▶ Council of Europe: *Convention on Human Rights and Biomedicine*
- ▶ European Union: *Charter of Fundamental Rights*
- ▶ UNESCO: *Universal Declaration on the Human Genome and Human Rights*
- ▶ World Health Assembly / World Health Organization: “Cloning for the replication of human individuals is ethically unacceptable and contrary to human dignity and integrity.”
- ▶ Group of Eight: *Final Communique of the Denver Summit of the Eight*

Some 50 nations around the world have either passed laws against human reproductive cloning or issued regulatory guidelines forbidding it:

Argentina	Germany	Portugal
Australia	Greece	Romania
Austria	Hungary	Russia
Belgium	Iceland	Singapore
Brazil	Ireland	Slovakia
Bulgaria	Israel	Slovenia
Canada	Italy	South Africa
Colombia	Japan	South Korea
Costa Rica	Latvia	Spain
Croatia	Lithuania	Sweden
Cyprus	Moldova	Switzerland
Czech Republic	Netherlands	Turkey
Denmark	New Zealand	Ukraine
Estonia	Norway	United Kingdom
Finland	Panama	Vietnam
France	Peru	
Georgia	Poland	

Almost all of Europe has now banned reproductive cloning, whereas only two African countries have yet addressed the issue, and relatively few Asian and American countries. Nowhere in the world is it explicitly legal, and nowhere has the national leadership expressed support for reproductive cloning.

Opinion Polls on Cloning

Reproductive Cloning

Public opinion on reproductive cloning remains remarkably consistent. Immediately after the announcement of the first cloned sheep, a *CNN/Time* poll reported that 89% considered it morally unacceptable to clone humans.

Gallup has asked the same question each year. (“Regardless of whether or not you think it should be legal...please tell me whether you personally believe that in general [human cloning] is morally acceptable or morally wrong.”) The answers are astoundingly similar.

Date of Gallup poll	Cloning Humans	
	Morally Acceptable	Morally Wrong
May 2001	7	88
May 2002	7	90
May 2003	8	90
May 2004	9	88
May 2005	9	87
May 2006	8	88

Other repeated polls similarly demonstrate that there has been no change in public attitudes. The numbers vary slightly from one organization to another, depending on the question and context, but they all show massive and sustained opposition.

This consistency is remarkable. Over the same five years, for example, Gallup found views on the legality of abortion fluctuating far more, with those thinking it should be legal under all circumstances varying from 23% to 30% and those thinking it should never be legal varying from 15% to 22%. Death penalty support has ranged from 64% to 74%. The “general mood of the country” has ranged from 25% to 70% satisfied. A maximum 3-point shift, in the 87–90 range, is almost unheard of, on any issue.

These numbers are born out, with slight differences, by polls from the European Union, Australia, Taiwan, Canada — and every major American news organization: Opponents outnumber supporters of human cloning by roughly 10 to 1.

The Center for Genetics and Society has been tracking public opinion about reproductive cloning, and some other related issues, and collected the results at <http://www.genetics-and-society.org/analysis/opinion/>

Research Cloning

Public opinion on *research cloning* (technically known as *somatic cell nuclear transfer* or *SCNT*) is far less clear. Survey responses vary dramatically, even absurdly, depending on the wording and context of the question. The extremes tend to be in polls commissioned by advocates, either religious opponents of research (such as the Conference of Catholic Bishops) or dedicated supporters of research (such as the Coalition for the Advancement of Medical Research).

The Genetics and Public Policy Center (GPPC) at Johns Hopkins University conducted a detailed survey in 2004. The response to the question, “Do you think that human embryo cloning for research should be allowed at all?” was 24% “Yes” and 76% “No.”

Virginia Commonwealth University (VCU) has conducted an annual Life Sciences Survey since 2002, which suggests that public opinion on research cloning has been both divided and fairly stable for several years. The exact question asked each time was: “Do you favor or oppose using human cloning technology IF it is used ONLY to help medical research develop new treatments for disease?”

VCU poll on research cloning	2005	2004	2003	2002
Strongly favor	17	16	21	21
Somewhat favor	26	26	29	24
Somewhat oppose	16	18	16	13
Strongly oppose	35	38	32	38
Don't know/no answer	6	3	3	3
Summary (PRO–CON)	43–51	42–56	50–48	45–51

The specific reference to curing diseases may explain the difference between the VCU and GPPC results.

Animal Cloning

There are fewer surveys of animal cloning, but they are also consistent: Opponents outnumber supporters by at least 2 to 1. This was the case immediately after the announcement of the first cloned sheep, when 66% considered it morally unacceptable to clone animals. Here are results from the annual Gallup surveys:

Date of Gallup poll	Cloning Animals	
	Morally Acceptable	Morally Wrong
May 2001	31	63
May 2002	29	66
May 2003	29	68
May 2004	32	64
May 2005	35	64
May 2006	29	65

According to the Pew Initiative on Food and Biotechnology, “Consumers’ knowledge of cloning appears to translate to greater opposition.” Their November 2005 survey shows that 66% are uncomfortable with animal cloning, and only 23% think that food from animal clones is safe. Also: “A strong majority (63%) of Americans believe governmental agencies should consider moral and ethical factors when making decisions about cloning and genetic modifications, with 53% feeling that way strongly.”

Overwhelming Support for Prohibiting Reproductive Cloning

An overwhelming majority of Americans opposes human reproductive cloning. Opinion polls show consistent majorities of about 90% rejecting it.

Almost all relevant scientific, industry, professional, and patient advocacy groups support a legal ban on reproductive cloning. Most scientists, including many of those with experience cloning mammals, believe that reproductive cloning is far too dangerous to try in humans. Many have social and ethical concerns beyond safety.

1. Medical societies

- American Medical Association
- World Medical Association
- British Medical Association
- Australian Medical Association
- Italian Medical Association
- American Society for Reproductive Medicine
- Association of Reproductive Health Professionals

2. Scientific organizations

- National Academy of Sciences
- American Association for the Advancement of Science
- American Society for Cell Biology
- Federation of American Societies for Experimental Biology (FASEB)
- The California Institute for Regenerative Medicine

3. The biotechnology industry

- Biotechnology Industry Organization
- Geron Corporation
- Advanced Cell Technology

4. Patient advocacy organizations

- Coalition for the Advancement of Medical Research
- American Association for Cancer Research
- American Diabetes Association
- Christopher Reeve Paralysis Foundation
- Parkinson's Action Network
- CuresNow
- Juvenile Diabetes Research Foundation
- Kirsch Foundation

5. International organizations

- Council of Europe: *Convention on Human Rights and Biomedicine*
- European Union: *Charter of Fundamental Rights*
- UNESCO: *Universal Declaration on the Human Genome and Human Rights*
- Group of Eight: *Final Communique of the Denver Summit of the Eight*
- United Nations: *Declaration on Human Cloning*
- World Health Assembly / World Health Organization: *"Cloning for the replication of human individuals is ethically unacceptable and contrary to human dignity and integrity."*

Key Quotes Against Cloning Human Beings

“[Cloning a dying child] should not be permitted. Not only does this encourage the parents to produce one child in the image of another, it also encourages all of us to view children as interchangeable commodities. The death of a child thus need no longer be a singular human tragedy, but rather an opportunity to try to duplicate the no longer priceless deceased child.” — **George Annas, Chair, Department of Health Law, Boston University; member, Massachusetts State Stem Cell Oversight Committee**

“The instrumentalisation of human beings through the deliberate creation of genetically identical human beings is contrary to human dignity and thus constitutes a misuse of biology and medicine.”
— **The Council of Europe, *Convention for the Protection of Human Rights and Dignity of the Human Being***

“No amount of data from laboratory animals will make the first human trials anything but experimental.”
— **Dr. Stuart Newman, Professor of Cell Biology and Anatomy, New York Medical College**

“If anyone should be wary of medical techniques to ‘improve’ on ordinary reproduction, it’s women. History is riddled with examples of abuses of the bodies of women and their children in the name of progress and profit, sometimes with women’s eager consent, sometimes without even their knowledge.”
— **Judith Levine, author, “What Genetic Modification Means for Women,” *World Watch***

“[E]ven if you show us the face of a beautiful baby, behind the face there might be a terrible problem.”
— **Hans Scholer, Professor of Reproduction Medicine, University of Pennsylvania School of Veterinary Medicine**

“As environmentalists, we strongly oppose all human reproductive cloning and inheritable gene modification ... [It] would irrevocably turn human beings into artifacts. It would bring to an end the human species that evolved over the millennia through natural evolution, and set us on a new, uncontrollable trajectory of manipulation, design and control.” — **Brent Blackwelder, Mark Dubois, Randy Hayes, Robert F. Kennedy, Jr., John A. Knox, Robert K. Musil, John Passacantando, Michele Perrault, Mark Ritchie, National Environmental Leaders’ Letter to the US Senate**

“BIO has long advocated a ban on human reproductive cloning as unsafe and unethical. The majority of Americans agree.” — **Biotechnology Industry Organization**

“Human reproductive cloning serves no good purpose, does real harm to individuals, encourages us to regard people as objects, and opens the door to new eugenic technologies that could divide humanity at its core. All countries should move expeditiously to ban human cloning.”
— **Richard Hayes, Executive Director, Center for Genetics and Society**

“A third of cloned animals die shortly after birth. If an infectious disease killed a third of babies, we’d be trying to stop it—not opening clinics to carry it out....And pity the 10-year-old clone of Michael Jordan who breaks his knee. He might think he’s worthless—and so might his parents, who paid big money for him. And if the original Michael Jordan dies early of an inheritable cancer, his clone as a young child would become uninsurable.” — **Lori Andrews, Distinguished Professor of Law, Chicago-Kent College of Law; Director, Institute for Science, Law and Technology**

Experts on Cloning and Human Biotechnology

Lori Andrews

Contact: (312) 906-5359

Professor Andrews is Distinguished Professor of Law and Director of the Institute for Science, Law and Technology at Chicago-Kent College of Law, Illinois Institute of Technology. She has been an adviser on genetic and reproductive technologies to Congress, the World Health Organization, the National Institutes of Health, the Centers for Disease Control, the federal Department of Health and Human Services, the Institute of Medicine of the National Academies of Sciences, and several foreign nations. Professor Andrews is the author of many books including *The Clone Age: Adventures in the New World of Reproductive Technology*; *Future Perfect*; and *Genetics: Ethics, Law and Policy*. Her most recent book, a novel, is *Sequence*. Her media appearances include “Nightline” and “The Oprah Show.”

Richard Hayes

Contact: (510) 625-0819, ext. 302; rhayes@genetics-and-society.org

Richard Hayes is Executive Director at the Center for Genetics and Society. He has served as a political organizer for a wide range of environmental and social and economic justice organizations, including ten years on the national staff of the Sierra Club. Dr. Hayes has been widely published on topics related to human biotechnologies.

Rosario Isasi, J.D., MPH

Contact: (514) 343-7868; rosario.isasi@umontreal.ca

Rosario Isasi is Program Associate for International Affairs at the Center for Genetics and Society. An attorney specializing in health and human rights, she is currently a Postdoctoral Fellow for the Centre de Recherche en Droit Public (CRDP), Université de Montréal. She is also a member of the Advisory Board of Global Lawyers and Physicians, and serves as the Academic Secretary of the International Stem Cell Forum Ethics Working Party. She has particular expertise in the area of comparative legal and ethical research regarding cloning and stem cell research.

Bill McKibben

Contact: wmckibbe@middlebury.edu

Bill McKibben is an environmentalist who frequently writes about global warming, alternative energy, and the risks associated with human genetic engineering. He is the author of the award-winning book *Enough: Staying Human in an Engineered Age*; and of *The End of Nature*; *The Age of Missing Information*; *Hope, Human and Wild*, among others. He is currently a visiting scholar at Middlebury College.

Stuart Newman

Contact: (914) 594-4048; newman@nymc.edu

Stuart Newman is Professor of Cell Biology and Anatomy at New York Medical College. His research areas are cellular and molecular mechanisms of vertebrate limb development, physical mechanisms of morphogenesis, and mechanisms of morphological evolution. He has also written numerous articles on the social and cultural aspects of biological research and technology, and was a founding member of the Council for Responsible Genetics.