

REVIEW ARTICLE

The arrogance of teratology: A brief chronology of attitudes throughout history

John M. DeSesso^{1,2} ¹Health Sciences Center, Exponent, Alexandria, Virginia²Department of Biochemistry and Molecular & Cellular Biology, Georgetown University School of Medicine, Washington, District of Columbia**Correspondence**Dr. John M. DeSesso, Exponent, 1800 Diagonal Road, Suite 500, Alexandria, VA 22314.
Email: jdesesso@exponent.com

While the discipline of Teratology has existed for about 60 years, there has been a deep interest in the causes of human malformations for millennia. Absent the scientific method and acting on fervent beliefs that made sense to ancient/medieval populations, “mechanisms” were described and prognostications of future events were assigned to terata resulting in tragic (and unwarranted) sequelae. This article examines the collective beliefs and thinking within various eras in the hope of providing lessons to inform future behavior. The eugenics movement is an informative, recent example. Science of the 19th century had unraveled some of the mysteries of development and the role of genetics in determining birth outcomes. There was, however, a deep misunderstanding about the enormous amount of information that had yet to be uncovered. Based on immature science and faulty assumptions, it was suggested that “unfit” individuals be euthanized and their parents sterilized. Such “solutions” would be considered deplorable today. Surprisingly, such a reprehensible program was supported (at least in part) by many intelligent and highly regarded individuals. Today, it is imperative that we enter into the era of molecular biology and gene editing cautiously and perspicaciously. The history of teratology has elucidated our inability to understand where our new technologies and actions might take us and how unintended consequences could disrupt even our most carefully thought-out plans.

KEYWORDS

demonic influence, epigenesis, eugenics, hybrids, infanticide, maternal impressions, portents, preformation

1 | INTRODUCTION

Teratology as a defined, modern science has existed for about 60 years; however, human interest in congenital malformations and their possible causes reaches back over many millennia. If “teratology” is defined as the scientific study of the causes, mechanisms and manifestations of congenital malformations, the words “scientific,” “causes,” and

“mechanisms” carry contextual meanings that are strongly influenced by the time period in which they are applied. People of a given era interpret their observations based on the contemporary state of knowledge or understanding of the physical world, contemporary philosophical ideologies, and, importantly, the religious beliefs of the period.

If one overlays a timeline of history with various teratological “events,” it is possible to discuss several eras in teratological history (Figure 1). The presentation of these eras is arbitrary and is not meant to diminish the progress in understanding that occurred among scientists during these periods. Rather, the eras provide a framework within which to discuss the evolution of popular thought during the past four millennia.

Based on the 2018 Warkany Lecture presented at the 58th Annual Meeting of the Teratology Society

This article was published online on 4 December 2018. An error was subsequently identified. This notice is included in the online version to indicate that it has been corrected 17 December 2018.

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

© 2018 The Authors. *Birth Defects Research* published by Wiley Periodicals, Inc.

Timeline of History and Teratology

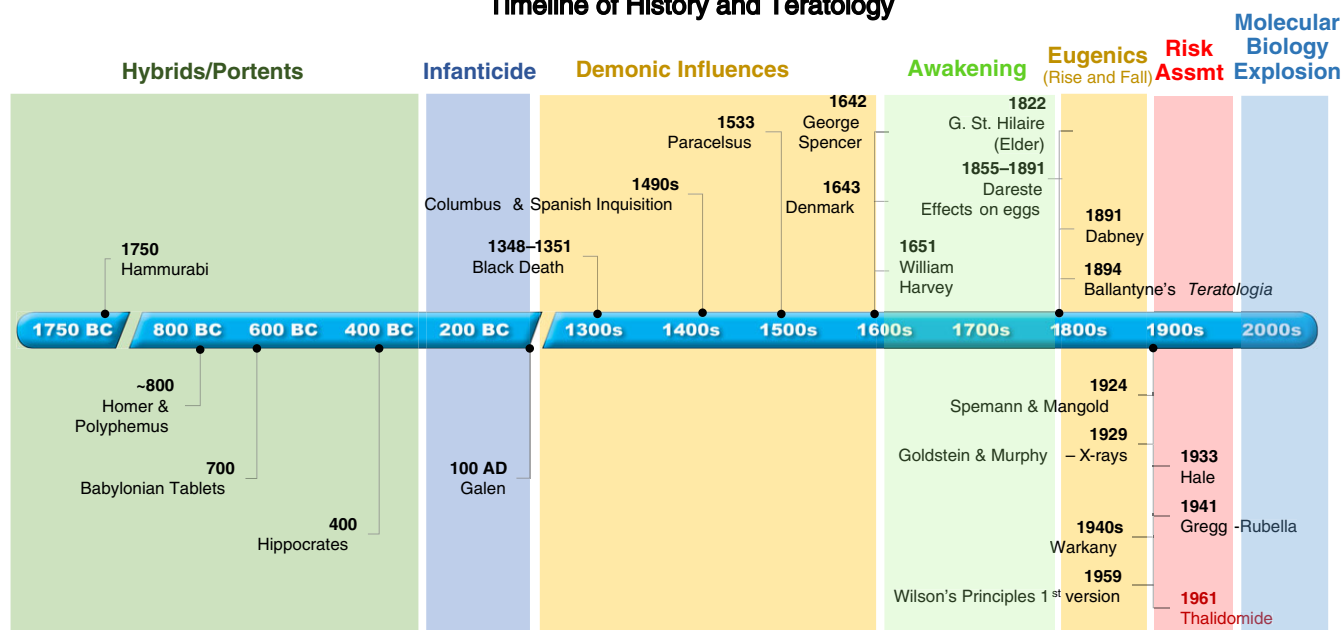


FIGURE 1 This timeline displays selected events occurring over the past four millennia. The events include some commonly appreciated historical milestones for context and various events in the history of teratology that are mentioned in the paper. The eras that are demarcated are arbitrary period that are useful for discussion in this article but are not meant to infer that there were sudden changes in attitudes or that attitude were not changing during each era

2 | ANCIENT TERATOLOGY: PORTENTS AND HYBRIDS

During ancient times in Western culture (for which we are more aware of historical documentation), going back at least as far as Hammurabi (ca.1750 BCE), congenital malformations were known to be rare events. Observers noted their descriptions and paid attention to the ensuing historical events (Warkany, 1959; Warkany, 1971). Based on their observations, they believed that occurrences of malformations were portents of future events. As a result, cuneiform clay tablets were prepared by Chaldeans (a tribe related to ancient Babylonians) that listed specific malformations and the predictions of future events. Such tablets prepared around 700 BCE have been found in the ruins of Mesopotamia (Jastrow, 1914; Warkany, 1971; Figure 2); the tablets are thought to be copies of original tablets prepared in the time of Hammurabi or even earlier (Jastrow, 1914). A few of the described malformations and their predictions are presented in Table 1 (Ballantyne, 1894; Lipton, 1969; Warkany, 1959).

Not only did congenital malformations have an impact on what ancient people believed the future held, but it is possible that the malformed babies may have influenced the depiction of some of the gods in their pantheon (e.g., Morison, 1975). For instance, is it possible that the image of the Greek god, Janus (god of beginnings and endings; gates; transitions; Figure 3), who had two faces that looked toward past and future, could have been influenced by observation of a janiceps type of craniopagus? Janiceps malformations are conjoined twins who are connected at the

thorax and head in such a way that there are two equal faces on either side of the head (Giovanni, Rocco, Elio, Andrea, & Domenico, 2007; Figure 4). Another possible example can be found in the Hindu religion, which is quite ancient (early consolidation of beliefs ~1500–500 BCE, Michaels, 2004). Several of the gods are depicted as multilimbed beings. Examples include Kali, goddess of death; Durga, protector of the universe; and Ganesh (Figure 5). Is it possible that the observation of parasitic twins (Figure 6) influenced the concept?

Another important concept that developed in antiquity related to hybrids. The early Greco-Roman religions worshipped gods with human attributes, who could interact with humans. When the interactions involved intercourse that resulted in the birth of a child, the child was a hybrid between a god and a mortal: a demigod. Demigods had human form but also had some traits transmitted to the child from the god-parent that made them “better” than normal humans. Demigods included such notable individuals as Hercules, Achilles, Asclepius, Helen of Troy, Aeneas, and Orion. The importance of demigods for our purposes, as will be discussed later, is that the concept of hybridization between humans and other beings, resulting in the transmission of nonhuman traits to the offspring, was accepted among ancient peoples.

3 | ANCIENT TERATOLOGY: INFANTICIDE

During the later portion of the ancient times, particularly in the Greco-Roman era, the fate of surviving malformed

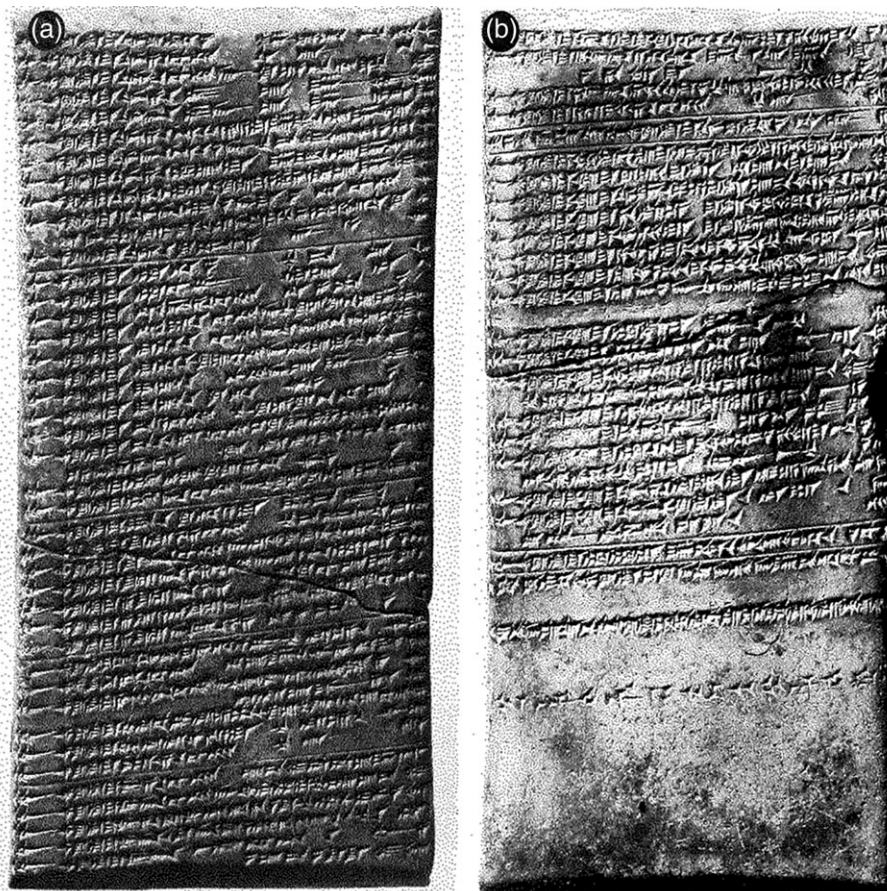


FIGURE 2 Photograph of the Chaldean clay tablets that recorded various malformation of head, limbs, and trunk with the events that they prophesied (Warkany, 1971)

babies was brutal by modern standards. In his treatise on *Politics* (at 1335b), Aristotle wrote “As to exposing or rearing the children born, let there be a law that no deformed child shall be reared.” In the case of malformed infants, exposure was a euphemism for infanticide; thus, the infants were not directly murdered. Rather, they were abandoned and left for nature to take its course. Unwanted infants were not always left in the bush; oftentimes, they were placed in well-known public places where they could be rescued by passersby who could raise the foundling as an adopted child or a slave (Bennett, 1923). Thus, exposure did not always mean death.

The decision to expose a child was not taken lightly. During much of the Greco-Roman era, infants were not considered individuals until about 10 days to 2 weeks after birth when the infant was presented to the head of the family (*paterfamilias*)—or in some city-states, like Sparta, to a committee of elders to decide if the child should be raised (Bennett, 1923). The rights and responsibilities of *paterfamilias* were codified in Table IV of the 12 Tables of Law that were published in the Forum (Cook, Adcock, & Charlesworth, 1928; Duhaime, 2014; Kreis, 2009). Reasons for not raising a child included not only deformity or poor health, but also illegitimacy and economic considerations

(Bennett, 1923). Economic considerations often involved having too large of a family and the sex of the child. Female children were considered more of a financial burden than males because when they grew up they would likely move away through marriage (which would also mean that a dowry was needed), whereas male children were more likely to remain at or near home and could care for their aging parents.

4 | DARK AGES AND EARLY RENAISSANCE: DEMONIC INFLUENCES

As the Roman Empire began to deteriorate, Europe and portions of the territories of Africa and Asia that bordered the Mediterranean Sea entered the Dark Ages. In Europe especially, intellectual curiosity ebbed. The human body was considered unclean. Normal bodily functions such as menstruation were considered impure and intercourse with a woman who was menstruating was thought to be causative in the birth of monsters (McCracken, 2003).

The prevailing thought throughout most of the time preceding the Renaissance was that the imperfect human body should be kept hidden. This is clearly evident in the art of the time, most of which was produced for the Church and in

TABLE 1 Selected congenital malformations and prophecies recorded in Chaldean tablets

When a woman gives birth to an infant:	
With the ears of a lion	There will be a powerful king
That wants the right ear	The days of the king will be prolonged
That wants both ears	There will be mourning in the country
Whose ears are both deformed	The country will perish and the enemy rejoice
That has no mouth	The mistress of the house will die
Whose nostrils are absent	The country will be in affliction and the house of the man will be ruined
That has no tongue	The house of the man will be ruined
That has no right hand	The country will be convulsed by an earthquake
That has no fingers	The town will have no births
That has the heart open with no skin	The country will suffer from calamities
That has no penis	The master of the house shall be enriched by the harvest of his field
Whose anus is closed	The country shall suffer from want of nourishment
Whose right foot is absent	His house will be ruined and there will be abundance in that of the neighbor
That has no feet	The canals of the country will be cut and the house ruined
If a queen gives birth to:	
An infant with teeth already cut	The days of the king will be prolonged
A son and a daughter at the same time	The land will be enlarged
An infant with the face of a lion	The king will not have a rival
An infant with 6 toes on both feet	The king shall rule the enemies' country

Selected from the extensive lists in Ballantyne (1894) and Lipton (1969)

which the human form was always cloaked beneath copious robes. The exception to this was for images of the crucified Christ. An example of art from this period is Giotto's fresco "The Lamentation" in the Scrovegni Chapel, which was created near the end of the middle ages in 1306 and which depicts Christ's body after being removed from the cross (Figure 7).

People believed that diseases and plagues (e.g., The Black Death, ca. 1343–1356) were due to God's wrath, which resulted from his displeasure with human imperfection and sinful activities. These thoughts carried over into the belief that deformities in infants were either a punishment from God visited upon the parents or the work of the devil (Ambroise Paré, [1649] cited in Landauer, 1962). In the latter case, the ancient concept of hybridization was invoked to explain the genesis of deformities. The devil could take on the form of an animal and copulate with a woman resulting in the birth of a monster that had attributes of both its animal and human parentage. The result of such hybridization was the antithesis of the demigods of the ancient world, who were the result of procreation between mortals and a god. This thinking perfused into future eras, as will be discussed further on.



FIGURE 3 Janus, the Greek god of beginnings and endings; transitions; and gateways and after whom the month of January is named. He is often depicted with the face of an old man looking back towards the past and that of a young man gazing forward to the future

5 | AWAKENING OF SCIENCE: HUMAN INTERVENTION AND RATIONALE

With the advent of the Renaissance, people's outlook on life improved. Science and art enjoyed a resurgence. However, many deep-rooted, erroneous beliefs were slow to be purged from popular culture. In particular, the notion that bestiality (sexual contact with animals) could result in viable offspring remained strong well into the 17th century and spread from Europe to the New World (Gould & Pyle, 1896; Landauer, 1962). This belief had deadly consequences when it was wielded by leaders or persons in authority who applied "justice" according to their own set of standards, without regard for logic, but based firmly on statements found in scripture. For example,

And if a man lie with a beast, he shall surely be put to death: and ye shall slay the beast.
And if a woman approach unto any beast, and lie down thereto, thou shalt kill the woman, and the beast: they shall surely be put to death; their blood shall be upon them.
Leviticus 20: 15-16 (King James Version)

5.1 | Copenhagen, 1638—Thomas Bartholin (1661)

Even when individuals were not caught in the act, the evidence against them could include their offspring. According to the Danish physician and scientist, Thomas Bartholin (1661, cited via Morison, 1975¹), there was a case in 1638

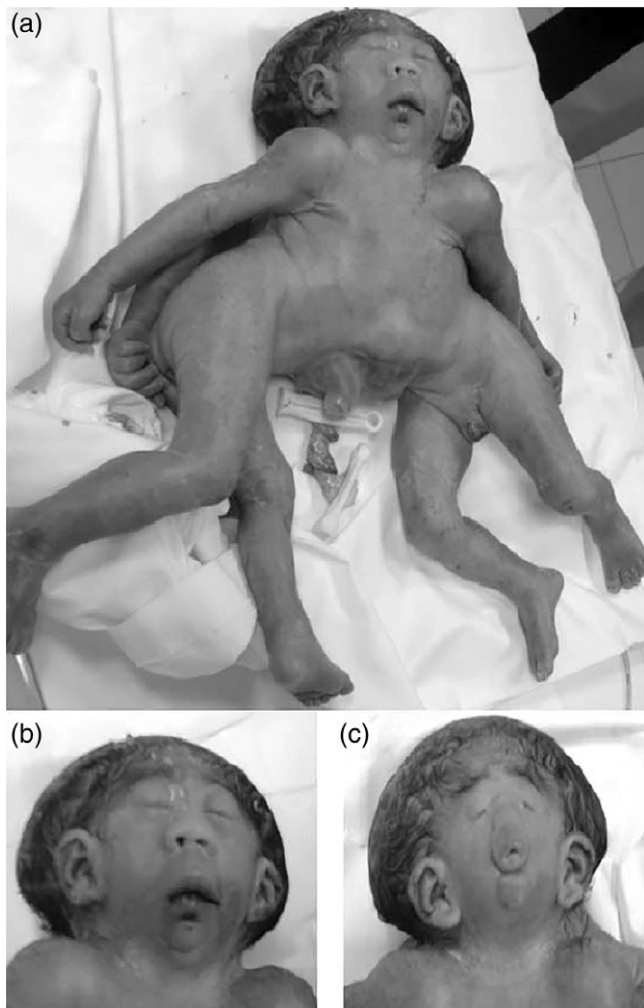


FIGURE 4 Janiceps twins are shown in this figure. Note the separate lower bodies with a single head (upper panel). The head has two equal faces; one on each side of the head (lower panels). One half of each face is contributed by each of the twins (Giovanni et al., 2007)

of a young woman who was accused of bestiality for giving birth to an infant “with the head of a cat.” This was likely a premature delivery of an anencephalic fetus. However, based

on the “evidence” of the fetus, the poor woman was convicted. In a complete miscarriage of justice, she was tied to a ladder and burned alive in the public square of Copenhagen (Figure 8).

5.2 | George Spencer, New Haven 1642

The New World was not immune from the tyranny of self-righteousness. A capital case of alleged bestiality occurred in 1642 (Blue, 2015; Murrin, 1998). The circumstance involved a widely disliked servant named George Spencer, described as an ugly, bald man with one eye. Descriptions of him mention that he had a “pearl” eye; it is not clear if this refers to a glass eye or, more likely, a cataractous eye. Spencer had the misfortune of living and working on a farm in New Haven Colony, one of the most religiously conservative regions of New England. He was characterized as being of “lewd spirit”: he was open about his lack of faith; he declined to pray; and he read the Bible only when he was ordered to do so by his master. A stillborn cyclopic piglet was discovered on a nearby farm and was presented to the elders of the Colony. The consensus was that the piglet had a striking resemblance to Spencer: the piglet had a single eye (which likely had a cataract) and the skin of the head was white and hairless. Using the piglet as evidence, Spencer was accused and arrested for bestiality. Under “enhanced” interrogation, he confessed but later recanted. There appear to have been multiple rounds of interrogation, confession, and recanting. Regardless, under New Haven law a capital offense required two witnesses. Because no one actually witnessed the act, the town elders deemed that Spencer's first confession was true and served as one witness and the existence of the cyclopic piglet served as a second witness. As a result, Spencer and the sow were convicted. They were taken to the

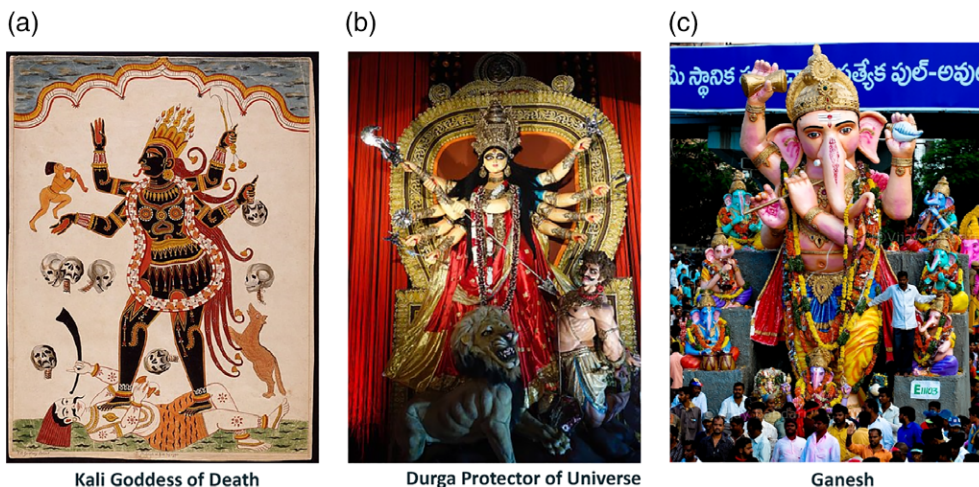


FIGURE 5 Depictions of three Hindu multi-limbed gods. (a) Kali, Goddess of Death; (b) Durga, Protector of the Universe; (c) Ganesh (Bandari retrieved from https://www.flickr.com/photos/vijji_vijju_vjay/2855894213/sizes/o). It is possible that the concept of the forms of these gods were inspired by parasitic twins such as the case of Lakshmi Tatma



FIGURE 6 Lakshmi Tatma was born in India in 2005. She was actually one of a pair of conjoined twins, of which the other twin had become parasitic (with no head or trunk) leaving Lakshmi with the appearance of having four arms and four legs (retrieved from <https://en.wikipedia.org/w/index.php?curid=15858080>)

public square, where the sow was run through with a sword in front of Spencer prior to his hanging.

Interestingly, in 1647, one Thomas Hogg was accused of similar charges (Murrin, 1998) involving two piglets in a litter that allegedly resembled him. Hogg was also generally disliked and thought to be blight on the Colony. However, Hogg never confessed to “laying” with the sow in question. Consequently, he was spared the death penalty due to the lack of witnesses and was flogged instead.

6 | THE AWAKENING OF SCIENCE: OBSERVERS

By the middle of the 17th century, a popular belief was that offspring developed from fully formed miniature versions of themselves that previously existed within their parents. One view (spermist) was that the father's semen was the source of the embryo and the mother's uterus served only as an incubator; another view (ovist) was that the woman's eggs



FIGURE 7 Giotto di Bondone (1270–1337) painted this fresco of the lamentation of the Death of Christ in the Scrovegni (Arena) Chapel in Padua. Note that all of the figures are completely draped, hiding their bodies, except for the body of Christ



FIGURE 8 Illustration of the mode of execution for those convicted of witchcraft or bestiality in Denmark. The victim was tied to a ladder and then thrown alive into a fire

had a completely formed individual that only needed stimulation by semen (Pitts-Taylor, 2008). This view fit well with the concept that malformations were the result of God's wrath and were punishments visited on the parents. The concept was espoused by some notable scientists of the time, such as Marcello Malpighi (1628–1694; Figure 9a). Malpighi first described the corpuscles of the kidney and was among the first to describe red blood cells (West, 2013). Based on his study of what he erroneously thought were unincubated eggs, he believed he saw tiny complete individuals. Some contemporaries, such as Nicolas Hartsoeker, claimed to have seen homunculi (tiny complete individuals;

see Figure 9b) in the heads of sperm. This was at a time when stains were not available and microscopic magnifications were limited. In their defense, it is important to recognize that while spermatozoa are very small cells, there are millions of them; whereas the ovum is a single, large cell that is difficult to find in the capacious uterine lumen. A human ovum was not discovered until Karl Ernst von Baer described it in 1827 (Mikhailov, 1997).

Other near contemporaries of Malpighi, such as Caspar Friedrich Wolff (1733–1794; Figure 9c), believed that embryos were assembled out of the chaos of fluids provided by the parents through the process of epigenesis. While the

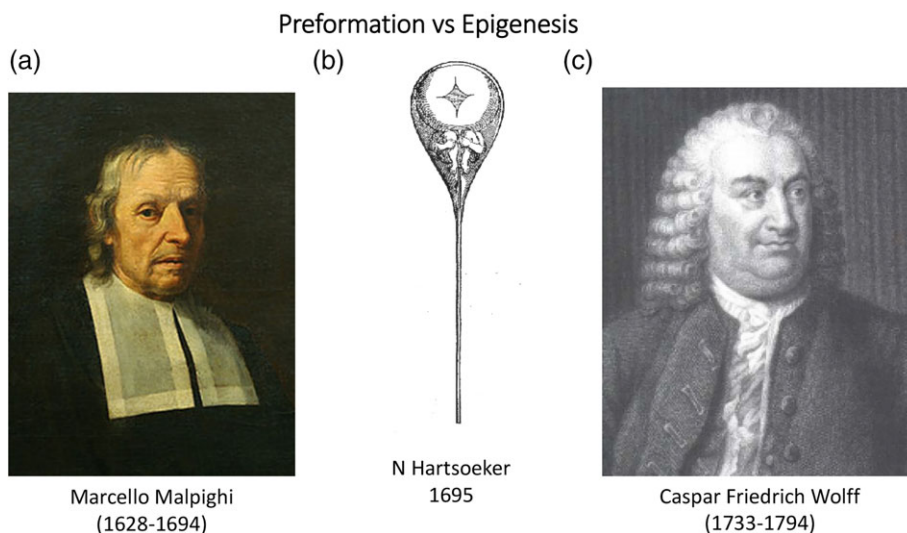


FIGURE 9 Preformation versus epigenesis. (a) Marcello Malpighi was an Italian physician and early microscopist. He is credited with first describing capillaries and renal corpuscles (which bear his name). Because stains were not yet available, many very small structures were unable to be discerned; consequently he noted that they appeared as if they were preformed. (b) Hartsoeker's illustration of a "homunculus," which was a small human form that he believed he saw within the head of a sperm. (c) Caspar Friedrich Wolff was a German physician and physiologist who is considered a founder embryology. He espoused ideas that embryos developed from undifferentiated components that gradually become more specialized as the embryo matures



**Etienne Geoffroy St. Hilaire, the Elder
(1772 – 1844)**

FIGURE 10 Etienne Geoffroy St Hilaire, the elder was a French zoologist whose interest in experimental embryology was an offshoot of his interest in concepts related to evolution. He was a close acquaintance of Lamarck and his interest in “monsters” was an attempt to explain the sudden transition of one species to another. His experiments on perturbing chicken eggs (which gave birth to the science of experimental teratology) were designed to identify and halt development of the embryo at a stage before the transition to the mammalian stage (as held by the concept of ontogeny recapitulating phylogeny)

details had not been worked out, this concept would downplay the intervention of divine retribution or demonic influences as causative in malformations. During the 1820's, Etienne Geoffroy St Hilaire, the Elder (Figure 10) performed experiments on chicken eggs that further supported the concept of epigenesis (Racine, 2013). He shook the eggs, prodded the embryos through holes in the shell, and injected various substances into the eggs. His work laid the groundwork for the scientific understanding that malformations could be caused by the perturbation of developmental processes by external influences.

7 | THE AWAKENING OF SCIENCE: COLLECTORS

Coincident with the rise in experimental science, physicians, and surgeons of the time were interested in obtaining



**Willem Vrolik
(1801 – 1863)**

FIGURE 11 Willem Vrolik was a Dutch anatomist and pathologist who was an early expert in vertebrate teratology. He wrote one of the early texts on vertebrate malformations. He and his father (also a physician) amassed a large collection of anatomical and teratological specimens in their cabinet, which is now housed at the University of Amsterdam as the Museum Vrolik

“curiosities” which they collected and displayed in museums known as “cabinets.” While most of the curiosities related to tumors and various disease states, some of the curiosities were congenital malformations. Based on his own collection and that of his father, Willem Vrolik (1801–1863; Figure 11) published a magnificent, early atlas of malformations (Vrolik, 1849). Vrolik's atlas is beautifully illustrated in great detail. Figure 12a shows the general appearance and skeletal arrangement of an achondroplastic dwarf. Figure 12b presents the skeletal arrangement of a janiceps twin and the detailed anatomy of the brain of the patient, which includes separate cerebella, medullae and pontes, but a shared, singular midbrain.

There were no willed body programs at that time. The question that arises is “What was the source for the specimens?” While many of his specimens were stillbirths, there is no record that describes how the adult specimens in the Vrolik museum were obtained (Leroi, 2003). However, there are records for specimens of other surgeons. These records likely involved the participation of body snatchers. Two prominent cases are recounted below.

7.1 | Body snatch at the firth of forth

A hydrocephalic boy who lived in the countryside near London at the Firth of Forth would have made a prize specimen for any collection and was coveted by Scottish surgeon

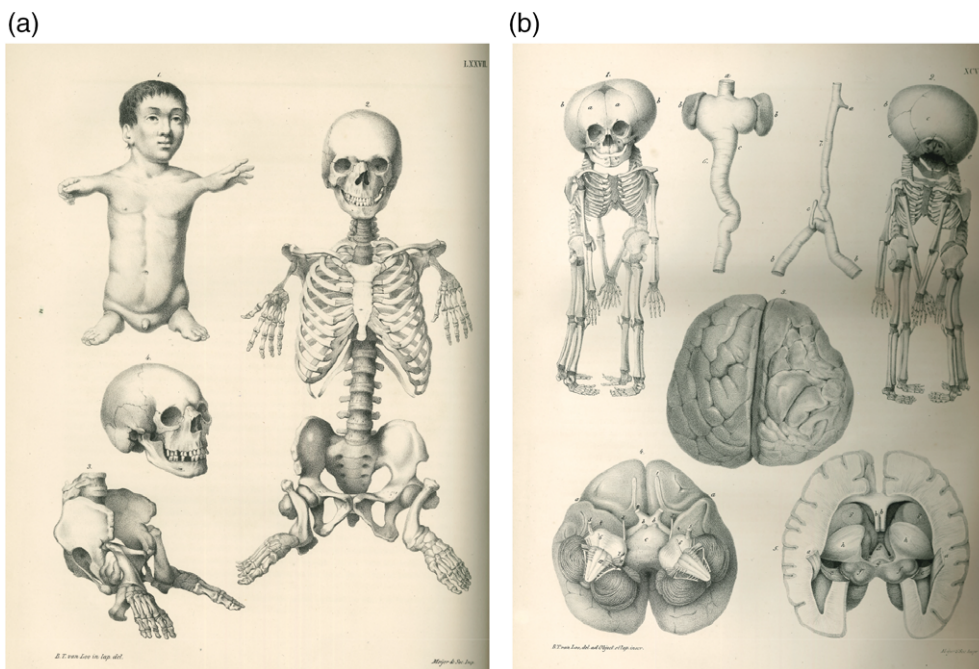


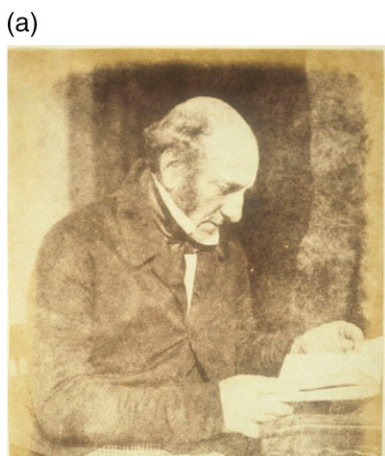
FIGURE 12 Illustrations from Vrolik's *Tabulae ad illustrandam embryogenesisin hominis et mammalium tam naturalem quam abnormem*. Image (a) is that of a dwarf and his skeleton, which is now part of the museum Vrolik. Image (b) is a series of illustrations of a janiceps twin. Note the anterior and posterior view of the skeletal preparation and the detailed view of the brain for the twins, which presents with separate brainstems and cerebella but a fused thalamus and single optic chiasma

Robert Liston (1794–1847; Figure 13a). When the boy died in approximately 1838, his family guarded his grave to protect it from body snatchers (Adams, 1972). After a month or so, when the body would have decomposed significantly, the protection was slackened somewhat and was apparently only in force during the night.

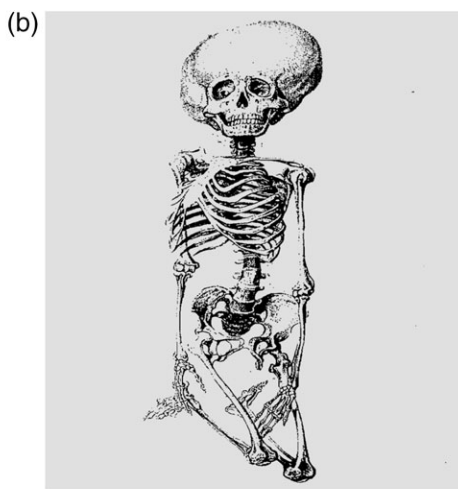
One afternoon, two well-dressed gentlemen smoking cigars arrived in town in a horse-drawn cart. They stopped at a livery station and asked that the horse be tended to and said that they would return in about an hour. They also said

that a package was expected and should be installed under the cart's seat. Shortly thereafter a deliveryman arrived and locked a package under the seat. The gentlemen returned and drove off smartly (Adams, 1972).

That evening, the grave watchers discovered that the boy's grave had been disturbed and the boy's remains were missing. A witness thought he recognized the deliveryman as one of the gentlemen. The entire affair had taken less than 30 min. Dr. Liston denied any involvement in the sordid affair; however, when he published his textbook, *Elements*



Robert Liston
(1794 – 1847)



Fyleaf from Liston's *Elements of Surgery* (1840)

FIGURE 13 (a) Robert Liston was a prominent Scottish surgeon who was noted for the speed with which he performed operations, which was particularly important in the era before the advent of anesthetics. (b) Fyleaf image from Liston's *Elements of Surgery*, which was published 2 years after the bodysnatching of the hydrocephalic child at the Firth of Forth

(a)



John Hunter (1728 – 1793)

(b)



FIGURE 14 (a) John Hunter was a distinguished Scottish surgeon who advocated scientific study and hands-on observations to advance medicine. He assembled a large cabinet of medical curiosities that included congenitally malformed individuals. His collection is housed in the “Hunterian Museum” which belongs to the Royal College of surgeons. (b) The skeleton of the Irish giant, Charles Byrne (retrieved from <https://strangerremains.com/2013/12/19/the-colossal-skeleton-of-the-18th-century-irish-giant/>). The colorful story of its eventual arrival at Hunter's laboratory is recounted in the text

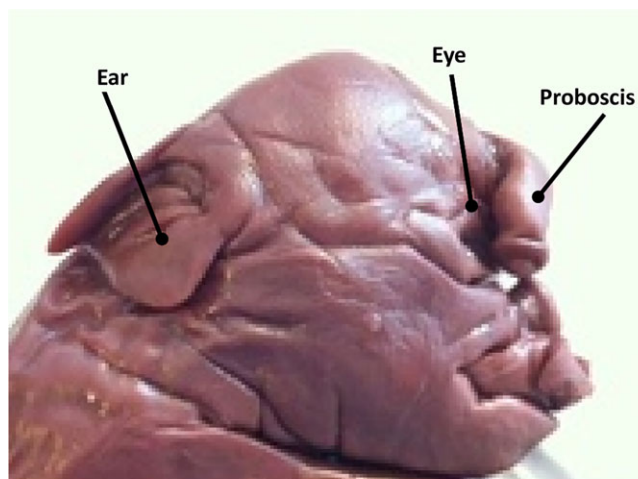
of *Surgery*, in 1840, there was a drawing of a skeletal preparation of a hydrocephalic child on the flyleaf (Figure 13b). This was likely the specimen snatched from the Firth of Forth.

7.2 | Charles Byrne, the Irish Giant

Charles Byrne was a young Irish man who continued to grow beyond his teenage years, confirmed later to have been due to a pituitary tumor (Bondeson, 1997). He moved to London, where he made money by showing himself (he was approximately 7 ft 10 in. tall). He was an alcoholic and in deteriorating health at the age of 22, when he was approached by a representative of the Scottish surgeon, John Hunter (1728–1793; Figure 14), about donating his remains (Moore, 2006). Byrne emphatically rebuffed the offer and made plans that when he died, he should be buried at sea in a lead coffin (Fleetwood, 1959).

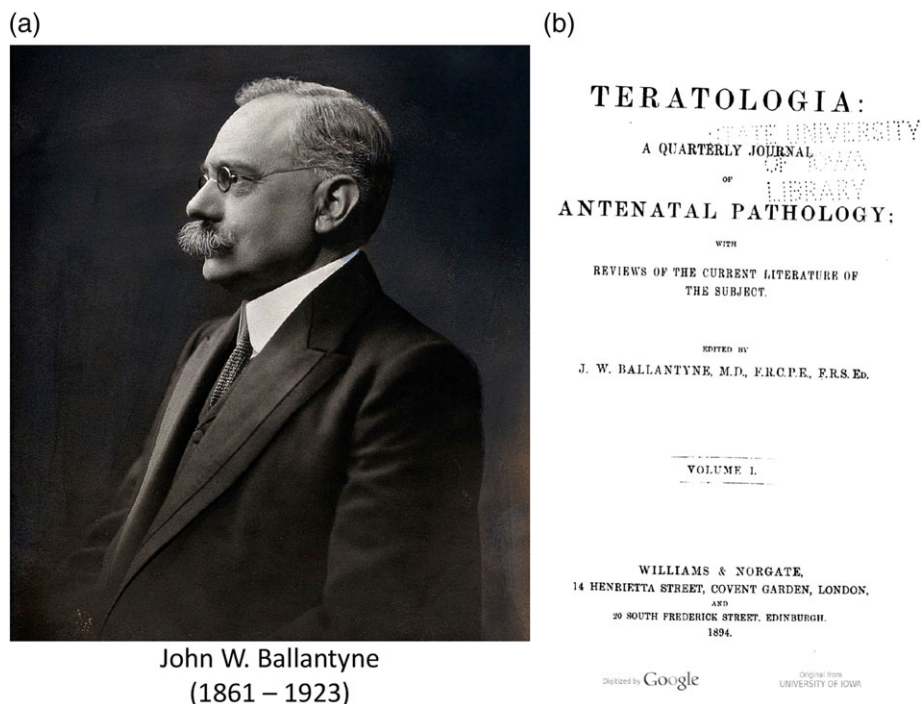
When Byrne died a few months later, the plans to convey his coffin to the sea became known to Hunter. By several accounts, the entourage stopped at a number of taverns *en route* to enjoy a drink and celebrate their friend's life (Adams, 1972). The coffin was secured at each stop. However, the entourage had been infiltrated by some of Hunter's students. At one stop, other students were hiding in a barn that was used to secure the coffin. The hiding students removed Byrne's body and placed an equal weight of sand and rocks in the coffin (Adams, 1972; Fleetwood, 1959;

Moore, 2006). The coffin continued its trip to the sea before the switch was discovered. In the meantime, Byrne's body was delivered to Hunter, who quickly reduced it to bones. Hunter disavowed any involvement in the switch, but several years later, a very tall skeleton was displayed in his cabinet (Figure 14b).



Cyclopic piglet

FIGURE 15 Photograph of the head of a cyclopic piglet which may have been similar to one mentioned by Dabney. Note the shape of the ear (somewhat similar to that of an Indian elephant) and the proboscis located above the eye (similar to the form of an elephant's trunk)



John W. Ballantyne
(1861 – 1923)

FIGURE 16 (a) J. W. Ballantyne was a Scottish obstetrician who made great strides in teaching female physicians and midwives. He is credited with founding the field of antenatal pathology. He was the editor of *Teratologia* (b), the first scientific journal dedicated to presentation of cases and discussions of causes of birth defects

8 | THE AWAKENING OF SCIENCE: EARLY MECHANISMS

Camille Dareste (1822–1899) was a French zoologist who specialized in experimental embryology. His book, *Research on the Artificial Production of Monstrosities, or Essays on Experimental Teratogenesis* (Dareste, 1876), provided the first well-documented evidence that neural tube defects were caused by failure of the neural tube closure rather than by a bursting of the closed neural tube. Importantly, Dareste outlined five principles of experimental teratology that foreshadowed and inspired Wilson's principles which appeared nearly a century later (Wilson, 1959; Wilson, 1973).

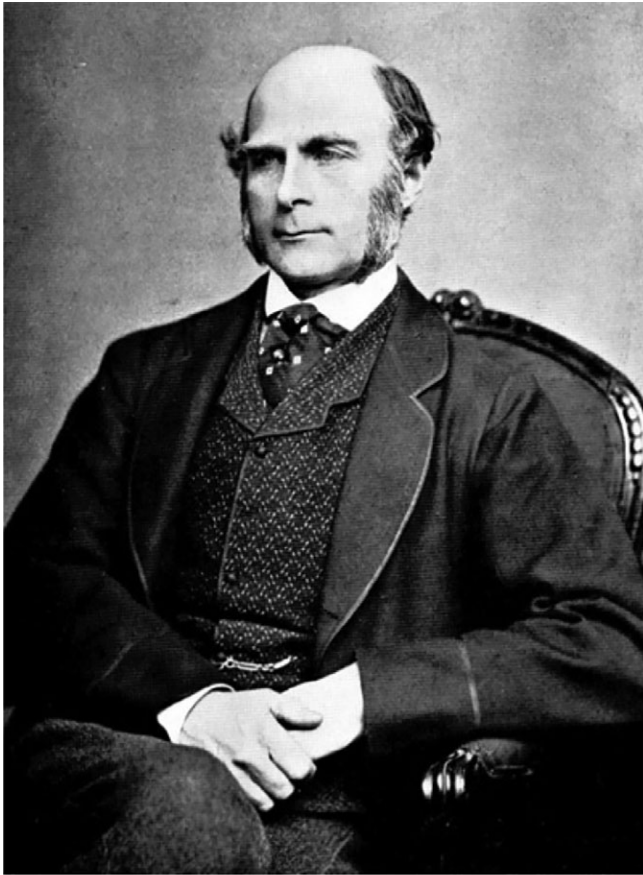
8.1 | Maternal impressions

The notion has been around for millennia that if a pregnant woman experiences a great scare or a devastating loss during her pregnancy, she is at risk of having a child with some physical sign of the mother's experience. The physical sign of the maternal impression could be a birthmark or deformity. All of the “proof” relative to such effects from maternal impressions is, of course, anecdotal. One such anecdotal case involved Hippocrates of Kos (460–370 BCE), the father of modern medicine. The following story was attributed to St Jerome (Bondeson, 1997).

In ancient Greece, an aristocratic lady was accused of adultery by her husband. While there were no witnesses to her infidelity, the circumstantial evidence against her was fairly strong. Both she and her husband were white, but the

child was dark-skinned. Shortly before the jury was about to render its verdict and sentencing, Hippocrates appeared in court of his own volition and motivation. He reminded the jury that the woman spent much of pregnancy abed in her room and that she had a picture of a Moor in her room. Consequently, she spent much of her time looking at that picture. In addition, the child bore a strong resemblance to the image in the picture. Thus, it was Hippocrates's opinion that these circumstances had created a “maternal impression” that altered the child's skin color and overall body shape. Based on Hippocrates's widely acknowledged medical knowledge and reputation, the jury acquitted the woman.

More than 2000 years later, William Dabney (1891) wrote a paper that attempted to separate facts from fantasy to determine if maternal impressions are a cause of malformations. He collected many anecdotal cases that alleged a causative role for maternal impressions. He excluded those cases wherein there was no specific stimulus or there was no specific period of gestation in which the stimulus occurred. One of his conclusions was that birth defects were observed only if the stimuli occurred during the first 2 months of gestation (which corresponds with the period of organogenesis in humans). Nevertheless, Dabney's reasoning and final conclusions were faulty. For one thing, Dabney believed that stimuli could include dreams. (There is no way to verify when, or if, the dreams actually took place.) The weakest link in his argument is the one that he believed was his paper's strength: animals could be affected. The following text from his paper (Dabney, 1891) lays out his argument and erroneous conclusion:



Francis Galton
(1822-1911)

FIGURE 17 Sir Francis Galton was an English polymath and cousin of Charles Darwin. He made contributions to statistics (introduced the concept of correlation; fostered the use of regression toward the mean), anthropology, sociology, psychology, meteorology (first weather map) and more in his 340+ papers and books. His many contributions to sociology (coined the term “eugenics” and introduced the phrase “nature versus nurture”) included books on *Hereditary Genius* (1869) and *Inquiries into Human Faculty and Its Development* (1883) that laid out the principles for eugenics

Abnormalities may occur in animals. This is not a valid objection, for animals possess emotions as well as Mankind...In Henderson, Kentucky there passed through the town a menagerie with which was an elephant; a sow pregnant a short time saw this elephant, and one of her pigs born some time afterwards had skin, ears, and *trunk* similar to those of an elephant... *Now, unless we deny the facts, the conviction that the relationship... is that of cause and effect seems almost irresistible.* (Emphasis added)

The subject piglet from Henderson, Kentucky was not physically examined by Dabney. In all likelihood, the piglet was a cyclops with a proboscis (Figure 15). Dabney fell prey to reliance on anecdotal evidence similar to that which he had

excluded from his assessment of human case reports due to the lack of evidence for a specific stimulus at a known time in gestation.

While Dabney failed to follow the scientific method, his contemporaries were making great advances in the field. The prolific Scottish physician, J. W. Ballantyne (1861–1923; Figure 16) edited the first (albeit short-lived) scientific journal devoted to birth defects: *Teratologia: A Quarterly Journal of Antenatal Pathology* (Figure 16b). *Teratologia* first appeared in 1894 and provided a forum for physicians and scientists to report and discuss birth defects and their prognoses. In 1896, his treatise on the possible causes of teratogenesis appeared (Ballantyne, 1896). The treatise thoroughly debunked the notion of a causative role for maternal impressions in the etiology of birth defects.

9 | EUGENICS

The eugenics movement was gaining in popularity at the same time that Dabney and Ballantyne were addressing birth defects in scientific forums. Eugenics embodies a set of beliefs and practices that aim to improve the human genetic pool (Allen, 2011). This was to be accomplished by controlled breeding, such that breeding was encouraged among those with desirable traits, while reproduction was discouraged (or prohibited—even to the point of sterilization) among those with less-desired traits. The concept has deep roots in history. It was espoused by Plato (~400 BCE) (Galton, 1998; Güvercin & Arda, 2008) and may have been practiced in Sparta (Bennett, 1923). During the late 1800's, the concept became popular, largely due to the efforts of Francis Galton (1822–1911; Figure 17). During the early 20th century, the movement spread across Europe, North America, and Asia (Figure 18). The movement lost favor after its perversion by the Nazis leading up to and during World War II.

While current thinking finds eugenics as advocated early last century to be repellant, it is important to recognize that in general, the politics, beliefs and state of knowledge of the early 20th century were different than they are now. Thought leaders of the time made statements that are reflections of their times. The following quotations are meant to provide a window into the thinking of that time—they are taken out of context and are not meant to besmirch the memories of these individuals, nor to vilify them in any way.

Theodore Roosevelt (Figure 19), the outspoken former President of the United States, stated in a letter to Charles Davenport of the Eugenics Records Office (Roosevelt, 1913):

Society has no business to permit degenerates to reproduce their kind. It is really extraordinary that our people refuse to apply to human beings such elementary knowledge as every

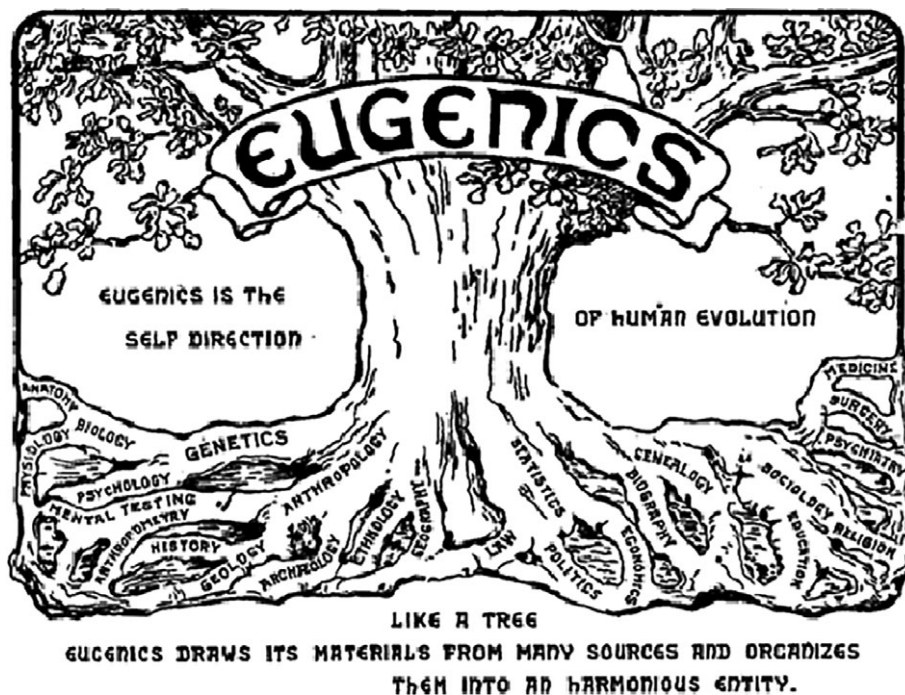
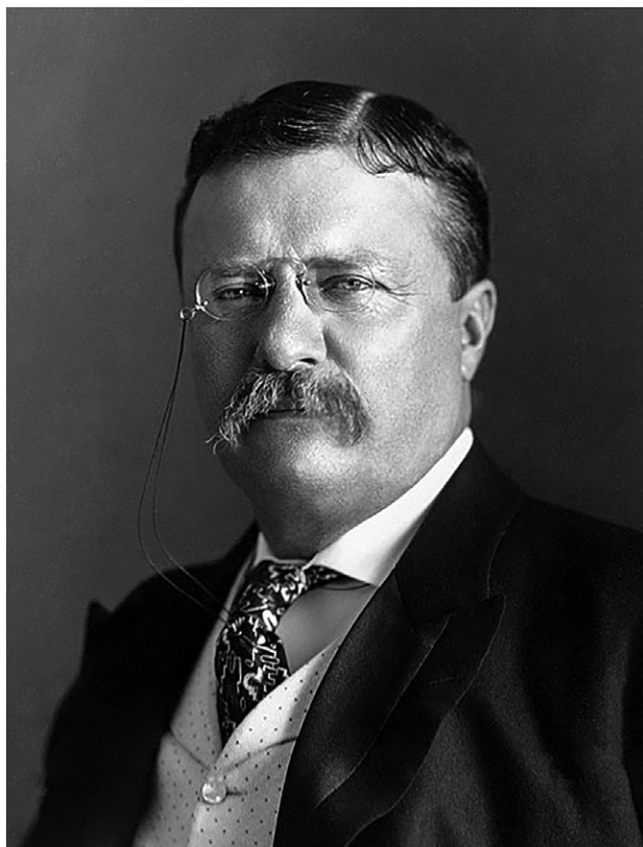


FIGURE 18 Logo for the Second Eugenics Conference (1921). Eugenics is depicted as a tree with many roots, each of which is labeled with a scientific discipline or a religion/philosophical ideal that allegedly contributed support to the movement



**Theodore "Teddy" Roosevelt
(1858 – 1919)**

FIGURE 19 Theodore Roosevelt was the youngest President of the United States. He was extremely well-read and had a buoyant personality that he coupled with a vigorous "masculine" lifestyle to project an image of an idealized American male: An erudite cowboy

successful farmer is obliged to apply to his own stock breeding ... We fail to understand that such conduct is rational compared to the conduct of a nation which permits unlimited breeding from the worst stocks, physically and morally ... Some day we will realize that the prime duty—the inescapable duty—of the good citizen of the right type is to leave his or her blood behind him in the world; and that we have no business to permit the perpetuation of citizens of the wrong type.

In November, 1915 a severely malformed infant ("Baby Bolinger") was delivered in Chicago (Oveyssi, 2015). The baby was paralyzed on his left side, exhibited left-sided anotia, (apparent) iniencephaly with scoliosis, and gastroschisis, or omphalocele. The hospital's chief surgeon, Dr. Harry Haiselden, refused to operate on the infant believing it would be a morally wrong to attempt to keep the baby alive. He shared his reasoning with the parents and with the press. This initiated much public outcry with support (and condemnation) on both sides of his decision. Helen Keller (Figure 20), the blind and deaf political activist and humanitarian, published her reaction to the situation in an open letter in *The New Republic* (Keller, 1915) in which she argued that the sanctity of life emanates from the ability to enjoy and understand it. Consequently, she felt that "it is the possibility of happiness, intelligence and power that give life its sanctity, and they are absent in the case of a poor, misshapen, paralyzed, unthinking creature." She praised Haiselden's position as "weeding of the human garden that shows a sincere love of



Helen Keller
(1880 – 1968)

FIGURE 20 Helen Keller was a deaf-blind political activist, educator and author. She was an outspoken advocate for women's suffrage, workers' rights, and socialism. She was a co-founder of the American Civil Liberties Union (ACLU)

true life.” Furthermore, Keller held the opinion that “the mental defective... is almost sure to be a potential criminal.” She concluded her letter by saying “Meanwhile we must decide between a fine humanity like Dr. Haiselden's and a cowardly sentimentalism.” In another reaction to the case, she was quoted as saying “Our puny sentimentalism has caused us to forget that a human life is sacred only when it may be of some use to itself and to the world” (Pernick, 1996).

During 1915, Clarence Darrow (Figure 21), was a prominent and soon-to-be famous attorney. He was beginning to build his reputation as a defender of the downtrodden, with pithy quotations such as one coined a few years later: “You can only protect your liberties in this world by protecting the other man's freedom” (Darrow, 1920). In response to questions regarding his feelings concerning the Baby Bollinger case, Darrow said “Chloroform unfit children. Show them the same mercy that is shown beasts that are no longer fit to live” (Dowbiggin, 2005).

Lastly, the views of Supreme Court Justice, Oliver Wendell Holmes, Jr. (Figure 22) were published in the opinion of the court regarding the case of *Buck v Bell* (Holmes Jr, 1927). The case involved the court-ordered sterilization of a “feeble-minded” woman. The Supreme Court sustained the ruling of the lower courts. Holmes wrote the opinion for the majority, wherein he stated:



Clarence Darrow
(1857 – 1938)

FIGURE 21 Clarence Darrow was a prominent member of the ACLU and was famed for being a defense attorney who litigated for the underdog. He defended numerous unpopular clients (whose opinions/positions may have been repugnant to him) because he believed they had the right to hold and express those opinions. He also defended clients in murder cases because of his belief that capital punishment was morally wrong

We have seen more than once that the public welfare may call upon the best citizens for their lives. It would be strange if it could not call upon those who already sap the strength of the State for these lesser sacrifices, often not felt to be such by those concerned, to prevent our being swamped with incompetence. It is better for all the world, if instead of waiting to execute degenerate offspring for crime, or to let them starve for their imbecility, society can prevent those who are manifestly unfit from continuing their kind. The principle that sustains compulsory vaccination is broad enough to cover cutting the Fallopian tubes.

Taken together, the statements from some of the well-known, admired leaders of the time indicate the sentiment among a sizable portion of the populace that serious malformations were indicators of one's lack of fitness to



Oliver Wendell Holmes, Jr.
(1841 – 1935)

FIGURE 22 Oliver Wendell Holmes, Jr. was a longstanding supreme court justice known for his succinct and compelling opinions. He was a learned person and is one of the most cited American legal scholars of the 20th century

meaningfully contribute to society. To those folks, eugenic “weeding of the human garden” should occur early in life.

As a counterpoint to the arrogance inherent in the eugenics movement, it is instructive to see who would have been lost if their procedures had been implemented. I have selected two individuals who likely would have been judged to be unfit at birth: Charles Proteus Steinmetz and Matthias Buchinger. Their stories follow.

Charles Proteus Steinmetz (1865–1923; Figure 23) was a kyphotic dwarf with hip dysplasia. The condition was familial, as both his father and his grandfather had the same condition. Steinmetz was a brilliant electrical engineer. He was a major contributor to the nascent General Electric Company, for which his work contributed greatly to making alternating current practical (Bly, 2018). His sobriquet was “The Wizard of Schenectady” and he counted Einstein, Tesla, and Edison among his friends and peers (Figure 23b). Steinmetz was known for his ability to simplify complex issues into understandable, solvable problems. As an example, Einstein's theory of relativity (especially the field equations)

was difficult for most people to comprehend. Steinmetz (1923) prepared an explanation of relativity using simple language, analogies and comparisons that conveyed the essence of Einstein's reasoning to a lay audience. It remains an excellent educational resource.

Another individual who might have been lost was the phocomelic overachiever, Matthias Buchinger (1674–1740) (Jay, 2016). Buchinger was only 29 in. tall; he had no lower extremities and his upper extremities ended at the elbow. He had no hands or feet, although the ends of his upper extremities had small nubbins that he could control.

Despite his anatomical challenges, Buchinger was able to build ships in a bottle, play numerous musical instruments, and could display impressive feats of marksmanship. Most incredible were his creation of very detailed engravings, such as his self-portrait (Figure 24), and his skill as a microcalligrapher (Johnson, 2016). The latter competence is displayed when one looks carefully at his hair in the self-portrait. His curls are made up of the words (in German) to the Lord's Prayer and seven Biblical Psalms. Buchinger was a famed lothario. He was married four times and had at least 14 children by eight women. He was rumored to have had about 70 mistresses. Recalling that he had no legs or feet, in reference to his condition, a popular euphemism for the vagina was “Buchinger's boot.”

10 | RISK ASSESSMENT

The world's perception of the safety of the womb changed dramatically in 1961, when the public became aware of the horrible effects on the fetus of a seemingly innocuous sedative that was also used for morning sickness: thalidomide (Sunday Times Insight Team, 1979; Brynner & Stephens, 2001). During the middle of the 20th century, scientific headway had been made in understanding that external factors like X-irradiation (Goldstein & Murphy, 1929), vitamin deficiencies (Hale, 1935; Warkany & Nelson, 1940), and certain viruses (Gregg, 1941) could cause malformations. In 1959, James Wilson published his first set of five principles of teratology (Wilson, 1959). Over the next 14 years, guidance for performing teratology safety tests were designed (Goldenthal, 1966) and Wilson would modify and augment the principles that he republished in updated form (Wilson, 1973). This more recent history has been reviewed elsewhere (DeSesso, 2017), but suffice it to say here that developmental and reproductive toxicology studies are the most complex safety tests from the standpoint of the large numbers of animals on test, as well as the specialized training and wide-ranging knowledge of anatomy and development required of both technical staff and investigators.

During the ensuing six decades since the thalidomide episode, great strides have been made in understanding the

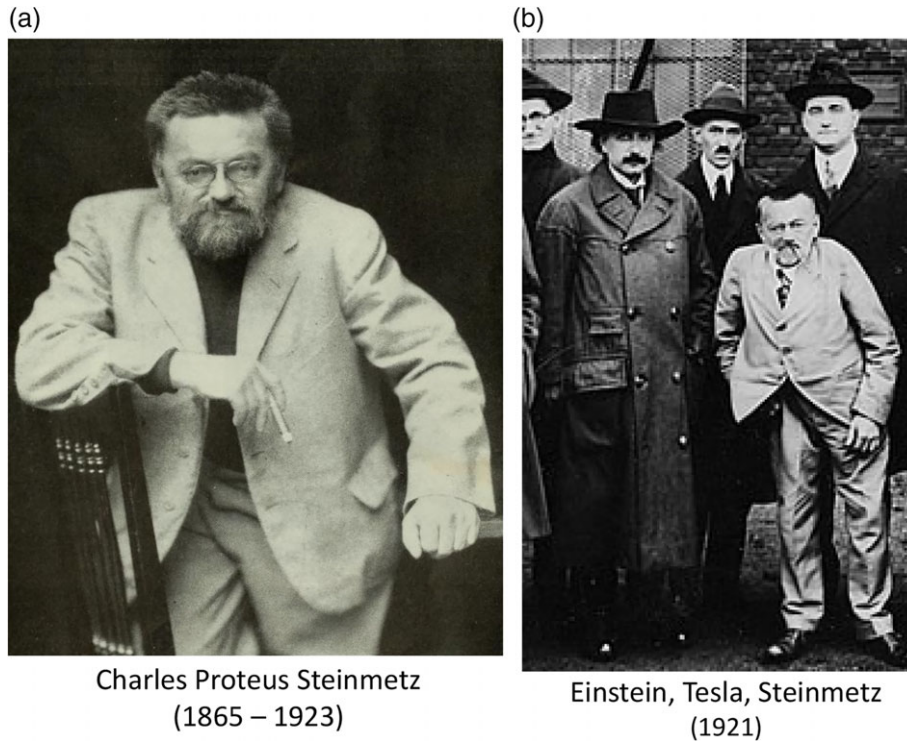


FIGURE 23 (a) Charles Proteus Steinmetz was a German-born, American electrical engineer and mathematics expert. He spent most of his career with what became the General Electric company where he is credited with making a large contribution to development of alternating current as the basis for the electric power industry. (b) Photograph of Albert Einstein, Nikola Tesla, and Steinmetz at a meeting of scientists and engineers held at the Marconi RCA radio station, New Brunswick, New Jersey in 1921

biology of development. Gene–environment interactions have been explored, signal transduction pathways have been identified and their roles in development are being

deciphered. Assisted reproductive technologies have become mainstream therapies to help infertile couples conceive and to assist couples who wish to conceive but do not want to

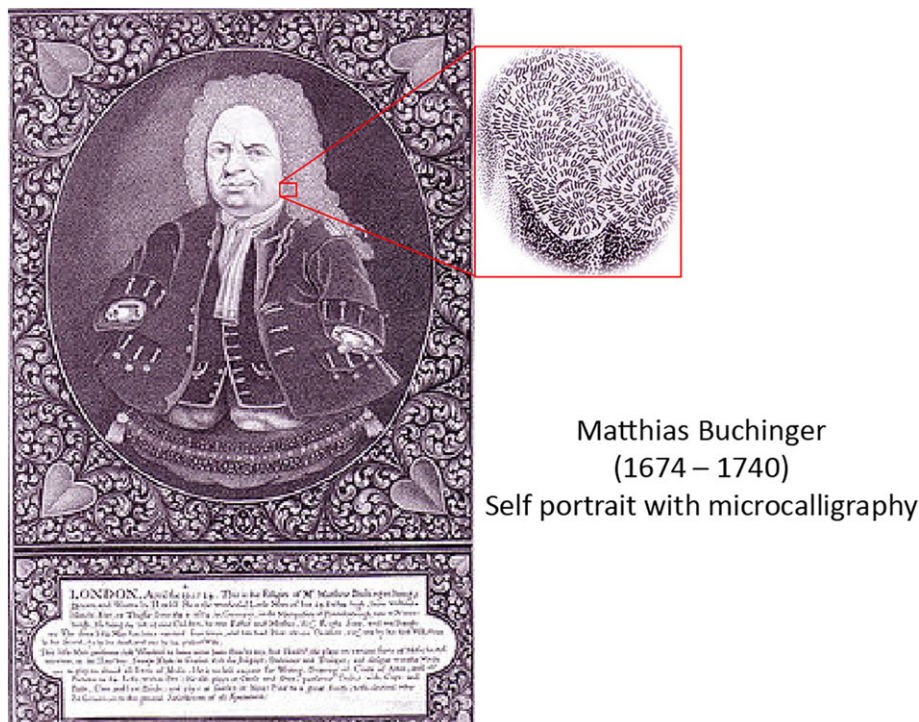


FIGURE 24 Matthias Buchinger had no lower extremities and no forearms or hands yet he was able to perform magic tricks, play musical instruments, draw portraits, and master microcalligraphy. Inset shows a high magnification of his hair, which is composed of the words to biblical verses



Belgian Blue Bull

FIGURE 25 Belgian blue bull has a naturally occurring mutation of the gene for myostatin (MSTN). The mutation results in “double muscling” of the animals. Image retrieved at <https://www.youtube.com/watch?v=4cduCnWfgZY>

transmit a genetic disorder (Jones & Fallon, 2002; McKnight & McKenzie, 2016). Electronic and surgical advances have led to the ability to treat some malformations in utero. Fetal surgery has been used to correct meningocele (spina bifida cystica; Adzick et al., 2011), sacrococcygeal teratomata (Coleman et al., 2002), some forms of diaphragmatic hernia (Harrison et al., 1997), and certain cardiac defects (Arzt & Tulzer, 2011).

11 | MOLECULAR BIOLOGY EXPLOSION

Within the last 30 years or so, technology has advanced to the point where we have begun to map out many molecular events that contribute to health and disease. Associated with this new molecular knowledge, the specific roles within the body of numerous genes have been identified. For instance, Kambadur, Sharma, Smith, and Bass (1997) determined that



Wild type
Control

Twin with mutated
MSTN gene

FIGURE 26 Nellore “twin” cattle were both created by in vitro fertilization. There is a readily apparent phenotypic difference between the two animals. The animal on the right was MSTN gene edited; the animal on the left is the wild type (Proudfoot et al., 2015)

a single a mutation in the gene for myostatin (GDF8) is responsible for the “double muscled” appearance of the Belgian Blue (Figure 25) and other strains of cattle. Following up on this, Proudfoot et al. (2015) edited the genome of Nellore cattle by targeting the myostatin gene to produce offspring with much greater musculature compared to a nonedited “twin” (Figure 26). Armed with successes such as these and the progress in assisted reproductive technology, it may be possible to edit genes in embryos fertilized ex vivo that are diagnosed with certain genetic mutations (e.g., the glycogen storage diseases; Tay-Sachs disease), allowing healthy development to proceed. While gene editing offers great hope for the diseased and their families, it also carries a great risk for potential misuse. Selecting certain traits to make people “more fit” (i.e., faster, stronger, more attractive) smacks of the eugenics movement and could lead quickly to exploitation if not carefully monitored. Caution on the use of gene editing has been voiced by the National Academy of Science (2015), and in the opinion of this author, should be heard.

12 | CONCLUSIONS

The history of “Teratology” in various eras is replete with arrogance, hubris and rationalization for what we consider today to be inhumane behavior. Within the past 3–4 centuries, there has been a willingness among much of the lay population to eliminate the malformed and punish their progenitors, whom it was presumed had invoked the wrath of the supernatural. During much of that same period, the medical and scientific community's zeal for obtaining malformed specimens for study condoned unsavory methods that dehumanized the “specimen” and disregarded the desires of his/her loved ones and families. In more recent times, premature, yet fervent, confidence in investigatory approaches that are faulty or unproven have resulted in populist types of social movements that continue to pervade the environment. Such an ambience has contributed to the interpretation of results and recommendations for actions that have been influenced more by social and political environments or religious beliefs rather than by objective assessment of a sufficient body of data. The result has been the consideration (and in some places the implementation) of callous treatment of a vulnerable segment of the population. In most cases, the pendulum of social conscience has swung back in a more humane direction, but it would have been a more pleasant experience had these events not occurred. Thus, as argued by Stephen Pinker (2018), there has been progress, albeit slowly over the past few millennia but in a continuing rise, especially in the last two and a half centuries.

It is incumbent on the present generation of teratologists not to repeat the errors that have preceded us. As we add to the history of our discipline, let us remain scientifically humble. We must ensure our analyses are based only on the data

before us without being affected by preconceived ideas or social/emotional influences. We should be wary of making too ambitious of jumps in applying the results of new science without fully considering the potential implications of these actions on both the social and individual levels. We must be content with the realization that we will continue to make incremental advances in the science and that we all contribute to the effort. Lastly, we must be on our guard not to fall victim to an overly optimistic or exaggerated sense of our accomplishments. Indeed, in the half-century since the thalidomide episode, there has been a burgeoning movement to protect and support individuals who have birth defects and their families. Science and engineering advances have made major strides in alleviating the impacts of birth defects. It remains our challenge to continue this compassionate trajectory in the centuries to come.

NOTE

¹Morison and several other authors incorrectly report the date of the execution as 1683. The execution occurred in 1638. Thomas Bartholin died in 1680.

ORCID

John M. DeSesso  <https://orcid.org/0000-0002-3134-4207>

REFERENCES

- Adams, N. (1972). *Dead and buried?: The horrible history of bodysnatching*. Aberdeen: Impulse Publications Ltd.
- Adzick, N. S., Thom, E. A., Spong, C. Y., Brock, J. W., Burrows, P. K., Johnson, M. P., ... Farmer, D. L. (2011). A randomized trial of prenatal versus postnatal repair of Myelomeningocele. *New England Journal of Medicine*, *364*, 993–1004. <https://doi.org/10.1002/14651858.CD008825.pub2>
- Allen, G. E. (2011). Eugenics and modern biology: Critiques of eugenics, 1910–1945. *Annals of Human Genetics*, *75*, 314–325. <https://doi.org/10.1111/j.1469-1809.2011.00649.x>
- Arzt, W., & Tulzer, G. (2011). Fetal surgery for cardiac lesions. *Prenatal Diagnosis*, *31*, 695–698. <https://doi.org/10.1002/pd.2810>
- Ballantyne, J. W. (1894). The teratological records of Chaldea. *Teratologia*, *1*, 127–142.
- Ballantyne, J. W. (1896). Teratogenesis: An inquiry into the causes of monstrosities. *Transactions Edinburgh Obstetrical Society*, *21*, 12–296.
- Bennett, H. (1923). The exposure of infants in ancient Rome. *The Classical Journal*, *18*, 341–351.
- Blue, J. C. (2015). *The case of the Piglet's paternity: Trials from New Haven Colony 1639–1663*. Middletown, CT: Wesleyan University Press.
- Bly, R. W. (2018). *Charles Proteus Steinmetz: The electrical wizard of Schenectady*. Fresno, CA: Quill Driver Books, Linden Publishing.
- Bondeson, J. (1997). *A cabinet of medical curiosities*. Ithaca, New York: Cornell University Press.
- Bryner, R., & Stephens, T. (2001). *Dark remedy: The impact of thalidomide and its revival as a vital medicine*. New York: Basic Book-Perseus Publishing.
- Coleman, B. G., Adzick, N. S., Crombleholme, T. M., Johnson, M. P., Howell, L., Hori, S. C., ... Iyooob, C. (2002). Fetal therapy: State of the art. *Journal of Ultrasound in Medicine*, *21*, 1257–1288.
- Cook, S., Adcock, F., & Charlesworth, M. (1928). *The Hellenistic monarchies and the rise of Rome*. In W. E. Heitland (Ed.), *The classical review* (Vol. 7). Cambridge, England: Cambridge University Press.

- Dabney, W. C. (1891). In J. M. Keating (Ed.), *Maternal impressions in Cyclopaedia of the Diseases of Children* (Vol. 1, pp. 191–216). Philadelphia, PA: Lippincott Co.
- Dareste, C. (1876). *Recherches sur la Production Artificielle des Monstruosités, ou Essais de Tératogénie Expérimentale*. Paris: C Reinwald.
- Darrow, C. (1920, 1941). *Address to the Court in "The Communist Trial" People v Lloyd* cited in Stone I. In *Clarence Darrow for the defense*. New York: Doubleday Doran.
- DeSesso, J. M. (2017). Future of developmental toxicity testing. *Current Opinion in Toxicology*, 3, 1–5.
- Dowbiggin, I. (2005). *A concise history of euthanasia: Life, death, god, and medicine*. Lanham, MD: Rowman and Littlefield.
- Duhaime, L. (2014, May). Timetable of world legal. *History* Retrieved from <http://www.duhaime.org/LawMuseum/LawArticle-303/450-BC-The-Twelve-Tables.aspx>
- Fleetwood, J. F. (1959). The Irish resurrectionists. *Irish Journal of Medical Science*, 403, 309–321.
- Galton, D. J. (1998). Greek theories on eugenics. *Journal of Medical Ethics*, 24, 263–267.
- Giovanni, L., Rocco, A., Elio, C., Andrea, M., & Domenico, A. (2007). Symmetric cephalothoracopagus "Janiceps" twins: Sonographic features. *Journal of Ultrasound in Medicine*, 26, 1635–1637.
- Goldenthal, E. I. (1966). *Guidelines for reproduction studies for safety evaluation of drugs for human use*. Washington, DC: Bureau of Science, Drug Review Branch, Division of Toxicological Evaluation, Food and Drug Administration.
- Goldstein, L., & Murphy, D. P. (1929). Etiology of the ill-health in children born after maternal pelvic irradiation. II. *Defective Children born after post conception pelvic irradiation. American Journal of Roentgenology and Radiation Therapy*, 22, 322–331.
- Gould, G. M., & Pyle, W. L. (1896). *Major terata, chapter V IN: Anomalies and curiosities of medicine* (pp. 161–212). New York, NY: Bell Publishing Company.
- Gregg, N. M. (1941). Congenital cataract following German measles in the mother. *Transactions of the Ophthalmological Society of Australia*, 3, 35–46.
- Güvercin, C. H., & Arda, B. (2008). Eugenics concept: From Plato to present. *Human Reproduction and Genetic Ethics*, 14, 20–26.
- Hale, F. (1935). The relation of vitamin a to anophthalmos in pigs. *American Journal of Ophthalmology*, 18, 1087–1093.
- Harrison, M. R., Adzick, N. S., Bullard, K. M., Farrell, J. A., Howell, L. J., Rosen, M. A., ... Filly, R. A. (1997). Correction of congenital diaphragmatic hernia in utero VII: A prospective trial. *Journal of Pediatric Surgery*, 32, 1637–1642.
- Holmes, O.W. Jr. (1927). *Rock v. Bell*, 274 US 200. Opinion of the Supreme Court. Retrieved from <https://supreme.justia.com/cases/federal/us/274/200/>
- Jastrow, M. (1914). Medicine of the Babylonians and Assyrians. *Proceedings of the Royal Society of Medicine*, 7, 109–176.
- Jay, R. (2016). *Matthias Buchinger: The Greatest German living*. Catskill, NY: Siglio Press.
- Johnson K. 2016. Astounding feats in pen, ink and magnifying glass. *New York Times*, 14 January, Retrieved from <https://www.nytimes.com/2016/01/15/arts/design/astounding-feats-in-pen-ink-and-magnifying-glass.html>
- Jones, S. L., & Fallon, L. A. (2002). Reproductive options for individuals at risk for transmission of a genetic disorder. *Journal of Obstetric, Gynecologic, and Neonatal Nursing*, 31, 193–199.
- Kambadur, R., Sharma, M., Smith, T. P. L., & Bass, J. J. (1997). Mutations in myostatin (GDF8) in double-muscled Belgian blue and Piedmontese cattle. *Genome Research*, 7, 910–916.
- Keller, H. (1915). Physicians juries for defective babies. *New Republic*, 5, 173–174.
- Kreis, S. (2009, August). The Laws of the Twelve Tables, c.450 B.C. Retrieved from <http://www.historyguide.org/ancient/12tables.html>
- Landauer, W. (1962). Hybridization between animals and man as a cause of congenital malformations. *Archives of Anatomy*, 44, 155–164.
- Leroi, A. M. (2003). *Mutants: On genetic variety and the human body*. New York: Penguin Books.
- Lipton, M. (1969). The history and superstition of birth defects. *The Journal of School Health*, 38, 579–582.
- McCracken, P. (2003). *Menstruation and monstrous birth The curse of eve, the wound of the hero: Blood, gender, and medieval literature* (Chapter 4). Philadelphia, PA: University of Pennsylvania Press.
- McKnight, K., & McKenzie, L. J. (2016). *Evaluation of infertility, Ovulation Induction and Assisted reproduction*. In L. J. De Groot, G. Chrousos, K. Dungan, K. R. Feingold, A. Grossman, J. M. Hershman, et al. (Eds.), *Endotext*. South Dartmouth, MA: MDText.com.
- Michaels, A. (2004). *Hinduism. Past and present*. Princeton, New Jersey: Princeton University Press.
- Mikhailov, A. T. (1997). Epigenesis versus preformation: First chapter of the Russian embryological research. *International Journal of Developmental Biology*, 41, 755–762.
- Moore, W. (2006). *The knife man: Blood, body snatching, and the birth of modern surgery*. New York, NY: Doubleday Broadway Publishing Group of Random House.
- Morison, J. E. (1975). One entrance into life. *Ulster Medical Journal*, 44, 1–14.
- Murrin, J. M. (1998). Things fearful to name: Bestiality in colonial America. *Pennsylvania History*, 65(special supplemental issue), 8–43.
- National Academy of Science (2015 December). On Human Gene Editing: International Summit Statement. Retrieved from <http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=12032015a>
- Oveyssi, N. (2015 October). The short life and eugenic death of baby John Bollinger: The 1915 medical case that rocked the nation. Retrieved from <https://www.psychologytoday.com/us/blog/genetic-crossroads/201510/the-short-life-and-eugenic-death-baby-john-bollinger>
- Paré, A. (1649) *The Workes of that famous Chirugion Ambroise Parey*, translated by T. Johnson, London: Richard Cotes, cited in Landauer, 1962
- Pernick, M. S. (1996). *The black stork: Eugenics and the death of defective babies in American medicine and motion pictures since 1915*. New York, NY: Oxford University Press.
- Pinker, S. (2018). *Enlightenment now: The case for reason, science, humanism, and progress*. New York: Viking Press - Penguin Books.
- Pinker, S. (2018). *Enlightenment now: The case for reason, science, humanism, and Progress*. New York: Viking Press - Penguin Books.
- Pitts-Taylor, V. (2008). *Cultural encyclopedia of the body*. Westport, CT: Greenwood Press.
- Proudfoot, C., Carlson, D. F., Huddart, R., Long, C. R., Pryor, J. H., King, T. J., ... Fahrenkrug, S. C. (2015). Genome edited sheep and cattle. *Transgenic Research*, 24, 147–153.
- Racine, V. (2013, August). Etienne Geoffroy Saint-Hilaire (1722–1844). Retrieved from <https://embryo.asu.edu/pages/etienne-geoffroy-saint-hilaire-1772-1844>
- Roosevelt, T. (1913, January). Letter to Charles Davenport, Eugenics Record Office, Cold Spring Harbor, Long Island. Retrieved from <https://www.dnalc.org/view/11219-T-Roosevelt-letter-to-C-Davenport-about-degenerates-reproducing-.html>.
- Steinmetz, C. P. (1923). *Four lectures on relativity and space*. New York, NY: McGraw-Hill Book Company.
- Sunday Times Insight Team. (1979). *Suffer the children: The story of thalidomide*. London: Penguin Putnam.
- Vrolik, W. (1849). *Tabulae ad illustrandam embryogenesis in hominis et mammalium tam naturalem quam abnormem*. Amsterdam: GMP Londonck.
- Warkany, J. (1959). Congenital malformations in the past. *Journal of Chronic Diseases*, 10, 84–96.
- Warkany, J. (1971). *Congenital malformations: Notes and comments*. Chicago: Year Book Medical Publishers.
- Warkany, J., & Nelson, R. C. (1940). Appearance of skeletal abnormalities in the offspring of rats reared on a deficient diet. *Science*, 92, 383–384.
- West, J. B. (2013). Marcello Malpighi and the discovery of the pulmonary capillaries and alveoli. *American Journal of Physiology. Lung Cellular and Molecular Physiology*, 304, L383–L390.
- Wilson, J. G. (1959). Experimental studies on congenital malformations. *Journal of Chronic Diseases*, 10, 111–130.
- Wilson, J. G. (1973). *Environment and birth defects*. New York: Academic Press.

How to cite this article: DeSesso JM. The arrogance of teratology: A brief chronology of attitudes throughout history. *Birth Defects Research*. 2019;111: 123–141. <https://doi.org/10.1002/bdr2.1422>