# Was the Darwin/Wedgwood Dynasty Adversely Affected by Consanguinity?

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*Charles Darwin, who was married to his first cousin, Emma Wedgwood, was one of the first experimentalists to demonstrate the adverse effects of inbreeding and to question the consequences of consanguineous mating. He documented the phenomenon of inbreeding depression for numerous plant species, and this caused him to worry about the health of his own children, who were often ill. To determine whether Darwin's fears were justified, we constructed a pedigree of the Darwin/Wedgwood dynasty from the large quantity of genealogical information published on these families. The inbreeding coefficients (F) computed from the pedigree show that Darwin's children were subject to a moderate level of inbreeding (F = 0.0630), and the progeny of related families had still higher inbreeding values (e.g.,* F = *0.1255 for the progeny of Henry Wedgwood, Emma Wedgwood's brother). The analysis of a sample of 25 Darwin/Wedgwood families belonging to four consecutive generations shows a statistically significant positive association between child mortality (death at or before the age of 10 years) and inbreeding coefficient detected by means of nonparametric tests (*$\tau = 0.309$, P = *0.040). Our findings suggest that the high childhood mortality experienced by the Darwin progeny (3 of his 10 children died at age 10 or younger) might be a result of increased homozygosity of deleterious recessive alleles produced by the consanguineous marriages within the Darwin/Wedgwood dynasty.*

*Keywords: consanguineous marriage, Darwin, inbreeding coefficient, pedigrees, Wedgwood*

**Charles Darwin's (1809–1882) life has been thor**oughly chronicled by himself (in an autobiography edited by his granddaughter; Barlow 1958) and prominent historians (Desmond and Moore 1991, Browne 1995, 2002); it has also been recounted concisely (Berra 2009). His paternal grandfather (Erasmus Darwin, 1731–1802), father (Robert Waring Darwin, 1766–1848), and older brother (Erasmus Alvey Darwin, 1804–1881) were medical doctors, and Charles had two years of medical education at Edinburgh University before he completed his bachelor of arts at Cambridge University in 1831. He was obsessed with his health, maintained a health log, and continually referred to his unwellness (Colp 2008). His symptoms included heart palpitations, nausea, violent vomiting, indigestion, flatulence, dizziness, boils, eczema, and finger numbness (paresthesia), to name a few. For treatments he tried "galvanization," whereby an electric current from a battery was applied to his body, and the "water cure" (hydropathy), during which he was scrubbed with cold water, wrapped in a sheet, and soaked. (The water cure was supposed to move blood from the viscera to the skin.) Darwin's medications included mercurous chloride (calomel), mercuric chloride, bismuth nitrate, chalk (calcium carbonate), and opium. For a time, his diet did not allow "any sugar, butter, spices, tea, or anything good" (Colp 2008). These treatments had varying degrees of success, but illness followed Darwin, beginning when he was about 30, after his return from the voyage around the world on the HMS *Beagle* (1831–1836), and continuing until the end of his life. In a letter to his botanist friend Joseph Dalton Hooker in June 1857, Darwin referred to himself as a "wretched contemptible invalid" (Burkhardt and Smith 1990, p. 404).

Colp (2008) reviewed various possible diagnoses including arsenic poising, pigeon allergy, psychosomatic ailments, immune dysfunction, adrenal disease, lupus erythematosus, lactose intolerance, and Crohn's disease. His work reinforced the view of Adler (1959): Darwin suffered from Chagas disease, picked up on the *Beagle* voyage when he was bitten by the benchuga bug (*Triatoma infestans*), the vector of the protozoan parasite *Trypanosoma cruzi*. Colp believed that Chagas disease inflicted permanent damage on Darwin's stomach and small intestine, which made them more reactive in times of stress. Darwin's symptoms were acute, and erupted when he thought about his heretical evolutionary ideas, was overworked, or worried about family matters, such as the deaths of his father and his daughter Annie, or the health of his children. Darwin's health did improve somewhat in the latter part of his life, after the general acceptance of his theory by the scientific community (Colp 2008). Hayman (2009) contended that Darwin suffered from cyclical vomiting syndrome, a vaguely defined

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disorder associated with abnormal mitochondrial DNA (and therefore maternally inherited). Darwin ultimately died of a heart attack on 19 April 1882 at home (Down House), with wife Emma and several children in attendance.

Charles's wife Emma Darwin (née Wedgwood; 1808–1896) was his first cousin. She was the daughter of Josiah Wedgwood II (1769–1843), Charles's uncle. Charles's mother, Susannah Wedgwood (1765–1817), was the daughter of Josiah Wedgwood I (1730–1795), an entrepreneur and the founder of the Wedgwood pottery firm, and Sarah Wedgwood (1734–1815), who were third cousins (figure 1). Darwin's maternal grandparents, mother, and wife were Wedgwoods. As pointed out by Freeman (1984), Darwin, and to a greater extent, his children, carried more genetic material of Wedgwood origin than Darwinian. Charles's son George said to his daughter, "You've none of you ever seen a Darwin who wasn't mostly Wedgwood" (Raverat 1952, p. 154). In the Wedgwood family there were other consanguineous marriages, as well. Three of Emma's brothers were married to relatives: Henry Wedgwood (1799–1885) was married to his double first cousin Jessie Wedgwood (1804–1872); Josiah Wedgwood III (1795–1880) married his first cousin Caroline Darwin (1800–1888), who was Charles's sister; and Hensleigh Wedgwood (1803–1891) was married to his first cousin Frances MacKintosh (1800–1889; figure 1). In addition, an uncle of Erasmus Darwin, William Darwin of Cleatham (1681–1760), was married to his first cousin Elizabeth Darwin (1688–1713; Freeman 1984, King-Hele 2003).

Darwin wrote three botanical books (Darwin C 1862, 1876, 1877) based on experiments he performed in the heated greenhouse at Down House. He demonstrated by means of carefully controlled experiments that the offspring of cross-fertilized plants were more vigorous and numerous than the progeny of self-fertilized plants (Darwin C 1876). In this fashion, he documented the phenomenon of inbreeding depression for numerous plant species (Pannell 2009). After Bemiss (1858), who had studied the effects of consanguineous marriage on offspring mortality by using data obtained through correspondence with physicians, Darwin was one of the first experimentalists to discuss the effects of consanguineous mating. His research led him to worry about the health of his children, who were often ill (Jones 2008). He suspected that his marriage to his first cousin Emma Wedgwood might have caused some of his children's health problems. In addition to his concern about the consanguineous Darwin/Wedgwood intermarriages, Darwin's own ill health led him to fear that his children may have inherited his medical problems. In April 1858, he wrote to Leonard Jenyns, friend, naturalist, and clergyman: "I have now six Boys!! & two girls; & it is the great drawback to my happiness, that they are not very robust; some of them seem to have inherited my detestable constitution" (Burkhardt and Smith 1991, p. 60). Charles and Emma had 10 children, 3 of whom died in childhood (Anne Elizabeth, Mary Eleanor, and Charles Waring).

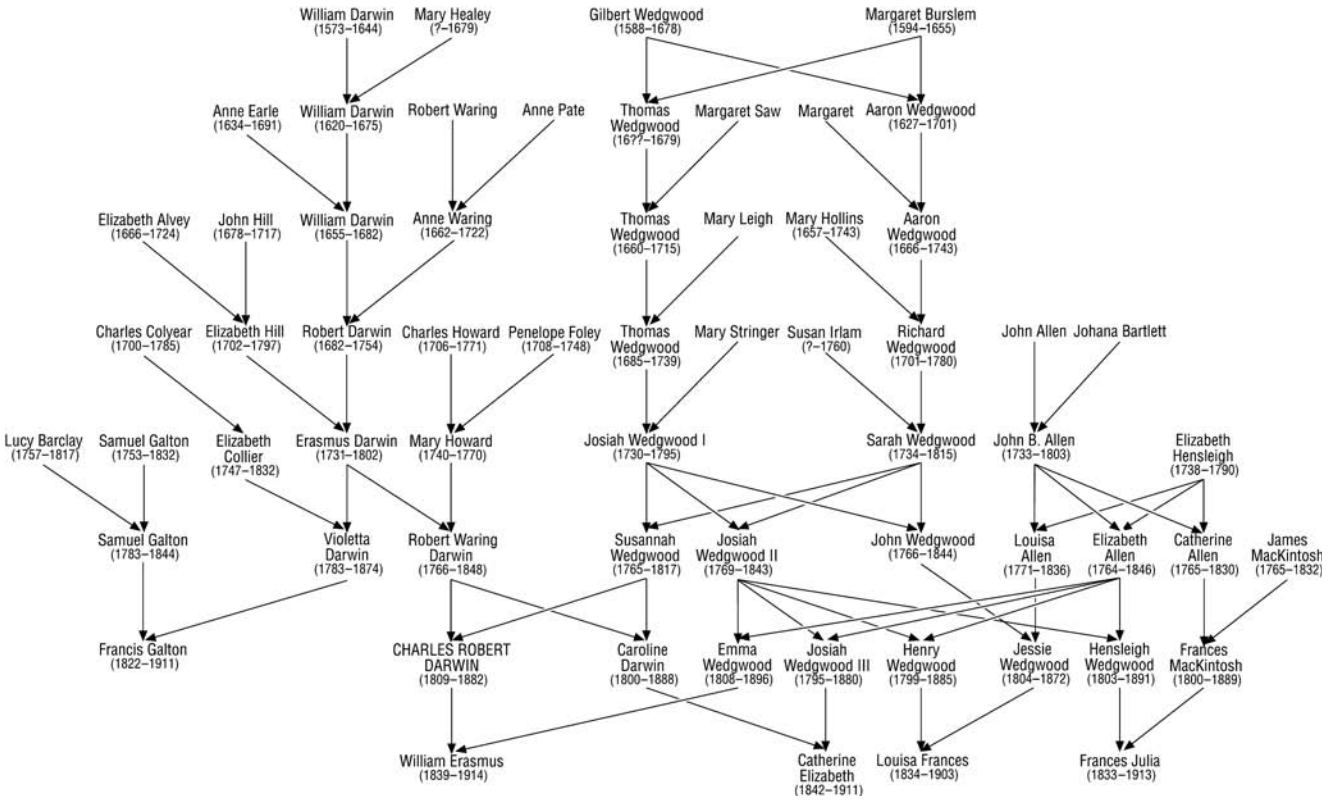


***Figure 1. Pedigree of the Darwin/Wedgwood dynasty represented as chains of descent.***

Chapter 17 of *The Variation of Animals and Plants under Domestication* is titled "On the Good Effects of Crossing, and on the Evil Effects of Close Interbreeding" (Darwin C 1868). Darwin presented data from animals and plants to support his contentions, and he mentioned consanguineous marriages, although not his own. Charles was so worried about consanguineous marriage that he asked his neighbor and member of Parliament, John Lubbock, in a letter dated 17 July 1870, to append a consanguineous marriage question to the 1871 census form:

My Dear Lubbock:

> As I hear that the Census will be brought before the House tomorrow, I write to say how much I hope that you will express your opinion on the desirability of queries in relation to consanguineous marriages being inserted. As you are aware, I have made experiments on the subject during several years; & it is my clear conviction that there is now ample evidence of the existence of great physiological law, rendering an enquiry with reference to mankind of much importance. In England & many parts of Europe the marriages of cousins are objected to from their supposed injurious consequences; but this belief rests on no direct evidence. It is therefore manifestly desirable that the belief either be proved false, or should be confirmed, so that in this latter case the marriages of cousins might be discouraged. If the proper queries are inserted, the returns would show whether married cousins have in their households on the night of the census as many children, as have parents who are not related; & should the number prove fewer, we might safely infer either lessened fertility in the parents, or which is more probable, lessened vitality in the offspring.
>
> It is moreover much to be wished that the truth of the often repeated assertion that consanguineous marriages lead to deafness & dumbness, blindness &c, should be ascertained; & all such assertions could be easily tested by the returns from a single census—
>
> Believe me
> yours very sincerely
> Charles Darwin

A few years later he wrote: "With respect to mankind, my son George has endeavoured to discover by a statistical investigation whether the marriages of first cousins are at all injurious, although this is a degree of relationship which would not be objected to in our domestic animals; and he has come to the conclusion from his own researches and those of Dr. Mitchell that the evidence as to any evil thus caused is conflicting, but on the whole points to its being very small." (Darwin C 1876, p. 460–461).

Darwin's census request was unsuccessful, but his son George (1845–1912) was an advocate of marriage reform and pursued the subject, probably stimulated by Alfred Huth's 1875 book, *The Marriage of Near Kin* (Browne 2002). In addition, George Darwin (1875) introduced the idea of using the frequency of occurrence of the same surname in married couples (isonymy) to study the level of inbreeding in a population, which is the basis of the surname models in present human population biology (Colantonio et al. 2003). Darwin's son Leonard (1850–1943) was president of the First International Congress of Eugenics in London, 1912 (Laughlin 1932), a movement founded by Sir Francis Galton (1822–1911), Charles Darwin's half first cousin. George Darwin's daughter Gwen Raverat (1952, p. 121–122) wrote a charming personal account of the Darwin family's attachments to each other through their ailments and hypochondria: "The trouble was that in my grandparents' house it was a distinction and a mournful pleasure to be ill. This was partly because my grandfather was always ill, and his children adored him and were inclined to imitate him; and partly because it was so delightful to be pitied and nursed by my grandmother." She further added, "At Down, ill health was considered normal."

All was not genetic doom and gloom, however. Three of Darwin's sons were fellows of the Royal Society (George, Francis, and Horace) and were knighted. The latter honor escaped Charles; he was much too controversial for Queen Victoria's tastes. Freeman (1984) pointed out that Darwins have been fellows of the Royal Society in father-to-son sequence longer than the members of any other family. The streak ran from Erasmus Darwin, elected in 1761, to Sir Charles Galton Darwin (1887–1962), elected in 1922, a span of 201 years over five generations and seven fellows.

This article examines the role of inbreeding within the Darwin/Wedgwood lineage to determine if Darwin's fears were justified.

## The Darwin/Wedgwood pedigree

The pedigree of the Darwin/Wedgwood dynasty (figure 1) was constructed from genealogical information on both the Darwin and the Wedgwood families obtained from different sources (Pearson 1914, 1930, Raverat 1952, Barlow 1958, Tobias 1972, Freeman 1984, Bowlby 1990, Burkhardt and Smith 1990, Healey 2001, King-Hele 2003, Burkhardt 2008, Clift 2008, Heiligman 2009, Geneall Project 2009). The most complete pedigree is found in Freeman's (1984) work. He issued a facsimile of the pedigree privately published in 1888 by H. Farnham Burke (1859–1930) titled *Pedigree of the Family of Darwin*. It begins with a William Darwin of Marton in Lincoln County who died before 1542 and extends 13 generations to Charles's grandchildren, with a token entry for the 14th generation. The original pedigree was limited to 60 copies and only a few survive today. Freeman (1984) augmented and explained the contents of the Burke document, and made it accessible to the public. Not all the obtained genealogical information is included in the

pedigree shown in figure 1. Thus, the parents of William Darwin (1573–1644), Elizabeth Alvey, John Hill, Charles Colyear, and both parents and grandparents of Charles Howard and Penelope Foley are not included in the pedigree because they are not relatives of any other individual of the pedigree—their inclusion would unnecessarily complicate figure 1. Inbreeding coefficients (*F*) were computed from the Darwin/Wedgwood pedigree by means of the FSpeed computer program. The inbreeding coefficient is the probability that at a given locus, an individual receives two genes identical by descent as a result of the common ancestry between his or her parents (Cavalli-Sforza and Bodmer 1971). To evaluate the impact of inbreeding on survival in the Darwin/Wedgwood dynasty, mortality data (deaths and survivals from birth to 10 years) of the progeny of 25 families were obtained from several sources (Freeman 1984, Burkhardt and Smith 1990, Burkhardt 2008, Clift 2008). These families are distributed along four consecutive generations, and they are listed in table 1. All statistical analyses were performed by means of the SPSS statistical software system.

## Inbreeding in the Darwin/Wedgwood dynasty

Several consanguineous marriages occurred in the Darwin/Wedgwood dynasty, as shown in the pedigree depicted in figure 1. Most of these consanguineous marriages were contracted by the children of Josiah Wedgwood II, Charles Darwin's uncle. Of eight children surviving to adulthood, four were married to cousins. Emma Wedgwood was mar-

*Table 1. Child mortality and inbreeding coefficient (*F*) in the progeny of Darwin/Wedgwood families.*

| Marriage | Number of children | Deaths to 10 years | Survivals | Mortality to 10 years (percentage) | Inbreeding coefficient (*F*) |
|---|---|---|---|---|---|
| **Generation 1** | | | | | |
| Erasmus Darwin × Mary Howard and Elizabeth Collier (second wife) | 12 | 3 | 9 | 25.00 | 0 |
| William A. Darwin × Jane Swineshead[a] | 6 | 3 | 3 | 50.00 | 0 |
| Thomas Hall × Elizabeth Darwin[a] | 5 | 2 | 3 | 40.00 | 0 |
| Josiah Wedgwood I × Sarah Wedgwood | 8 | 2 | 6 | 25.00 | 0.0039 |
| John B. Allen × Elizabeth Hensleigh | 11 | 1 | 10 | 9.09 | 0 |
| **Generation 2** | | | | | |
| Samuel Galton × Violetta Darwin | 7 | 0 | 7 | 0 | 0 |
| Francis Darwin × Jane Harriet[a] | 8 | 0 | 8 | 0 | 0 |
| Robert W. Darwin × Susannah Wedgwood | 6 | 0 | 6 | 0 | 0 |
| William B. Darwin × Elizabeth Croix[a] | 7 | 1 | 6 | 14.29 | 0 |
| Samuel Fox × Ann Darwin[a] | 6 | 0 | 6 | 0 | 0 |
| Josiah Wedgwood II × Elizabeth Allen | 9 | 1 | 8 | 11.11 | 0 |
| John Wedgwood × Louisa Allen | 6 | 0 | 6 | 0 | 0 |
| James MacKintosh × Catherine Allen | 4 | 0 | 4 | 0 | 0 |
| **Generation 3** | | | | | |
| Charles R. Darwin × Emma Wedgwood | 10 | 3 | 7 | 30.00 | 0.0630 |
| Edward Elston × Sarah Darwin[a] | 7 | 0 | 7 | 0 | 0 |
| Francis Rhodes × Charlotte Darwin[a] | 9 | 1 | 8 | 11.11 | 0 |
| William Darwin Fox × Ellen Sophia Woodd and Harriet Fletcher (second wife)[a] | 16 | 1 | 15 | 6.25 | 0 |
| Samuel Beesthorpe × Mary Ann Darwin[a] | 4 | 0 | 4 | 0 | 0 |
| Josiah Wedgwood III × Caroline Darwin | 4 | 1 | 3 | 25.00 | 0.0630 |
| Henry Wedgwood × Jessie Wedgwood | 6 | 1 | 5 | 16.67 | 0.1255 |
| Hensleigh Wedgwood × Frances MacKintosh | 6 | 0 | 6 | 0 | 0.0625 |
| Francis Wedgwood × Frances Moseley[a] | 7 | 0 | 7 | 0 | 0 |
| **Generation 4** | | | | | |
| George H. Darwin × Maud du Puy[a] | 4 | 0 | 4 | 0 | 0 |
| Horace Darwin × Emma Ferrer[a] | 3 | 0 | 3 | 0 | 0 |
| Mathew Harrison × Lucy Wedgwood[a] | 5 | 1 | 4 | 20.00 | 0 |

a. Marriage not included in pedigree of figure 1.

ried to her first cousin, Charles Darwin. Josiah Wedgwood III married his first cousin, Caroline Darwin, Charles Darwin's sister. Hensleigh Wedgwood married his first cousin, Frances MacKintosh, and Henry Wedgwood married his double first cousin, Jessie Wedgwood. In addition, Josiah Wedgwood I and Sarah Wedgwood (the parents of Susannah Wedgwood, Charles Darwin's mother) were third cousins. As a result of these consanguineous unions, the progeny of some families presented relatively high values of the inbreeding coefficient ($F$). The children of Henry Wedgwood had a high inbreeding coefficient ($F = 0.1255$) since their parents were double first cousins. The progeny of both Charles Darwin and Josiah Wedgwood III had a moderate inbreeding coefficient ($F = 0.0630$), and the progeny of Hensleigh Wedgwood had an inbreeding coefficient of 0.0625. Charles Darwin's mother, Susannah Wedgwood, and her brother, Josiah Wedgwood II, had very low inbreeding values ($F = 0.0039$). All the remaining individuals in the pedigree depicted in figure 1 had $F = 0$, as did Charles Darwin and his father, Robert W. Darwin. However, one must take into account that the inbreeding coefficients computed for the Darwin/Wedgwood dynasty could be underestimates, as the pedigree in figure 1 is incomplete, was developed using limited genealogical information, and the ancestors of some individuals are unknown. In spite of this, the reliability of the inbreeding coefficients for many individuals—for example, Charles Darwin's progeny—is high because they are based on a nearly complete four-generation pedigree. It has been shown that data from the most recent four or five generations are sufficient to capture most of the information relevant to the calculation of inbreeding coefficients. This is a result of the fact that recent inbreeding events have a disproportionately large influence on an individual's inbreeding coefficient relative to events deeper in the pedigree (Balloux et al. 2004).

The effect of inbreeding on survival in the Darwin/Wedgwood dynasty was investigated from child mortality data (deaths from birth to 10 years) of 25 families belonging to four consecutive generations, which were named arbitrarily 1, 2, 3, and 4 (table 1). Generation 1 includes five families: those of Erasmus Darwin, Charles Darwin's grandfather; his brother, William Alvey Darwin; his sister, Elizabeth Darwin; Josiah Wedgwood I; and John B. Allen. Generation 2 has eight families: those of Violetta, Francis, and Robert W. Darwin, Erasmus's children; William B. Darwin and Anne Darwin, William Alvey Darwin's children; Josiah Wedgwood II; John Wedgwood; and James MacKintosh. Generation 3 includes nine families: those of Charles R. Darwin; William Alvey Darwin's grandchildren, Sarah Darwin, Charlotte Darwin, William Darwin Fox, and Mary Anne Darwin; and Josiah Wedgwood II's children: Josiah Wedgwood III (married to Caroline Darwin, Charles Darwin's sister), Henry Wedgwood, Hensleigh Wedgwood, and Francis Wedgwood. Generation 4 includes three families: those of Charles Darwin's children, George and Horace Darwin; and Lucy Wedgwood, daughter of Josiah Wedgwood III and Caroline Darwin. Not all of these families are represented in the pedigree depicted in figure 1, as their inclusion would overcomplicate the figure. The 25 families had a total of 176 children; 155 survived, but 21 died at 10 years of age or younger. The total child mortality was 11.93%. The mean number of children per family was 7.04 (±0.59), and the mean child mortality of the families was 11.34% (±2.86). The incidence of childhood mortality in the families of the Darwin/Wedgwood dynasty is clearly low as compared with contemporary rates for the general population in England. Infant mortality rates calculated from data on births and infant deaths in England for the period 1850–1900 were at the level of 150 infant deaths per 1000 live births (Williams and Galley 1995, Woods 2000). Early childhood mortality rates from one year to age four were about 15% during the middle decades of the 19th century and showed a continuous decline until the level of about 7.5% at the beginning of the 20th century (Woods 2000).

A statistically significant positive association between childhood mortality and inbreeding coefficient among the 25 Darwin/Wedgwood families was detected by nonparametric tests (Kendall's and Spearman's coefficients of rank correlation are $\tau = 0.309$, $P = 0.040$ and $r_s = 0.369$, $P = 0.035$, respectively, under one-sided tests). Those progeny with higher inbreeding coefficients had higher mortalities in general; for example, the offspring of Charles Darwin (30.00% mortality), Josiah Wedgwood III (25.00%), and Henry Wedgwood (16.67%). Nevertheless, several progeny from families of generation 1 with $F = 0$ or very low inbreeding coefficients had high mortalities (25% to 50%); however, these deaths were easily explained as the result of environmental causes. In fact, if all families of generation 1 are removed from the analysis, the association between mortality and inbreeding coefficient is clearly increased ($\tau = 0.456$, $P = 0.013$ and $r_s = 0.537$, $P = 0.007$). The Darwin/Wedgwood dynasty exhibits a moderate level of inbreeding depression for child survival, estimated to be 5.4% ±6.3 (or 9.5% ±3.8 when data of generation 1 are removed from the analysis) for the progeny of a first-cousin marriage ($F = 0.0625$) under a linear regression model. These values are rather close to the mean value of inbreeding depression for the progeny from a first-cousin marriage, which had been estimated to be 4.4% ± 4.6 using data from 38 human populations and has been recently revised downward to 3.5% on the basis of a study of 69 populations in 15 countries located across four continents (Bittles and Neel 1994, Bennet et al. 2002, Bittles and Black 2009). The magnitude of inbreeding depression detected in the Darwin/Wedgwood families is far from the strong inbreeding depression found in some families, such as the dynasty of the Spanish Habsburg kings in the 16th and 17th centuries, where the cost of inbreeding on survival for the progeny of a first-cousin marriage has been estimated at 17.8% ± 12.3 (Alvarez et al. 2009).

To what extent were Charles Darwin's progeny affected by inbreeding? His children had an inbreeding coefficient of 0.0630, meaning more than 6% of their autosomal genome is expected to be homozygous. However, the effects of inbreeding

can vary considerably between individuals with the same expected *F* because large stochastic variation is associated with the proportion of the genome identical by descent (Carothers et al. 2006). In an analysis of 10,000 single-nucleotide polymorphisms spread throughout the genome, individuals with autosomal recessive disease whose parents are first cousins and who come from communities that frequently practice consanguineous marriage showed a genome homozygosity ranging from 5% to 20%, with a mean value of 11%, which is clearly higher than the expected value from pedigree information ($F = 0.0625$; Woods et al. 2006). As a consequence of consanguineous marriage, Darwin's children had an increased risk of suffering the effects of detrimental recessive alleles, which is a characteristic effect of inbreeding. It is known that three of Charles Darwin's six children with long-term marriage history suffered from infertility (William Erasmus, 1839–1914; Henrietta, 1843–1929; and Leonard, 1850–1943). It has been pointed out that the most likely cause of this unexplained infertility might be the segregation of some recessive autosomal meiotic mutation manifested in the Darwin progeny as a result of inbreeding (Golubovsky 2008). On the other hand, child mortality of the Darwin progeny was very high in the context of the studied Darwin/Wedgwood families, as 3 of his 10 children died in childhood (Anne Elizabeth, Mary Eleanor, and Charles Waring). Only two of the studied Darwin/Wedgwood families had a higher mortality (table 1). The statistical association between child mortality and inbreeding coefficient detected in the Darwin/Wedgwood dynasty suggests that an increase of homozygosity for deleterious recessive alleles produced by consanguineous marriages could be involved in the high childhood mortality experienced by Darwin progeny. This hypothesis is also supported by recent evidence that shows that inbreeding is an important risk factor in susceptibility to a number of human diseases, including infectious diseases (Lyons et al. 2009a, 2009b). The cause of death of two of Darwin's children (Anne Elizabeth and Charles Waring) is known. Mary Eleanor, Darwin's third child, lived only 23 days, from 23 September to 16 October 1842, just after the Darwins moved into Down House. The cause of her death is unknown (Colp 2008). Anne Elizabeth (1841–1851), Darwin's second child and first daughter, was diagnosed with "bilious fever with typhoid character." She most likely died from what was then called consumption. Her malady is now easily attributable to childhood tuberculosis (Keynes 2001, Colp 2008)—Lyons and colleagues (2009a) recently studied microsatellite genome screen data and suggested that inbreeding increases risk of tuberculosis infection in humans. The last child, Charles Waring (who lived from 6 December 1856 to 28 June 1858; figure 2), never learned to walk or speak, lived only 18 months, and died of scarlet fever (Burkhardt and Smith 1991). A genomewide screen study with microsatellite markers by Lyon and colleagues (2009b) showed that homozygosity is strongly associated with childhood mortality resulting from invasive bacterial diseases, such as bacteremia, bacterial meningitis, or neonatal sepsis. Therefore, it can be speculated that inbreeding could be behind Charles Waring's death. Charles Darwin wrote a touching memorial to his son Charles (appendix V in Burkhardt and Smith 1991), and his death prevented Darwin from attending the meeting of the Linnean Society on 1 July 1858, where the joint papers of Darwin and Alfred Russel Wallace announcing their evolutionary ideas were read by the society secretary (Browne 2002).

***Figure 2. Photograph of Emma Darwin holding her last-born child, Charles Waring, photographed by her first-born child, William, in 1857. The overexposed image from the English Heritage Photographic Library, London, was rephotographed from Keynes (2001) and the brightness and contrast were digitally enhanced to retrieve as much detail as possible.***

Although the disorder is not related to consanguinity, Keynes (2001) suggested that Charles Waring also suffered from Down syndrome. The probability of a Down syndrome baby rises with increasing maternal age (Huether et al. 1998); the risk of having a live-born child with Down syndrome is 1 in 1667 for a 20-year-old mother, 1 in 500 for a 34-year-old mother, and 1 in 14 for a 48-year-old mother (Beers and Berkow 1999). Indeed, Emma Darwin was 48 years old when she gave birth to her last child. Two pediatricians who treat Down syndrome chil-

dren examined figure 2 and noted a number of dysmorphic features: There appears to be macrocephaly with frontal bossing, the eyes are wide set with a suggestion of slanting, the nasal bridge is depressed, and the lips are thin. The hands appear to have short, wide digits, and there is an indication of clinodactyly of the fifth finger. The infant appears to be hypotonic. Certainly many of these features can be seen in Down syndrome, although most Down syndrome children have microcephaly. The frontal bossing, depressed nasal bridge, and stubby digits can be seen in the many forms of achondroplasic dwarfism. These children are often hypotonic, with delayed motor development. Further, achondroplastic infants can have hydrocephalus, which could account for Charles Waring's macrocephaly and delayed speech. However, achondroplasia is an autosomal dominant disorder, and one would expect to see other children affected in the family.

## Conclusion

Our answer to the question posed by the title of this article is yes. Charles Darwin's fears of consanguinity appear to have been justified given the context of the Darwin/Wedgwood marriages.

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## References cited

Adler S. 1959. Darwin's illness. Nature 184: 1102–1103.

Alvarez G, Ceballos FC, Quinteiro C. 2009. The role of inbreeding in the extinction of a European royal dynasty. PLoS ONE 4: e5174. doi:10.1371/journal.pone.0005174

Balloux F, Amos W, Coulson T. 2004. Does heterozygosity estimate inbreeding in real populations? Molecular Ecology 13: 3021–3031.

Barlow N, ed. 1958. The Autobiography of Charles Darwin 1809–1882: With Original Omissions Restored. Collins.

Beers MH Berkow R. 1999. The Merck Manual of Diagnosis and Therapy. 17th ed. Merck Research Laboratories.

Bemiss SM. 1858. Report on influence of marriages of consanguinity upon offspring. Transactions of the American Medical Association 11: 319–425.

Bennett RL, et al. 2002. Genetic counseling and screening of consanguineous couples and their offspring: Recommendations of the National Society of Genetic Counselors. Journal of Genetic Counseling 11: 97–119.

Berra TM. 2009. Charles Darwin: The Concise Story of an Extraordinary Man. Johns Hopkins University Press.

Bittles AH, Black ML. 2009. Consanguinity, human evolution, and complex diseases. Proceedings of the National Academy of Sciences 107 (suppl. 1): 1779–1786.

Bittles AH, Neel JV. 1994. The costs of human inbreeding and their implications for variations at the DNA level. Nature Genetics 8: 117–121.

Bowlby J. 1990. Charles Darwin: A New Life. Norton.

Browne J. 1995. Charles Darwin: Voyaging. Knopf.

———. 2002. Charles Darwin: The Power of Place. Knopf.

Burkhardt F, ed. 2008. Charles Darwin: The *Beagle* Letters. Cambridge University Press.

Burkhardt F, Smith S, eds. 1990. The Correspondence of Charles Darwin, vol. 6. Cambridge University Press.

———. 1991. The Correspondence of Charles Darwin, vol. 7. Cambridge University Press.

Carothers AD, Rudan I, Kolcic I, Polasek O, Hayward C, Wright AF, Campbell H, Teague P, Hastie ND, Weber JL. Estimating human inbreeding coefficients: Comparisons of genealogical and marker heterozygosity approaches. Annals of Human Genetics 70: 666–676.

Cavalli-Sforza LL, Bodmer WF. 1971. The Genetics of Human Populations. Freeman.

Clift I. 2008. The Wedgwood/Darwin Dynasty. Melrose Books.

Colantonio SE, Lasker GW, Kaplan BA, Fuster V. 2003. Use of surname models in human population biology: A review of recent developments. Human Biology 75: 785–807.

Colp R. 2008. Darwin's Illness. University Press of Florida.

Darwin C. 1862. On the Various Contrivances by which British and Foreign Orchids are Fertilised by Insects and on the Good Effects of Intercrossing. John Murray.

———. 1868. The Variation of Animals and Plants under Domestication. John Murray.

———. 1876. The Effects of Cross and Self Fertilisation in the Vegetable Kingdom. John Murray.

———. 1877. The Different Forms of Flowers on Plants of the Same Species. John Murray.

Darwin GH. 1875. Marriages between first cousins in England and their effects. Journal of the Statistical Society 38: 153–184.

Desmond A, Moore J. 1991. Darwin: The Life of a Tormented Evolutionist. Warner Books.

Freeman RB. 1984. Darwin Pedigrees. Printed for Author.

Geneall Project. 2009. Genealogical Information on European Countries. (26 February 2010; *www.geneall.net*)

Golubovsky M. 2008. Unexplained infertility in Charles Darwin's family: Genetic aspect. Human Reproduction 23: 1237–1238.

Hayman JA. 2009. Darwin's illness revisited. British Medical Journal 339: b4968: 1414–1415.

Healey E. 2001. Emma Darwin: The Inspirational Wife of a Genius. Headline.

Heiligman D. 2009. Charles and Emma: The Darwins' Leap of Faith. Holt.

Huether CA, Ivanovich J, Goodwin BS, Krivchenia EL, Hertzberg VS, Edmonds LD, May DS, Priest JH. 1998. Maternal age-specific risk rate estimates for Down syndrome among live births in white and other races from Ohio and metropolitan Atlanta, 1970–1989. Journal of Medical Genetics 35: 482–490.

Jones S. 2008. Darwin's Island: The Galapagos in the Garden of England. Little, Brown.

Keynes R. 2001. Annie's Box: Charles Darwin, His Daughter and Human Evolution. Fourth Estate.

King-Hele D, ed. 2003. Charles Darwin's "The Life of Erasmus Darwin." 1st ed. Cambridge University Press.

Laughlin HH. 1932. Historical Background of the Third International Congress of Eugenics in Scientific Papers of the Third International Congress of Eugenics held at the American Museum of Natural History New York, August 21–23, 1932: 1–14. Plate 7. A Decade of Progress in Eugenics. Williams and Wilkins.

Lyons EJ, Frodsham AJ, Zhang L, Hill AVS, Amos W. 2009a. Consanguinity and susceptibility to infectious diseases in humans. Biological Letters 5: 574–576.

Lyons EJ, et al. 2009b. Homozygosity and risk of childhood death due to invasive bacterial disease. BMC Medical Genetics 10: 55. doi:10.1186/1471-2350-10-55.
Pannell JR. 2009. On the problems of a closed marriage: Celebrating Darwin 200. Biological Letters 5: 332–335.
Pearson K. 1914. The Life, Letters and Labours of Francis Galton, vol. 1. Cambridge University Press.
———. 1930. The Life, Letters and Labours of Francis Galton, vol 3. Cambridge University Press.
Raverat G. 1952. Period Piece: A Cambridge Childhood. Faber.
Tobias PV. 1972. Darwin, "descent" and disease. Transactions of the Royal Society of South Africa 40: 239–260.
Williams N, Galley C. 1995. Urban-rural differentials in infant mortality in Victorian England. Population Studies 49: 401–420.
Woods CG, et al. 2006. Quantification of homozygosity in consanguineous individuals with autosomal recessive disease. American Journal of Human Genetics 78: 889–896.
Woods R. 2000. The Demography of Victorian England and Wales. Cambridge University Press.

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"Must you yell 'EUREKA!' every time an amoeba splits?"