The Contributions of Infection Control to a Century of Surgical Progress

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Although many surgical procedures were well-developed in principle before 1867, their application for the treatment of human disease was limited because of a mortality rate from postoperative infection alone of about 50%. It was the eventual acceptance of Lister's work and the development of the aseptic-antiseptic ritual that allowed operative therapy to be successful and made modern surgery possible. The background leading to the development of aseptic-antiseptic rituals is discussed.

ALTHOUGH TREPHINATION is known to have taken place more than 10,000 years ago, it has been barely a century since the results of elective operations became acceptable, coinciding temporally with the first issues of the *Annals of Surgery* in 1885. Many things combined to make the development of modern surgery possible at that time. Anesthesia was one of these, and improved concepts of pathology, physiology, and pharmacology were others of major importance. However, it was clearly the control of wound infections that was the primary determinant that allowed the development of surgery as we know it today.

Surgical Practice Before Lister

Surgery before 1800 was done primarily for life-threatening conditions, and speed rather than technique was emphasized since there was no anesthesia. However, even then, surgical innovation was apparent. Drainage of empyema and hemorrhoidectomy were described in the writings of Hippocrates (460–377 B.C.), tracheostomy was performed by Ascelepiades before the time of Christ (124–40 B.C.), and ligation of aneurysm and neck dissection was performed by Antyllus in the 7th century A.D.[1] Other major operations that were performed successfully included C-section (16th century), gastrotomy for removal of a swallowed knife (1609 and 1640), rhinoplasty (1793), and operations for strangulated hernia. The most common operations were lithotomy for bladder calculus and amputations for compound fracture or gangrene.[2]

In the first part of the 19th century, well before either anesthesia or antisepsis, technical accomplishments developed rapidly. Pott perfected lithotomy, Sims successfully repaired vesicovaginal fistulas, McDowell resected ovarian tumors, intestinal resections and anastomoses were performed, and vascular surgery developed with numerous cases of successful ligation of large arteries for aneurysms or tumors.[3] Other operations performed not infrequently included mastectomies, pedicle grafts, tonsillectomy, excision of bones and joints, glossectomy, rhinoplasty, mandible resection, resection of the alveolar ridge, repair of club foot, repair of hare lip, herniorrhaphy, extraction of cataract, and clavicle resections.[1–4] Thus it was clear that lack of anesthesia did not prevent surgical innovation and the application of surgical procedures for cure of disease.

When anesthesia was introduced by Morton in 1846, it was of major importance for surgeons and their patients. Surgeons could operate more deliberately and patients no longer were devastated by the pain. Yet, surgery, especially elective procedures, remained unacceptable for most patients for a very simple reason: as many as 80% of all operations were followed by hospital gangrene (presumably streptococcal infection and mixed synergistic infection), and almost one-half of all patients died after a major operation.[2]

Results of Surgery Before Lister

A comparison of the results of operations before and after Lister emphasizes the problem of infection in these deaths. Records were kept best during wartime, and

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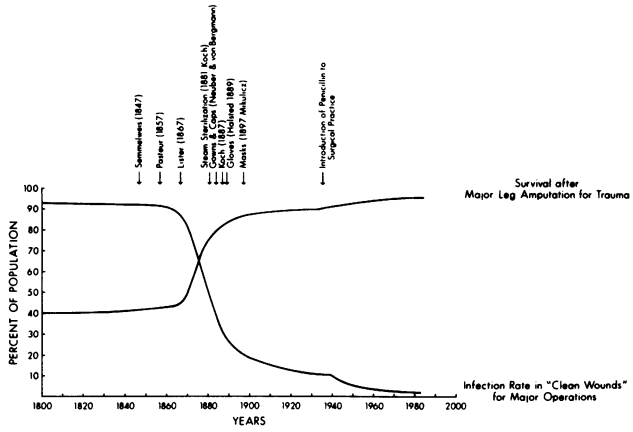

FIG. 1. An example of how prevention of wound infections have influenced surgical results. The values given are "best estimates" obtained from a compilation from many sources. Obviously, complete data are not available. The impact of antibiotics was almost imperceptible compared with the introduction of asepsis, which was already well-established.

accounts of the results of surgical operations not related to injury before the adoption of Listerism are sketchy and incomplete. Florence Nightingale, in 1863, was one of the first to champion accurate reporting of successes and failures of surgery, but surgeons, with abysmally few successes, were naturally reluctant. As an example, the noted surgeon James Paget (1863) disavowed accountability, claiming that his deaths resulted from coincidental factors.[2]

In the Battle of Fontenay (1745), only 30 or 40 men of 300 requiring immediate amputation survived.[2] However, others claimed 30% survival for amputation during this time. In 1870, during the seige of Paris, the mortality from amputation was nearly 100%. Smith[5] noted that in civilian practice, from 1850 to about 1875, "amputation wounds rarely, if ever, recovered at Bellevue [Hospital in New York City], except after long-continued suppuration." By 1885, after the adoption of Listerian principles, death from suppuration was uncommon. Others in civilian practice fared somewhat better: Alanson (1782) had a series of 35 amputations without mortality and Liston (1841) had a mortality of only 11.4%, both uncommon accomplishments for this time.

Most reports suggest that before Listerian principles, the wounds of almost all major amputations became infected and that about one-half of the patients died. With antiseptic practice, mortality dropped suddenly to less than ten per cent and sepsis was infrequent by comparison (Fig. 1).

Surgical Technique Before Lister

To understand the importance of infection in surgical practice, it is well to examine everyday techniques in use at the time of the introduction of antisepsis by Lister in 1867. One of the individuals uniquely qualified to make observations of surgical practice during this period was Stephen Smith (1823–1922).[6,7] Smith, himself a surgeon, wrote three surgical textbooks and numerous articles, many on medical history. He practiced surgery at New York's Bellevue Hospital for half a century and was equally active in public health affairs of the city. His efforts to correct the dreadfully unsanitary conditions there led to passage of a major health bill in 1886. He later became Commissioner of Health for New York City and was largely responsible for establishment of the New York State Health Department.

Smith's vivid account of surgical practice at Bellevue Hospital between 1850 and 1880 provides real insight.[5] During this time, the primary thought of the surgeon was to do the job as rapidly as possible, even though anesthesia was used routinely. His instruments were kept sharp and free of rust but were never thoroughly cleaned. They were often returned to their case after use with little more than a wipe, even if they had been dropped on the floor or used to amputate an infected leg with pus exuding from the cut surface. Sometimes the hair of the patient was shaved off, but the affected part was seldom washed free of dirt and filth; incisions through the skin carried the debris into the freshly made wounds, and little attempt was made to close the incision so that the filthy skin surfaces were not placed in contact with the freshly cut edges. The surgeons themselves came directly from other duties in the hospital, giving little though to washing their hands. Not only were the surgeon's hands put directly into the wounds of the unfortunate patients, but bystanders were often invited to "take a feel," probing the wounds for educational purposes.

By that time, of course, silk ligatures were used regularly to secure hemostasis. These were "carried about in any convenient pocket, and at the operation, the silk was cut to proper lengths, waxed, and then drawn through a buttonhole of an assistant." One end was always left hanging out of the wound, later to be removed by traction as the suture slowly cut through the vessel wall by suppuration. It cannot be surprising that ligation of large arteries frequently ended with fatal hemorrhage.

The operating theaters themselves were astonishingly primitive, using the same tables and tools without much cleaning. Sawdust usually covered the floor to absorb spilled blood and pus, similar to the neighborhood butcher shops.

Pre-Listerian Hospitals

The conditions in hospitals further added to the problems of ill patients. Before 1800 there were, in fact,

few hospitals, and these were located in cities where sanitation practices were poor.[2,8] Often, the open wards contained many "giant" beds with numerous (as many as eight), usually naked, often very sick patients per bed, huddled together for warmth, because of inadequate heating. The surgical wards of the late 18th century and early 19th century were described as having admixtures of human feces, urine, blood, and pus on the floors, with the remnants of expectoration clinging to the walls. The stench was often formidable. Wounds were washed with the same sponges and water, passing from one patient to another. Bandages were reused without even washing. Many hospitalized patients died, about one of every four or five overall, and to a greater extent in the surgical wards.

The malodorous stench in the air that accompanied putrification of dead bodies, their wounds, and the hospitals came to be associated with an increased risk to good health and longevity. Thus, during the last part of the 18th century and first part of the 19th, putrid wounds and numerous serious illnesses, not yet recognized as infectious in origin, were thought to be caused by "bad air" or "humors."[8,9] Many believed that the air itself was contagious, and some believed that the air contained invisible, minute particles that caused disease. Such particles were felt to arise by spontaneous generation from decaying matter. It was the attempt to get rid of the bad smells and the accompanying disease caused by "bad humors" of the air that mothered ventilation and hygenic practices. Soon thereafter, and well before Lister's successes, good ventilation and observation of hygiene came to be known as primary factors in surgical success and healing without suppuration.

The theory that infectious diseases arose from causes other than germs was not unreasonable for the time. Microbes had not yet been discovered, and astute observers had made the following clear associations: (1) febrile diseases (usually lumped together) were more common near marshes; (2) smoke and fire seemed to protect against *mal aria,* fever caused by bad air; and (3) the healthy became ill more often when in close contact with the sick, especially the closed hospital environment. In addition, the necessity of using natural plants for food sources had well-established the presence of poisons in the environment. Would it not seem reasonable that decaying poisonous plants, such as water hemlock and fungi, would give rise to volatile poisons that would arise from the marshes? This poison was called miasma[9,10] and was believed to generate from virtually all sorts of decaying matter. Miasma was believed to be inactivated by heat and smoke and some chemicals, but the poison could be carried by contact. One curious feature was that there seemed to be different kinds of miasma, which led to different kinds of fevers, and this observation required explanation. By the first half of the 19th century, the germ theory to explain specific diseases was already being advanced by several persons, such as de Hildenbrand, Holland, and Henle, Koch's mentor. A real problem lay in the fact that there were many thinkers or theorists but few investigators that put the theories to test, partly because funds for research were scarce, but more important because of the intellectual rigidity of the medical profession.

An important concept that permeated the thoughts of surgeons during the pre-Listerian period was that of laudable pus. It is hard for modern surgeons to imagine that the sometimes technically sophisticated surgeons of the early 19th century welcomed the appearance of thick, creamy pus in their wounds. However, consider the alternatives. Virtually all wounds became infected, and there were basically two kinds of infection, one associated with laudable pus and a chronic infection that, although troublesome, usually healed, and the other, associated with the condition then known as hospital gangrene. Hospital gangrene usually ran a fulminant course, characterized by high fevers, pyemia, and sepsis. Death came swiftly and often. Untreated streptococcal sepsis is now a thing of the past, but 150 years ago, in the form of hospital gangrene, it was the major cause of death after surgery. Would it not be better to have an untreated staphylococcal infection than an untreated streptococcal infection? Without knowing the causative organism, our forefathers thought so, and surely so would we. Without realizing it, they practiced bacterial interference with at least partial success.

It was in this milieu that Semmelweiss developed the concept of cleanliness (asepsis) and that the findings of Pasteur became so important.

The Development of Antisepsis and Asepsis

To Joseph Lister goes the credit for the introduction of antisepsis into clinical surgery in 1867.[11,12] However, many predecessors helped to pave the way. Antiseptics, for example, had been used on an empiric basis for centuries.[1,2] Hippocratic writings in the 4th and 5th centuries B.C. clearly show that wine was used in the dressings of wounds. Application of alcohol (wine) to wounds was also made in biblical times by the Good Samaritan (Luke 10:33–34) and such were used extensively thereafter. Stronger alcoholic preparations were used after distillation was introduced. Perhaps the best documentation of results in the pre-Listerian era came from Néalaton (1863), who used alcohol on wounds with less than ten per cent hospital mortality from elective operations.[2] However, Néalaton's method was not accepted by the Paris Surgical Society, and his

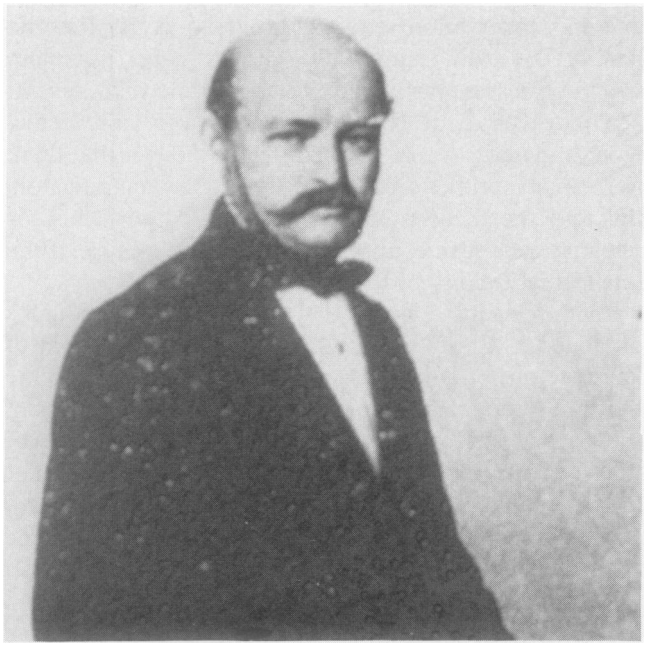

FIG. 2. Ignac Semmelweis (1818–1865) at the age of 39 years. (From Antall J,[15] figure 98.)

findings were not pursued. Turpentine, also used for its styptic properties, was used as early as 1363, often with myrrh, frankincense, benzoin, and balsam of Peru. Silver nitrate, mercuric chloride, and creosote all were used before Lister's time to reduce infections. Even carbolic acid (phenol) was used by Demaux (1859) and Wolfe (1865) to reduce the risk of infection before its popularization by Lister. At least 20 publications on the use of wound antiseptics appeared in the British literature in the decade before Lister's work.[13]

These empiric uses were met with neither enthusiasm nor acceptance because of lack of a logical basis for their effect. The germ theory of disease had not yet emerged, even though Fracastoro (1546) and many others thereafter thought disease was carried by invisible organisms that transmitted contagion by air currents or contact. Most, however, did not believe in such organisms and thought that even if there were germs in wounds, they surely arose by spontaneous generation. It is somewhat surprising that the role of microbes in infection were not understood at an earlier time, since von Leeuwenhoek clearly showed their existence with the invention of the microscope (1693). A real problem for most people was that these small organisms occurred in both infected wounds and the normal mouth, suggesting that they could not be pathogenic. However, Gaspard (1822) demonstrated pathogenicity of pus well before the investigations of Pasteur, by injecting pus intravenously into a dog. When that dog came near death, blood was taken and injected into a second animal, causing death, an event not observed after injection of blood from a normal animal. These findings, using the horse, were duplicated by Hamont in 1827.[14]

A quarter of a century later (1847), Semmelweis (Fig. 2) confirmed that sepsis could be transmitted.[2,15] While Semmelweis was away on a trip from Vienna, his friend, Kolletschka, died of sepsis following a finger prick while doing an autopsy of a woman who had died of puerperal sepsis. Semmelweis, already convinced of the transmissibility of puerperal fever, through astute clinical and pathologic observations, quickly reached the connection offered by this "experiment of nature" and later performed the crucial animal study. Infected lochia or pus from women with puerperal sepsis was introduced into the vaginal canals of parturient rabbits and caused the classical signs of puerperal fever. This could be prevented by treatment of the rabbit's vagina with chlorinated lime. He correctly reasoned that pus transferred from one patient to another by the hands of the obstetrician was the cause of puerperal fever, and his introduction of ritualistic handwashing and use of disinfectants (a chlorine solution) virtually eliminated puerperal sepsis in the Vienna hospital. This was indeed the introduction of aseptic technique into clinical medicine. The astoundingly good results were based upon careful clinical observations, later supported by incisive laboratory experiments. How sad it is that jealousy resulted in the dismissal of Semmelweiss by the Ministry of Education. Already insecure and broken by this rejection, he left Vienna and returned to Pert. Unfortunately, he always felt himself an outsider[16] and never gained the drive to promote his discovery in a way similar to Lister. He subsequently developed overt mental illness and died in an insane asylum in 1865, ironically, of septicemia.

Louis Pasteur (Fig. 3) is the second major hero in the saga leading to control of surgical infections. He published his studies on fermentation in 1857 and proved that there were "organic corpuscles" in the air in 1861. These experiments led to research on putrification in 1863 and to studies of the process of fermentation in 1866–1868. The theory of spontaneous generation was disproven by his studies, and he showed that the germs causing fermentation and putrification were killed by heat. It was really his experiments that were able to change the mindset of the practitioners of the day eventually to accept the germ theory.

Pasteur's major contributions to infection control were still to come, but his investigations during the early 1860s caught the attention of Lister (Fig. 4), who had for some time, along with others, noted that death following amputation was much more common in patients treated in hospitals than those treated at home. Lister noted that septicemia was associated with venous invasion of the putrification process and was quick to realize the analogy between the suppurative process in wounds and the fermentation process described by Pas-

teur.[12] Once convinced that invisible living particles were the cause of suppuration, Lister tried carbolic acid as an antiseptic, since it was known to prevent putrification.[11] His first attempts failed, but he persisted in his clinical experiments, and subsequent cases involving compound fractures were quite successful. Antiseptic principles were quickly developed and soon applied to operations, with the mortality from amputation falling from 45% to 15%.[17] It is interesting that this pioneer of antisepsis never really practiced asepsis and never wore a mask, gown, or gloves.

The last hero of the era was Robert Koch (Fig. 5), who, in 1878, demonstrated for the first time the pathogenicity of single types of pyogenic organisms, who proved that different germs caused different disease, and who developed his famous postulates. Also, in 1881, he introduced steam sterilization.[2]

Conclusion

After the introduction of anesthesia, surgeons could work more slowly and more operations were done, but the results were certainly no better than before anesthesia, and all operations were to be dreaded. By 1880, the germ theory of disease had been generally accepted and antisepsis was widely although not universally used; at the first official meeting of the American Surgical Association in 1883, most people approved of Listerism, partly because of Lister's personal visit to the United States in 1876, but others, such as Samuel Gross, denounced the practice and felt that excellent results could be achieved with surgical cleanliness.[4] By the time of the first publication of *Annals of Surgery* in 1885, virtually all types (or prototypes) of modern operations were being done,[18] with the exception of cardiac operations, lung resection, arterial anastomoses, and implant

FIG. 3. Louis Pasteur (1822–1895) at the age of 67 years. (From Dubos RJ. Louis Pasteur: Free Lance of Science. Boston: Little, Brown & Co., 1950; 168.)

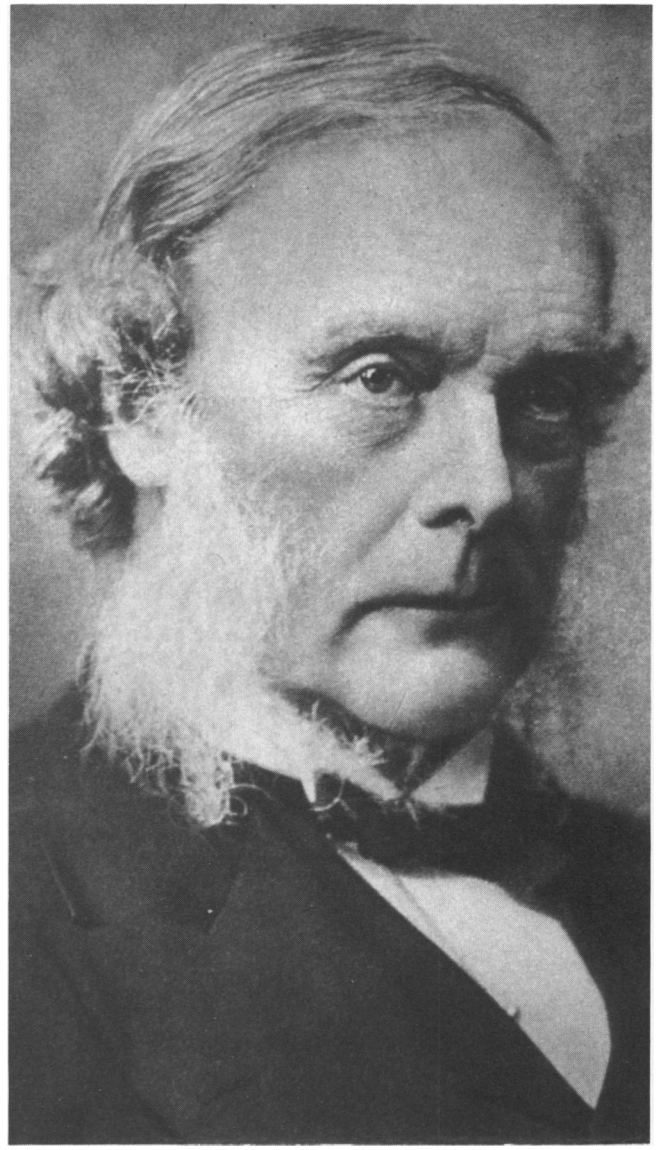

FIG. 4. Joseph Lister 1827–1894. (Courtesy, University of Cincinnati Health Sciences Library.)

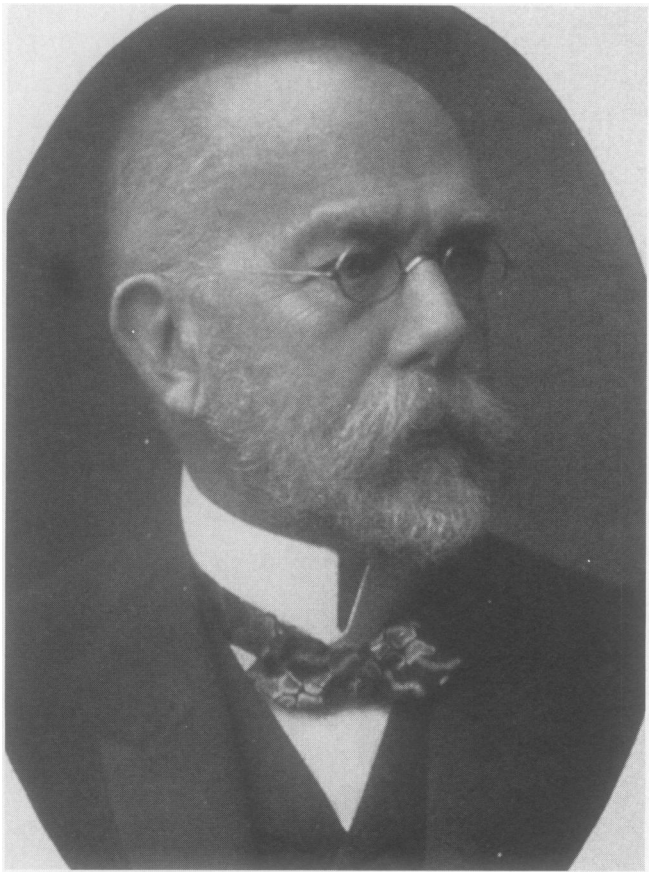

FIG. 5. Robert Koch 1843–1910. (From Sigerist HE. The Great Doctors: A Biographical History of Medicine. New York: WW Norton & Co., 1933; 368.)

surgery, and all with an acceptable mortality. This was in marked contrast to the pre-Lister era, only 20 years before.

Antisepsis served its purpose well, for it was really what set surgery free, but with the real and rapid appreciation of the significance of the contributions of Pasteur, Koch, and others that specific microorganisms caused surgical infections and that these organisms could be excluded from gaining entrance to wounds, surgical cleanliness as espoused by Gross and many others rapidly became surgical asepsis and was finally recognized as being more important than antisepsis. Gowns and caps were introduced by Neuber and von Bergmann in the 1880s and gloves by Halsted, Bloodgood, Mikulicz, and Thomas before 1900, completing the aseptic era, but acceptance came slowly, and it took still another three decades for general compliance with aseptic principles.[19,20] Asepsis, without change in concept in this century, continues to stand as the primary factor in surgical success. Development of the antiseptic era, introduced before Christ and made a practical reality by Lister, continues, but at a slow pace. Antibiotics, a part of the more global antisepsis, have had a significant impact on surgical practice during the last 50 years, but it appears that all of the major concepts for their use are now known and new antibiotics or antiseptics will not be of major additional importance.

It remains only for the third era of the control of surgical infection to make a major impact: improvement of the patient's own defense mechanism against microorganisms.[21] The importance of this approach for the control of surgical infection is not known at present, but it could be as great as either asepsis or antisepsis, at least for high-risk patients (*e.g.*, the immunocompromised host). When the last of the triad of asepsis–antisepsis–host defense is complete, it should form a solid base for allowing virtually any surgical feat to be accomplished without fear of death or disability from infection. It will be interesting and exciting to see what advances the pages of the *Annals* will see during the next century.

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