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Making darkness visible: the discovery of X-ray and its introduction to dentistry

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COVER STORY

Making Darkness Visible: The Discovery of X-ray and Its Introduction to Dentistry

The first radiograph of human anatomy, 1895.

ABSTRACT

Wilhelm Conrad Roentgen's discovery of the X-ray one century ago has been ranked in importance with the discovery and development of anesthesia and the discovery of microorganisms and their role in disease. Roentgen's scientific devotion and the persistence of C. Edmund Kells, who took Roentgen's discovery and applied it to dentistry, had a great impact on how dentists practice today.

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Nov. 8, 1895. Scientist Wilhelm Conrad Roentgen is at work in his laboratory in the Bavarian city of Würzburg, testing the ability of cathode rays to penetrate a vacuum tube. He determines that the rays are too weak to permeate the glass. He is about to end the experiment when he notices a faint glow rising from a paper coated with barium platinocyanide crystals—a glow that increases as he moves the paper closer to the tube and fades completely when he turns off the tube's power supply. Elated and mystified, Roentgen realizes that he has stumbled across a form of energy that neither he nor, likely, the rest of humankind has ever before encountered: energy that is capable of penetrating solid materials.[1-4] He christens this alien energy "the X-ray" and unknowingly places the world on the threshold of atomic medicine.

Roentgen's discovery of the X-ray has been ranked in importance with the discovery and development of anesthesia by Horace Wells and William Morton, both dentists, and the discovery of microorganisms and their role in disease by the likes of Pasteur and Lister. Today's dentistry would be impossible lacking the benefits of Roentgen's scientific devotion—and the persistence of C. Edmund Kells, who took Roentgen's discovery and shaped it for use in dentistry. Other European and American pioneers made contributions that furthered dental radiography. As dentistry observes the centenary of the X-ray's discovery, it seems fitting to review the lives and work of the men who had such a great impact on how dentists practice today.

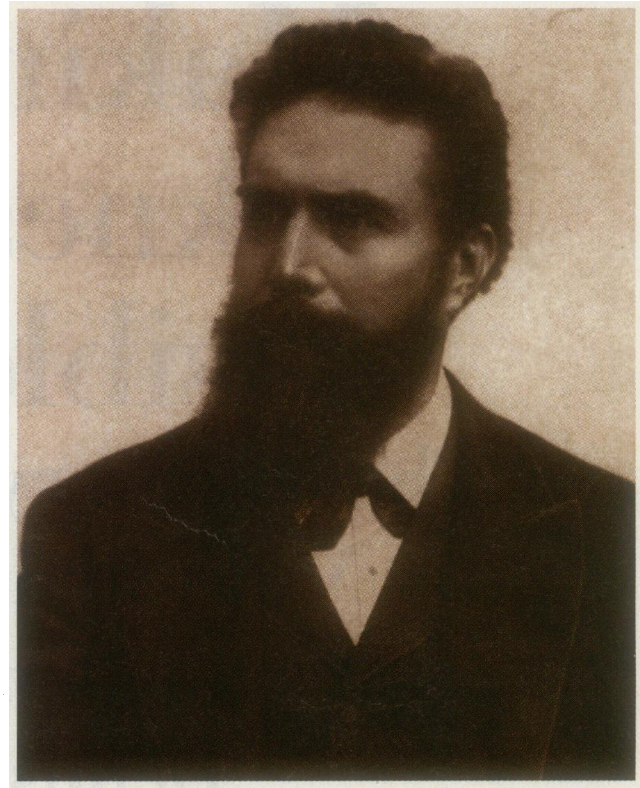
THE PATH OF A PIONEER: ROENTGEN'S CAREER AND GREATEST DISCOVERY

Anyone tracing the details of the X-ray's discovery could well ask whether it was brought about by the skill of the discoverer or an accidental occurrence.[2] Now, 100 years after the historic event, we can conclude that it was both the genius of a scientific investigator and the right set of circumstances that introduced the world to the science of atomic medicine.

Born on the Lower Rhine and brought up in the Netherlands in the middle of the 19th century, Wilhelm Roentgen led the placid life of a well-loved only child until his teens. At 16 years of age, he was expelled from school for his involvement in a prank and for refusing to divulge the names of his accomplices. This act would haunt his academic and professional career, because it barred his way into several universities and eventually thwarted some university appointments that his inherent abilities otherwise might have won for him.[5]

At last, however, he obtained a long-sought university degree from the Polytechnic Institute in Zürich, despite corneal ulcers that threatened his sight. He went on to add a doctorate in physics to his list of credentials. Then began his struggle for a university position—a struggle because he was still dogged by his lack of a high-school diploma. One of his mentors at the institute at last helped Roentgen secure a position as an associate professor of physics at the Imperial German University in Strasbourg.

Roentgen, finally having settled into employment and having given his wife of four years something of a permanent home, turned his attention to his research. His favorite experiments involved crystals, which he felt had many as-yet-unrevealed interactions in other facets of science. This fascination would later prove to be the catalyst for his historic discovery of the X-ray.[3]



William Conrad Roentgen succeeded dramatically as a scientist despite an embattled academic career.

Roentgen's research in physics gained him a great deal of respect in the academic and scientific worlds, and he made his way through several university positions of increasing responsibility. In 1894, he was appointed rector of the University of Würzburg, a position whose many administrative duties forced him to set aside his research work until the autumn of 1895.[2,3] That year found physicists throughout Europe—including Roentgen—conducting research experiments involving gaseous discharge tubes. They were particularly intrigued by the multicolor luminescence the tubes emitted when electrical current was applied to them.

The discovery. On a Friday evening—Nov. 8, 1895—Roentgen was conducting an experiment with a new kind of tube, called a Hittorf-Crookes tube, to determine if the cathode rays produced in it were strong enough to penetrate its glass wall. If they did penetrate the glass wall, a glow of colored light would appear around the outside of the tube when the rays encountered air. In an attempt to fully observe the phenomenon, he darkened the laboratory as much as possible. To help his weakened eyes, he also covered the tube with black cardboard to exclude any light interference.[1,3-5] He applied power to the electrodes and carefully observed the end of the tube but did not notice a glow around the outside of the tube. He concluded that cathode rays were not strong enough to penetrate glass.

As Roentgen was about to

turn off the power supply to the tube, he noticed a faint glow of light being emitted by some crystals of barium platinocyanide applied to a piece of paper that lay on a table some distance from the tube.[1,3-5] Knowing that cathode rays travel only about six to eight centimeters from their source, he moved the crystals closer to the tube and noticed that the glow grew brighter. As he moved the crystals farther away from the tube, they became dimmer. When the current to the tube was turned off, the barium platinocyanide crystals ceased to glow.[2,3] At this point, Roentgen realized that he was observing a new form of energy, a form of energy he knew nothing about that had the ability to penetrate solid material. He decided to call these rays "X" because of their unknown nature.

In the weeks after his discovery, Roentgen was so mesmerized by this new form of energy that he totally immersed himself in unleashing its properties. As he investigated the X-ray, he discovered that these rays not only caused crystals to fluoresce but also were capable of penetrating solid objects. His experiments dealing with penetration of objects included such materials as wood, paper, metals—and the human body, thus opening the door to the science of diagnostic radiology.

The first radiographic image of human anatomy ever recorded was of the hand of Roentgen's wife. This crude radiograph took 15 minutes to expose, and when Bertha Roentgen saw the bones of her hand made visible on the photographic plate, she said it created in her "a vague premonition of death."[2,3,5]

Roentgen carried out in silence his feverish work with the mystery energy. Not even his wife was aware of his historic discovery until after he was convinced that indeed had found a new form of energy. Shortly after that November night, however, he did remark to a friend, "I have discovered something interesting, but I do not know whether or not my observations are correct."

Publication and publicity. Forty days after the experiment in his Würzburg laboratory, Roentgen announced to his colleagues and the scientific community the news of his discovery of this new form of energy. He submitted to the Würzburg Physical-Medical Society a paper entitled "On a New Kind of Rays, A Preliminary Communication." This was the first of the three classical communications he would write about the X-ray—a cumulative 34 pages on the characteristics of this new form of energy that would prove his genius as an investigative scientist.[2,3,5]

Outside the scientific community, news of Roentgen's discovery spread rapidly throughout the world. He found it difficult to adjust to sensationalism and publicity, having never wanted to be famous but simply respected by his colleagues. The fame and honor his discovery won him led to an offer of the position of professor and head of the Physical Institute of the University of Munich.[2,3,5] He felt he could not refuse this request, and in 1900, he and his wife made their final move.

Roentgen received many honors—not the least of which was the change in the name of his discovery from "X-ray" to "Roentgen ray." He was recognized with awards from many nations, including, in 1901, the first Nobel Prize in physics.[1-5] His modesty and his determina-

Roentgen's Würzburg laboratory: an unassuming site for an amazing discovery.

tion not to reap personal benefit from his discovery led him to decline several of these tributes, and he donated his Nobel Prize money to the University of Würzburg and the German war effort. As a devoted scientist, Roentgen showed his appreciation for the honors bestowed upon him by giving to the world the gift of the X-ray to be used for the good of humankind; he never patented it.

C. Edmund Kells with some of the female assistants he dared to employ—just one example of the innovations he made in dental practice.

Roentgen died in Munich in 1923.[3] His will requested that all his papers dealing with his discovery of X-ray be destroyed. A meticulous scientist to the end, he worried about what might happen if his research notes were taken out of context by others not as exacting as he.

A MACHINE TO TAKE PICTURES OF THE TEETH: KELLS AND THE X-RAY IN DENTISTRY

If Roentgen gave of his scientific genius to bring the X-ray to the world, C. Edmund Kells gave of his ingenuity, his diligence and finally his physical health to bring the X-ray to dentistry. A true dental pioneer, Kells quickly grasped the potential for applying Roentgen's discovery to dentistry. Soon after Roentgen announced his discovery in December 1895, Kells went to work to make the capabilities of the X-ray available to the dental profession and thereby forever changed the way dentistry would be practiced.

Laying the foundation for a life of innovation. C. Edmund Kells, born in 1856, grew up in Union-occupied New Orleans during the Civil War.[6,7] Although living and practicing in New Orleans during Reconstruction, Kells described himself in his biography as an "unreconstructed Johnny Reb."[7] Almost all of Kells' 72 years were spent in New Orleans, except when he went away to school and during the Civil War when his parents sent him to the plantation home of friends because "there was no telling what those ferocious damn Yankees might do."[6]

Kells' father was a prominent New Orleans dentist, and after his high-school years Kells became an apprentice in his father's practice. The senior Dr. Kells was said to have had no superior as a prosthodontist, and in his practice he constructed many gold dentures. (Vulcanite was not yet available.) One of young Edmund's responsibilities in that practice was to electroplate his father's dentures with gold. This was the beginning of a lifelong interest in electricity for the younger Kells.[6,7]

In 1876, Kells entered New York Dental College and graduated in 1878 with a D.D.S. degree. While in dental school, Kells befriended several people who worked in the Edison laboratory in nearby Menlo Park, N.J. He and his friends would often "hang around" the Edison laboratory during their free time. Here Kells observed some of the early work with electricity, including the research on the first electric incandescent lamps.[7]

The flowering of an active mind. After finishing dental school, Kells returned to New Orleans, where he would practice dentistry for the next 50 years. He developed one of the most extensive and lucrative practices in the South.[6,8] He also became an inventor and innovator, patenting more than 30 inventions from 1880 through 1922. His active mind found an outlet in writing as well, and he published more than 200 articles and two books on all aspects of dentistry.

Many of the devices Kells conceived were electrically powered; in fact, in 1886, he became the first dentist to use electric street current in his dental office. A great deal of his work focused on improving the practice of dentistry: the first electric mouth lamp, the first electric air compressor and the first completely electric dental unit.[6,7,9,10] However, his ingenuity was not totally confined to innovation in his own field. He held patents on a thermostat, an electro-magnetic clutch and engine, an automobile jack, an automatic window closer, a fire alarm and extinguisher and an elevator starter and brake.[6,7] He developed instruments and devices to be used in medicine and surgery.

Of particular note was his invention of a suction apparatus for the irrigation and aspiration of fluids during surgery. The suction apparatus replaced the old technique of mopping the surgical wound with sponges.[11] Dr. Rudolph Matas of New Orleans, one of the world's most renowned surgeons, later paid tribute to Kells[11-13]: "The suction apparatus is sufficient to immortalize the name of Dr. C. Edmund Kells. He has won the eternal gratitude of every working surgeon in the world."[11] This fruit of Kells' creativity became a major advancement in modern surgery.

> The year 1896 saw Kells' greatest accomplishment: he became the first American dentist to take dental radiographs of a living subject.

Bringing the X-ray to dentistry. The year 1896 saw Kells' greatest accomplishment: he became the first American dentist to take dental radiographs of a living subject.[8,9,14] He also was the first to exhibit a dental X-ray apparatus at a dental meeting, thereby opening new vistas for the dental profession.[14]

Soon after the announcement of the discovery of the X-ray by Roentgen in December 1895, many physics laboratories in the country began their own experiments and demonstrations. Tulane University in New Orleans was one of these. Professor Brown Ayres of Tulane University gave an early exhibition that Kells attended.[7] The following report of that demonstration appeared in Kells' autobiography, "Three Score Years and Nine," published in 1926:

"Being interested, as I was, in electrics of all kinds, what more natural than that this phenomenon should interest me extremely?" he wrote. "Well, it did. Knowing Professor Ayres intimately, I suggested that I would like a machine with which to try to take pictures of the teeth. This aspect interested him also. With Professor Ayres' aid I was not long in getting a Tesla Coil and an improved Crookes tube, both having been specially designed for X-ray work.

"Just when I received this outfit and just when I took my first dental skiagraph [the term "skiagraph," from the Greek meaning "shadow picture," was in frequent use during Kells' day] I cannot say because I have no record of it. In the 'Transactions of the Southern Dental Association' there is reported my X-ray clinic given in Asheville in July 1896 and I remember full well that I had had the apparatus several months before giving this clinic and had developed a method of taking dental skiagraphs. Thus I must have begun this work in April or May, 1896. I say 'developed a method' because a method had to be developed. No one had taken, as far as I know, any dental pictures of living subjects and the whole technic had to be worked out by myself."[7]

Kells' initial radiographic work was not done with patients. His first subject—likely the first person in America to have a dental X-ray taken—was his female dental assistant. (In fact, Dr. Kells was the first dentist in the South with the courage to employ a young woman as an office assistant. Eventually, Kells would have five female assistants in his office.[6,12,15]) Kells also devised a film holder made of vulcanite to hold the film in the patient's mouth, as well as equipment to aid in developing X-ray film.[7]

Kells became a vigorous proponent of the use of X-rays in dental practice. In a presentation before the National Dental Association in 1919, he stated, "The time is now here when it is fully recognized that the general practitioner of dentistry is not fully capable of rendering his patients the very best services unless his equipment includes an X-ray machine."

He opposed the diagnosis of dental disease by anyone other than dentists. In his day, it was common for physicians or roentgenologists who were looking for foci of infection to take dental X-rays, then refer the patient to a dentist for dental extractions without consulting the dentist about dental pathology. Under this system, many teeth were needlessly extracted; this appalled Kells, who felt that tooth conservation was of the utmost importance. Kells took the position that while physicians and roentgenologists should be able to take dental X-rays, they were not always able to correctly diagnose dental lesions depicted on the film and, therefore, such diagnosis should be made by a dentist. Furthermore, he advised that physicians refer such patients only to a dentist for diagnosis and that dentists refuse to operate solely on a physician's instruction.[14]

The hazards of excessive radiation exposure not yet being appreciated, Kells and others who used X-ray in the early years had no qualms about using a technique known as "setting the tube."

Kells' practice involved all aspects of dentistry, including exodontia, which was a prominent feature of most dental practices. In fact, the first dollar he made in his practice was for removing a tooth for a very prominent Confederate general. Kells became an innovator in the field of oral surgery. After introducing X-ray into his practice, Kells began to X-ray all impacted and missing third molars—"whereupon," he wrote, "the faulty methods formerly used for their removal were made manifest and I devised the operation of cutting the crown in two and removing the tooth in sections."[7]

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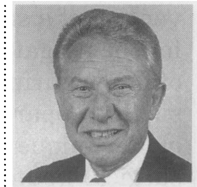

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The costs of pioneering. Many pioneers who venture into uncharted waters with their new discoveries and innovations pay a high price for their genius. Frequently, the danger of their work is not recognized immediately or does not manifest itself until years later. So it was with Edmund Kells.

The hazards of excessive radiation exposure not yet being appreciated, Kells and others who used X-ray in the early years had no qualms about using a technique known as "setting the tube." Variations in the quality and character of the X-ray were produced by a rheostat. The setting technique required that the operator hold a fluoroscope in one hand and place the other hand between the fluoroscope and the X-ray tube. The rheostat on the X-ray machine was then adjusted until the bones of the hand appeared on the fluoroscope screen and the operator was satisfied that proper penetration had been achieved. Every time the operator "set the tube," his hand was exposed to the X-ray for several seconds. The cumulative effects of this repeated exposure were not recognized for a number of years.

In Kells' case, approximately 12 years passed with no untoward effects. Eventually, however—in about 1914—the fingers and back of his left hand succumbed to radiation-induced cancer. During the next 14 years, Kells underwent more than 40 operations, the last of

Harnessing the X-Ray: Coolidge's Contribution

Shortly after the discovery of the X-ray, those in the healing arts soon realized that the equipment used to produce this new energy was extremely inefficient. The early tubes were unreliable and delivered radiation of varying intensities unsuitable for the types of medical and dental examinations being performed.[1] Scientists agreed that if the healing sciences of medicine and dentistry were to use this energy as a diagnostic and therapeutic tool, the mechanism for delivering it would have to provide predictable quantities of radiation.

Very little progress was made in the development of X-ray–generating equipment from 1895 to 1911. It was only after the danger of electrical and X-ray injuries was reported that changes in equipment were pursued.

In 1913, William David Coolidge, an American physical chemist and inventor, was working with tungsten wire filaments for electric light bulbs and observed that these filaments could be heated enough to liberate electrons from the tungsten wire.[1,16,17] The electrons were made available in a controlled manner, something that had never been done before. Like many inventors, he also had an interest in X-ray equipment and was aware of the problems involved in producing a useful quantity of X-rays.

William David Coolidge

He began work on the X-ray tube and built into the tube a cathode structure with a tungsten wire filament and a tungsten target at the anode. When heated, the filament boiled off electrons in a controlled amount determined by the amount of electric current applied to it. Thus, the "Coolidge Tube" ushered in the era of modern tube technology.[1,17] As director of the General Electric laboratory in Schenectady, N.Y., Coolidge developed an oil-immersed self-contained X-ray unit that could be safely operated by radiographic personnel.[1,17]

From 1932 until his retirement in 1944, Coolidge served as a consultant at General Electric and was involved in the development of the atomic bomb. When he died in February 1975, he left behind a body of work that included 83 patented inventions.[16] ■

which involved amputation of his arm. On May 7, 1928, unable to grapple any longer with the cancer that had claimed several organs and was causing him intense agony and suffering, Kells took his own life in his dental office.

Shortly before his death, he wrote his last article from a hospital bed in New York. In it were the following remarks: "Do I murmur at the rough deal the fates have dealt me? No, I can't do that. When I think of the thousands of suffering patients who are benefited every day by the use of X-ray I cannot complain. That a few should suffer for the benefits of the millions, is a law of nature."[11]

Kells died as he had lived—with concerns for the betterment of his profession and the alleviation of suffering.

CONCLUSION

The discovery of X-ray 100 years ago ranks high on the list of scientific discoveries, having had a major impact on the improvement of health care delivery. As a diagnostic tool, the X-ray plays a preeminent role in the armamentarium of both the physician and the dentist. The men who pioneered the discovery of X-ray and its introduction into medical and dental practice are, in large part, responsible for the high quality of health care we enjoy today. Health care providers and the public they serve are forever indebted to Roentgen, Kells and all the others who worked—often at personal peril—to make it all possible. The occasion of this centennial year gives us an opportunity to remember them and to thank them. ■

The photographs on p. 1359-61 and p. 1367 are reprinted from Glasser PO. Wilhelm Conrad Röntgen, 1931. Heidelberg, Germany: Springer-Verlag.

1. Fortier AP, Glover JA Jr. Origins of dental radiography. In: PW Goaz, SC White, eds. Oral radiology: principles and interpretation. St. Louis: Mosby;1982:1-17.
2. Glasser O. Wilhelm Conrad Roentgen and the early history of the Roentgen rays. Springfield, Ill.: Charles C Thomas;1934.
3. Grey V. Roentgen's revolution: the discovery of the X-ray. Toronto: Little, Brown;1973.
4. Bushong SC. Radiographic science for technologists. St. Louis:Mosby;1975.
5. Glasser O. W.C. Roentgen and the discovery of the Roentgen rays. Amer J Roentgenol Radium Ther 1931;25(4):437-50.
6. Varnado MB. Dr. C. Edmund Kells: as I remember him. Bull Hist Dent 1971;19(2):27-33.
7. Kells CE. Three score years and nine. Chicago:published by author, printed by Donnelly;1926.
8. Raper HR. Notes on the early history of radiodontia. Oral Surg Oral Med Oral Pathol 1953;6:70-81.
9. Gardiner JF. C. Edmund Kells: New Orleans' gift to dentistry. Bull Hist Dent 1981;29(1):2-7.
10. Carr JO. The great radiology debate: the letters of C. Edmund Kells and Howald R. Raper. Bull Hist Dent 1981;29(2):69-73.
11. Glenner R, Davis A, Barens S. The American dentist. Missoula, Mont.:Pictorial Histories Publishing Company;1990.
12. Asbell MB. Dentistry: a historical perspective. Bryn Mawr, Penn.:Dorrance;1988.
13. Langland OE, Fortier AP. The contribution of C. Edmund Kells: a bibliography. Bull Hist Dent 1971;19(2):34-43.
14. Kells CE. The X-ray in dental practice. J Natl Dent Assoc 1920;7(3):241-72.
15. Franke OC. Wilhelm Conrad Roentgen and other X-ray pioneers. Bull Hist Dent 1983;31(1):11-7.
16. Barr JH, Stephens RG. Pertinent basic concepts and their applications in clinical practice. In: Dental radiology. Philadelphia: Saunders;1980:27-8.
17. Richman V. Twentieth century scientists. Vol. 1 A-E. Gale Research Inc.;1995.
18. Glenner RA. The dental office: a pictorial history. Missoula, Mont.: Pictorial Histories Publishing Company; 1984.
19. Glenner RA. Eighty years of dental radiography. JADA 1975;90:549-63.
20. Morton WJ. The X-ray and its application in dentistry. Dent Cosmos 1896;38:478-86.

The other pioneers

As with most great discoveries and innovations, rarely is only one person fully responsible. While C. Edmund Kells probably made the greatest contribution to introducing the X-ray to dentistry, the efforts of several other pioneers should be recognized here.

Walkhoff: the first intraoral radiograph. Otto Walkhoff, a dentist in Brunswick, Germany, had been working with a professor of chemistry and physics in research involving cathode rays when Roentgen's discovery was announced. Within two weeks of the announcement by Roentgen, Walkhoff created an intraoral radiograph using a glass photographic plate wrapped in black paper and covered with a rubber dam. His exposure times were 25 minutes. His radiograph may very well have been the first intraoral radiograph.

Koenig: early dental radiographs. Wilhelm Koenig, a Frankfurt professor, was also among the very first to take dental X-rays. In February 1896, he made a series of 14 dental radiographs.

Harrison: a special vacuum tube. In January 1896, Frank Harrison, a dentist in Sheffield, England, reported to the British Medical Association that he had made a special vacuum tube for taking dental radiographs. Harrison was a pioneer in another aspect of dental radiography as well: as early as July 1896, he became one of the first people to report radiation injuries.[15,18,19]

Morton: envisioning the possibilities. William J. Morton was the physician son of Dr. William T.G. Morton of Boston, who introduced ether anesthesia in 1846. Morton, who had been experimenting with X-rays, presented his work to the New York Odontological Society in April 1896. He demonstrated four intraoral films taken from of human skulls and a film plate of the skull of a living subject. His presentation, which was later published in The Dental Cosmos, contained these prophetic remarks:

"The application of X-ray will, I believe, greatly aid in the art of dental surgery. The radiographs presented to you here tonight are but a first step toward taking pictures of the living teeth. They open out to your view a wondrous field for investigation and study and diagnosis. Each errant fang is distinctly