In this centenary anniversary of the first and largest specialty in dentistry, it is only proper that we turn to those who made it all possible. A short list would include John Nutting Farrar, Norman Kingsley, Edward Hartley Angle, Calvin Case, Benno Edward Lischer, Frederick B. Noyes, Edmund Wuerpel, Cecil Steiner, George Hahn, P. Raymond Begg, Allan Brodie, Brainerd F. Swain, Claude Broussard, and Charles H. Tweed.[1-19] There were many supporting actors and a perusal of Weinberger's[6] 2-volume History of Orthodontia, as it was originally called, will give the reader a superb background of the supporting cast of characters, each a leader in his own right. The AAO history by Wilbur Shankland[7] fills in the middle years and the just released AAO history from 1965 to the present by Eric Curtis brings us up to date on this amazing specialty.[8] As a well-known historian has said, "All history is biography." This article concentrates on the contributions of the "Father of Orthodontics," Edward H Angle (EHA), in the embryonic stages of orthodontics.

The personal life story of EHA is amply presented in articles by his wife, Anna Hopkins Angle,[11] Frederick B. Noyes,[9] Edmund Wuerpel,[13] Robert H. W. Strang,[12] Cecil Steiner,[10] George Hahn,[14] Richard Summa,[16] T. M. Graber,[20,21] etc. Abundant correspondence with many of his former students and colleagues, typed by the dedicated and indefatigable Anna Hopkins Angle, still remains in the AAO Library, Tweed Foundation Library, and with T. M. Graber, who delivered the first 2 AAO Heritage lectures. All this is in addition to detailed biographies in the Weinberger and Shankland histories.[7,8]

The thrust of this article is to concentrate on Angle, the hardware and the appliance innovator. Section I deals with his patented work; his nonpatented work is covered in Section II. A list of his patents is included in the references.

SECTION I: ANGLE'S PATENTED ORTHODONTIC DEVICES

The materia technica has advanced tremendously, but the ideas and principles behind the current appliances remain very similar to those developed by Angle and his colleagues. Edward Hartley Angle was a mechanical genius, as Frederick B. Noyes observed. A noted histologist and educator, Dr Noyes taught for many years in the Angle courses and was also a student of Angle.[5,9] During the 5 years one of us (TMG) was associated with Dr Noyes in practice, he gave a full oral history! Unlike his contemporaries, Angle patented many of his appliances, antagonizing some who saw similarities with their own orthodontic contrivances, particularly when Angle attributed devices to others, intentionally ignoring the originator (ie, credit for elastics [Baker anchorage]), when evidence was clear that Joseph Fox (1814)[4] as well as Calvin Case (1890), an Angle adversary, deserved earlier attribution.[3,4]

In some ways, Angle was a harbinger for the future, a pioneer in seeking legal protection of ideas and mechanisms. A large number of the things we use, see, eat, or even hear are patented today. Soybeans grown in the United States, a crop that ranks second after wheat, cannot be replanted without permission. Patented, genetically manipulated food is common in our groceries. A particular Shakespearean interpretation has been adjudicated, as are NBC's three chimes that accompany their peacock logo, as well as a certain move of an athlete.[22] If you, as a clinician, think that this is limited only to man-made things ("anything under the sun made by man," ie, your purchased tools), you are wrong; medical procedures are now patented like never before. The reason is simple: m-o-n-e-y.

The United States is the world's largest producer of intellectual property, from computer software to movies and pharmaceuticals, and its patents are its "crown jewels." Texas Instruments has earned more than $200 million in annual profits from licensing patents and winning infringement cases than from selling products. By exploiting their patents, pharmaceutical companies are not only covering the risk involved in bringing drugs from conception to FDA approval (which amounts in average to some $250 million) but also reaping a hefty profit.

The U.S. patent system is based on Article I, Section 8, of the Constitution that states that the Congress

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SPECIAL ARTICLE
Angle, the innovator, mechanical genius, and clinician
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has the power to "promote the progress of science and useful arts by securing for a limited time to authors and inventors the exclusive right to their respective writings and inventions." The Patent Act was signed by President Washington in 1790; Washington himself was the CEO of the new Patent Commission. Later on, President Lincoln showed that the system should add "the fuel of interest to the fire of genius."22

Over time, a series of eminent inventors, ranging from Benjamin Franklin to Jonas Salk have refrained from patenting, offering their creations free to mankind. What would have happened if each time Pasteur's vaccine or Heimlich's maneuver was used, permission would have been needed or a royalty perceived?

Until a few decades ago, medical patents focused only on palpable material items. A patent search today shows more and more patents on gene sequences, genomes, therapies, methods, tests, etc. Is patent protection endangering the Hippocratic oath? Does the reluctance of a student to disclose to professors the patentable aspects of the thesis he or she is defending signal the way for the new millennium? Does the meteoric rise in law suits, and the more frequent clinician-suing-clinician policy recently observed signal a new era?

Today, orthodontics seems to follow the example of E. H. Angle, who filed 32 patents23-52; the last was filed after his death (the first was issued in 188923 and the last in 193424). At that time, most of the titles he used could be very short, usually two words such as "orthodontic appliance," and the text was usually less than 3 pages. Over the past 100 years, patents are printed in considerably smaller fonts and usually are over 12 pages in length.

In any event, the personal antagonisms of Angle's contemporaries manifested themselves both in professional meetings and in the literature. Rodriguez Ottolengui and Benno Lischer maintained that to secure a patent for their inventions was unprofessional, amoral and "a stain upon the professional aim of dentistry…"7 Angle joined the company of those dentists like Taggart, who believed that securing a patent was an inherent right and should be accepted by the profession. His opponents accused him of profiteering and protectionism for his courses. It is reputed that Angle received $90,000 each for the ribbon arch appliance and edgewise appliance from S.S. White Manufacturing Company. In 1906, the American Society of Orthodontists, under the presidency of Rodriguez Ottolengui, passed a resolution condemning such patents. Angle and his wife, Anna Hopkins Angle, and a number of Angle disciples resigned! Patently, this was the genesis of a period of acrimony and antipathies and jealousies that divided the orthodontic specialty for more than 50 years![7]

Angle's 30 patents focused basically on arches, on tools to modify them, and on the best means of engaging banded teeth. Every invention is built on previous discoveries. The law requires the patent applicant to indicate previous related work, patented or not. At the time of Angle's applications, it was not yet necessary to provide references and it is probable, if not certain, that he copied prior similar orthodontic appurtenances, to the distaste of some contemporaries. This antagonism was intensified after Angle's resignation from the American Orthodontic Society.[6]

His first patent (1889) was a regulating screw that delivered a pushing action, a device combining an adjustable clamp band and a regulating screw.[23] The pushing action was exerted by controlling the movement of a tubular shaft in a threaded sheath by the use of a threaded nut (Fig 1A). He credited the adjustable clamp to Schange (1841), a Frenchman, and the regulating screw to Dwinelle (1848), disclaiming any contribution from his rival, Farrar,[1] who had described a similar mechanism in 1876, but with a reversed action

Fig 1. A, Angle's first patent in 1889, with an ingenious push-type jackscrew for increasing width; the nut could not loosen up accidentally; B, precursor for opening space using jackscrews, by Farrar in 1878.[1]

A

B

(Fig 1B). Although not mentioning specific materials, to avoid his patents being restricted to their specific use, he preferred to construct most of his appliances from nickel or German-silver by machining and then soldering them. Among the nonmetallic materials he used for attaching teeth were rubber and silk, as well as Magill's cement, a zinc oxycloride (1871).[6]

His next 2 patents were the first to focus on an arch wire[8] forcing teeth "outward and forward" (which he called at the time "rod") (Fig 2A), and a plier to be used to increase the arch's length.[27,28] This was an early improvement of his E arch. The arch, which had to be "as close as possible to the line of the dental arch," was lengthened by pinching with the help of a plier he patented. Incidentally, the female witness he used for these two patents, Emma Elmore, was to be replaced in the next one by his future wife, Anna Hopkins.

His quest for a better arch continued with what is known as the "E" (expansion) arch appliance, which had the ends threaded and extended in an anchor tube or into clamping bands[29] (Fig 2B). As a variation from his first patent, the 1899 telescopic arrangement had the nut provided with a threadless extension, an arrangement that worked as a friction-sleeve. According to the nut's position, the teeth could be moved either distally or mesially. Made of a "very elastic round bar conforming to an ideal dental arch," the E arch was solidly anchored to the first molars. As he will describe in a later patent, the banded teeth were attached to the arch with the help of a soft wire that allowed their tipping or aligning. Within the patent, the author refers for the first time to the "Angle system" he introduced in 1886.

Angle's subsequent 2 patents were additional improvements of his E arch, one allowing its detachment from the bands by unscrewing nuts,[30] and the other by superposing on it another piggyback arch. This additional arch (which he called "rib" and termed a B arch) was identical to the E arch in shape and tem-

Fig 2. 1895 Angle patents: A, a lingual arch soldered to bands that are cemented on teeth; special plier pinched the wire increasing its length; B, 1899 patent of an arch wire with threaded ends, extended in the tube of an anchor molar band; nut is provided with a threadless extension that works with a friction sleeve to hold the adjustment; C, 1901 patent of a ribbed arch to prevent the sliding of ligatures, which could occur in 2B; D, 1903 patent with both arches connected by elastic traction, with a modified Kingsley headgear bow and extraoral force potential, if needed.

A

D C

B

per, but had no threaded ends. Instead, it was provided with notches destined to prevent the sliding of the ligatures,[31] (Fig 2C).

Encouraged by his results, Angle added Kingsley's headgear and Baker's intermaxillary anchorage to his arch by patenting the system shown in Fig 2D.[32] The jaws were interconnected with an elastic, whereas the occipital headgear could be removed at will from the arch with the help of a ball joint.[32] At first, premolar extraction was a part of the Angle system, when indicated, even with intermaxillary elastics.

Between 1909 and 1915, Angle patented a series of improvements for the connection and detachment of the arch from the banded teeth.[33-38] The improvement of the connection of the threaded part of his arch was made to prevent the adjusting nut from being accidentally moved.[33] The search for a way to avoid soldering the arch to the anchor band resulted in a joint patent with one of his former students, J. Lowe Young, using a simple detachable connection[15] that "opened new ways." The mechanism he introduced, a pin-shaped end entering tubes soldered to bands (Fig 3A), was the first step toward the pin and tube appliance.[34] Subsequent steps were the introduction of 2 interchangeable arches; the second was not only less springy but also provided a series of individual spurs or fingers, entering small vertical tubes soldered to the bands[35] (Fig 3B). While the first arch was destined for "regulating," the other was needed for retaining the teeth. To provide for the arch exchange, he returned to the threaded connection between the end of the arch and the band, improving it.[36] In another patent registered the same day, he introduced detachable coils that exerted a torsion action between the arch and the band; to avoid their detachment, he locked them in place with pins[37] (Fig 3C).

The small vertical tubes that he soldered to bands amounted to the first use of brackets, and the use of coils permitted tooth rotation. Moreover, by changing the inclination of the pins, it became possible for the first time to produce controlled root movement. This radical departure from the simple "E arch" became known as the "pin and tube appliance." Interestingly, from that time on, Angle divided his quest for detach-

Fig 3. A, 1911 patent shows detachable arch bar, with a vertical 90o bent end inserted in a vertical tube; B, 1912 pin and tube appliance with soldered vertical pins on arch wire that insert in vertical tubes soldered to individual bands. Pins are resoldered each time as needed as the arch wire is straightened out toward the ideal arch configuration; C, in 1912, option to add coil springs, held in place by pins, similar to those used later in the ribbon arch (and Begg) appliances.

A

B

C

Fig 4. A, 1899 patent, clamp band with long buccal tube for threaded arch end; B, molar band is streamlined and formed in such a way that the band is thick where the hook (or tube) is soldered on the buccal, but the band is thin on the lingual ends to allow pinching up for a tight solder joint.

A

B

able connections in two: to those destined for anchorage on the first molars and to those for the other teeth. After his joint patent with Young to simplify molar bands,38 his attention turned to the problems raised by the need to solder and unsolder the pins as the treatment progressed, using the pin and tube appliance. In the mean time, he solved the problem caused by the bulky adjustable clamp band previously used as anchorage (Fig 4A), replacing it with the more refined and comfortable band shown in Fig 4B that is the pattern for today's bands (US 1,204,114).39 For the purpose, the band had to be thicker where the attachment was, but thinner at its ends so that these could be tightly joined by properly twisting it.40

The result of his desire to avoid soldering and to provide a free but controlled movement of the bands along the arch wire became apparent in 1915, when under the new name of "orthodontia appliance," he replaced the vertical tubes soldered to bands with brackets with a vertical slot, and the round arch bar with a ribbon. In his patent, he presented 2 variations.39 In one of these, the bracket received the ribbon arch with 2 walls; the third was supplied by the band itself40 (Fig 5A). In the second one, the arch was entirely contained in the "bifurcated lug" (Fig 5B), presaging the edgewise bracket that he would patent 10 years later. To secure the ribbon arch in the bracket, he devised a series of locking wedges or pins that inserted into each bracket, or in slots made both into the bracket and the arch.[39,41,42] This last approach, a return to his ribbed arch,[12] was the first example of a vertical slot in a bracket. The use of pins to immobilize the detachable end of the arch wire to the first molar band[43-45] was extended to all brackets. He also patented bifurcated pins to prevent both rotation and lateral tipping.[46] Their ends were bent back, as with today's Begg brackets, which is merely the ribbon arch bracket turned upside down to allow the ribbon arch to be inserted from the gingival aspect.[15]

At the end of 1925, Angle registered his most important gift to the profession, the edgewise bracket[46,50] (Fig 5C). P. Raymond Begg, then a student of Angle, cut the first bracket on the lathe. As its name suggested, the rectangular wire was inserted in a horizontal slot in the edgewise position and kept there with the help of ligature wires tied around the tie wings. It allows tooth movement in all 3 planes with the help of a single wire, and it is still today the orthodontist's work horse. As Angle intended its use in nonextraction cases, he claimed it as "the latest and best" nonextraction appliance. But its superlative versatility allowed equal validity for extraction cases, as Charles Tweed showed so convincingly later on.[19]

In a relentless pursuit to improve his bracket and protect his invention from other adaptations, Angle continued to patent ligating options that did not meet

Fig 5.A, 1915 patent, ribbon arch bracket with retaining pin. The band wall approximates the inner surface of the ribbon arch; B, advanced version with the arch wire wholly contained within the ribbon arch bracket; precursor of the Begg bracket, which inverts the bracket to allow arch insertion from the gingival aspect; C, 1926 edgewise bracket patent; D, streamlined edgewise bracket, using soldered eyelets on mesial and distal as needed to control rotations (1926).

A
D
C
B

with success.[49,50] As he realized that rotations need a more efficient approach and at the suggestion of Cecil Steiner, Angle devised minuscule eyelets soldered mesially and distally to the brackets[52] (Fig 5D), paving

the way to the twin brackets (Siamese brackets) of today, originally designed by Brainerd F. Swain.[17] Interestingly, as the trend toward miniaturization progresses, today there is a renaissance of the single bracket as Angle had designed it. Indeed, the distance between the 2 elements that form the Siamese bracket has decreased to such an extent that these have practically merged.
In his final years, Angle further stressed the advantages of a vertical slot, which could be used for both rotations and ligations.[24,52] His last patent was belatedly filed almost 3 years after his death by his wife, Anna Hopkins Angle, executrix of his estate. The highly popular Broussard bracket of the 60s and 70s was based on this patent.[17]
With all due respect to Edward H. Angle, his habit of patenting his findings has brought his inventions the best available guarantee, as well as an independent recognition, demonstrating that his contribution has been, if not entirely new, at least not well known at the time. In his early years, he actually tried to show the contributions of others. Smarting under personal attacks and jealousies, he subsequently expressed gratitude to only some of his predecessors and contemporaries—like most human beings do. This is done through the phenomenon of "incestuous interquote," a term coined by Doris Graber, a political scientist, for the tendency to quote only those selective studies with which the author agrees, ignoring others who did not have the same training in their vaunted institution or hallowed department (Graber, Doris, personal communication, December 1999). But tincture of time heals most of these animosities. As a mature specialty, orthodontists represent the crème de la crème of the dental profession and are poised for even greater achievements as we enter the new millennium.

SECTION II: NONPATENTED ORTHODONTIC MATERIALS

Section I concentrated on Angle's many patents and the major contributions to orthodontic armamentaria. These alone are sufficient to justify the title of "Father of Orthodontics." But this only one facet of the professional life of this gifted mechanical genius. A vital part of the success had to be more than patenting gadgets and gimmicks. Studying the complex mechanisms Angle patented to prevent the adjusting nuts of a "dental tooth-regulating appliance" from being accidentally turned or backed away from the anchoring band[33] (Fig 6) is enough to demonstrate his mechanical skill. Angle knew, early on, that the biological response to foreign bodies was important. A century ago, little was available on what materials to use or which ones were safe in an oral environment. This exceptional concern is reflected in many of his patents in which he has constantly tried to cover all possibilities for adverse use or unfavorable reaction. He knew what he wanted to accomplish and looked long and hard for the best solution. Astute observers credit Angle's contributions in this area as even more important than his patents, which contained many elements introduced by others.

At the time he started to create orthodontic appliances, Angle made an inventory of the available materials. These were gold, silver, platinum, platinous silver, iridio-platinum, the so-called platinoid, aluminum, and several of the baser metals and alloys, such as brass, copper, aluminum bronze, steel, and iron, as well as vulcanized rubber. After experimenting with all of these, he found that "the material most fitting was nickel silver," a brass (copper-zinc alloy) that did not have any silver in it at all![54]

In Angle's patents and publications there are many references justifying both his claims and his expertise in materials. He was largely self-taught, and yet he mastered complex metallurgy. Thus, in one of his publications, he explains that pinching the arch "not only spreads the particles of metal, so as to increase the length of the rod, but tempers the part subjected to the pinching action, thereby largely compensating for the reduction in the area of the rod section at that point, and consequently maintaining the strength and rigidity of the rod under the longitudinal strain thereon."[27]

His knowledge of noble metals is witnessed also by his use of gold[55] and of platinum-iridium arches in orthodontics. He was the first to use coil springs. But he connected them only to nobler metal arches[37] and

Fig 6. Nut and telescopic connection to a tubular anchor member (1909 patent).

preferred them to be the next step after the "regulating" appliances (elastic stiff spring wire) (ie, in the retention stage; the springs he recommended were "a very delicate spring of a Pt-Ir alloy, with little resiliency, exerting only a slight pressure."[35]

His main contribution, however, is the introduction in orthodontics of both soldering and a "baser" alloy.

He claimed to have introduced soldering as early as 1887. It is probable that Angle and the dental suppliers worked together to determine the optimal composition of the solders he used, giving the ratio of the components in grains.23

He may also have explored the whole range shown in the shaded area of Fig 7 to select his preferred formulas. With regard to base metal alloys, although noble metals were aesthetically pleasing and corrosion resistant, they lacked elasticity and tensile strength. As a result, his base metal alloys permitted the making of intricate appliances at a nominal cost. According to his description,54 nickel silver, or German silver, is an alloy of copper, nickel, and zinc, prepared in varying proportions according to the use for which it is intended. Great strength and rigidity are demanded by the jack and traction screws, and great elasticity by expansion arches. When properly annealed, it is very malleable, yet sufficiently rigid to give the reinforcing anchorage as required by the G wire. But the best is shown in making plain bands. Rolled into a flat ribbon, it can be drawn by band-forming pliers to conform to the tooth surface, while being rigid enough. The surfaces on nickel-silver may be united with solder. Its fusion point is high enough to be united with various grades of gold and silver solder." To achieve the performance of having a single alloy responding to such diverse requirements requires knowledge and an exceptional skill. In his words, "this metal varies greatly in quality, not only on account of differences in the formulae from which it is made, but also on account of the manner of manipulation in manufacture.

To properly assess Angle's feat, it should be viewed from a time perspective. His options were to use chemistry (ie, changing compositions), metallurgy (heat and cold work), or both. Early on, Angle linked up with dental manufacturers to fabricate his appliances. Wilmington Dental served this purpose at first, but he

Figure 7. Composition of the Cu-Zn-Ni phase equilibrium diagram with Angle's probable range of research.

switched to S. S. White & Company in Philadelphia, the largest dental manufacturer in the United States, for most of his innovative designs. It is reasonable to assume that these companies, dealing with products used in the mouth, at least had metallurgical advice and even a research and development department. Before manufacturing any product that might have deleterious consequences in the oral environment and legal liability, even then, some sort of checking was done. Suggestions were made to dentists like G. V. Black, Angle, Case, and Taggart of possible materials to use, based on their experiences with other dental products. There were only a few compositions known in Europe (ie, argentan, alpaca, maillechort [from Maillot and Charier] or nickel silver). Most of these varied in their proportions of copper (Cu) 70%, zinc (Zn) 15%, and nickel (Ni) 15% and Cu 65%, Zn 21%, and Ni 14%.55,56 To get the desired range of properties, the composition of Angle's nickel silver alloys ideally should have varied between the broader limits, very likely as much as 60% to 70% copper, 10% to 20% zinc, and 10% to 15% nickel.

When he introduced his first alloy in 1887, metallography was at the very beginning in its attempts to establish a relationship between microstructure and physical properties (Sorby, 1864); the first studies on phase equilibrium of nonferrous alloys were published just 7 years before.55 If we suppose that Angle's alloy had a content of 65% Cu, with Ni varying between 10% and 18%, this would place it within the US standardized alloys at that time, the ones marked with A, B, C, and D on the ternary diagram presented in Fig 7; the shaded area represents the range of the alloys he may have used. Under 30% Zn, the alloys are solid solutions. Some of these, known under the designation C74.500 (A), 75.700 (B), 75.400 (C), and 75.200 (D) (Tables I and II)56,57 are remarkable for their corrosion resistance and pleasing gold-like appearance. No matter how heavy the cold-working of any of these, it is possible to get an increase in tensile and yield strength of only 75% and 400%, respectively, which is not outstanding.

The silvery aspect of Angle's choice leads us to 2 other alloys containing less copper. The alloy marked with E, characterized by a ratio Cu: Zn 2:1 exhibits tensile and yield strengths of 10% and 12%, respectively, higher than any of the alloys marked with A, B, C, and D. Interestingly, a serendipitous choice could have been the alloy represented with F, which is found at the limit where 2 phases coexist (37.55% Zn). The precipitation of fine Zn particles leads to a duplex structure having a high tensile strength, even when the

Table I. Angle's probable nickel silver composition range

Present designation (see diagram)	A	B	C	D	E	F
UNS designation	C74,500	C75,500	C75,400	C75,200	C77,000	New (8)
Cu (%)	65	65	65	65	55	47.5
Zn (%)	25	23	20	17	27	37.5
Ni (%)	10	12	15	18	18	15.0

Table II. Properties of probable Angle's German nickel-silver composition range (flat products, 1mm thick) (letter values same as above)

	Tensile strength (MPa)					Yield strength* (MPa)					Elongation† (%)				
Temper	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
OSO070	340	360	365	–	–	125	125	125	–	–	49	48	43	–	–
OSO050	350	370	380	–	–	130	130	130	–	–	46	45	42	–	–
OSO035	365	385	380	–	415	140	145	145	170	185	42	40	40	40	40
OSO025	385	405	405	–	–	160	165	165	–	–	40	38	37	–	–
OSO015	415	420	420	415	–	195	185	195	205	–	36	32	34	32	–
HOO	415	415	425	–	–	240	240	240	–	–	34	32	30	–	–
HO1	450	450	450	450	–	310	310	340	343	–	25	23	21	20	–
HO2	505	505	510	510	–	415	415	425	427	–	12	11	10	8	–
HO4	590	585	585	585	690	515	515	515	510	585	4	4	3	3	3
HO6	655	640	635	–	745	525	545	545	–	620	3	2	2	–	3

*At 0.5% extension under load.
†In 50 mm or 2 inch.

alloy is annealed. Recent findings have shown that this alloy has a surprisingly high elongation, showing an exceptional plasticity when subjected to hot work.58 Although it is not unlikely that subsequent studies may have benefitted from his intuition and experience, it is certain is that the brasses used in dentistry today are, at least in part, due to Angle's pioneering work. The only difference is that zinc has been replaced with aluminum, a rare metal at the time when Angle introduced nickel silver to orthodontics.7

No matter how inventive Angle may have been from the clinical point of view, it is unlikely that he would have been considered the Father of Modern Orthodontics without his ability to demonstrate his concepts, supported by his mechanical and metallurgical acumen. His work is a shining beacon for young orthodontic clinicians of this new millennium, who want reasonable assurance that their ministrations are biologically sound.

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