

Operative dentistry's beginnings & its rapid but steady continuum

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Abstract

Generations before sugar was implicated with caries—vitamin-C deficiency (scurvy) had plagued humans for millennia. Early humans treated tooth pain with folk-remedies & bloodletting by moonlight—when these cures failed, roadside itinerants with little training promoted extractions. King Philip II established the Parisian Barber-Surgeon Guild in 1210, requiring proper credentials to extract teeth. Edentulous US colonists of the 1800's supported development of **MECHANICAL DENTISTRY** to fabricate dentures with artificial teeth. Cheap sugar inspired increased consumption, creating a rapid increase in worldwide caries. **OPERATIVE DENTISTRY** advanced in the Americas with a few clinicians attempting removal of cavity debris, decay, cleansing & restoration with agents to reestablish form & function. Dr. C.A. Harris of Ohio is acknowledged to have actively endorsed dentistry as a clinical profession. Dr. M.H. Webb's 1883 **OPERATIVE DENTISTRY** textbook commanded international recognition by defining gold-foil cavity preparation & restoration, stressing attention to detail. By 1890, Dr. G.V. Black had outlined scientific guidelines for amalgam composition & defined **OPERATIVE** cavity resistance & retention form & restoration. By 1839, Drs. Harris & Hayden were recognized to have given **OPERATIVE DENTISTRY** its parturition at Baltimore Dental College. By 1870, America gained international respect with the founding of 9-accredited dental schools. US clinicians organized active regional dental societies, developed vulcanite-dentures, scalers, rubber-dam, adjustable dental-chairs, steel burs, electric-handpieces, round-end burs, mouth-mirrors, matrix bands, local anesthesia & more. Circa 1967, Professor Takao Fusayama of Tokyo Medical Dental College introduced a caries stain that was 1st to differentiate non-vital from vital dentine & defined **MINIMAL CAVITY INTERVENTION** & restoration with polymers that hybridized vital enamel & dentine. This **OPERATIVE** continuum has endeavored to examine those dental materials & technologies, which have advanced our **OPERATIVE** standards. "Pay attention to the details—never be content with what you know—there is always more" Dr. Miles Markley (1903-2000).

Operative dentistry has emerged as a respected clinical profession

Dentistry is an ethical health care profession that is achieved by study, hard work & continued life-long learning. Dentistry's written history is recorded in thousands of books & journals by numerous authors. **OPERATIVE** treatments have rapidly evolved from the mid 1700's to today's polymer hybridization—swiftly enhancing clinical skills to save patients teeth—instead of just extracting teeth—to relieve tooth pain & pathology. **MECHANICAL DENTISTRY** seemingly started from necessity, fabricating plates with crude springs & clasps for millions of edentulous patients who had no alternative or substitution for their lost teeth. Opportunity, fueled by inspiration & hard work, propelled rapid advances in **OPERATIVE DENTISTRY**, which have enabled today's clinicians to provide high quality treatment in comfortable chairside procedures. The authors are confident this article will provide insight as to the clinical & technological advances, which have emerged since the mid-1700's (Table 1).

Advances in operative progress has arrived by the hard work of many individuals

History notes that Thomas A. Edison (1847-1931) made over

10,000 attempts to invent the light bulb before his success in 1879. He commented after his success, "Genius is 1% inspiration and 99.9% perspiration". And, in order we shouldn't forget—dedicated individuals who deserve recognition have driven thousands of our **OPERATIVE** advances. We can imagine that most dentists recognize the names of Dr. G.V. Black & Professor T. Fusayama, however, many of the notables discussed in this document—Drs. Martin Brännström, Oskar Hagger, Chapin Harris, Louis Jack, Miles Markley, Marshall H. Webb, Samuel S. White & J. Leon Williams—probably remain unknown to most of today's colleagues. The authors have endeavored to present the human side of these & other notables & to recognize the impact of their genius & perspiration to advance the operative character of our profession.

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Table 1. Noted events in operative dentistry's timeline.

Dentist / Clinician	Dates & Age	Observation
Herodotus	484-430 BC age-54-years	Wrote that "Egypt was full of physicians; ones who only treat diseases of the eyes; head, teeth, abdomen and internal organs" [10-13].
Hammurabi	1,810-1,750 BC age-60-years	Instructed that laws of medical jurisprudence must be inscribed on cuneiform tablets, which established physician fees & proposed punishments for clinical failure due to unskilled treatments [10].
Ebers Papyri	3,700 to 1,500 BC	Papyri containing herbal & medical treatments [15]
Marcus Claudius Marcellus	268 BC - 208 BC age-60-years	Opposed tooth extraction. He recommended to bathe the cavity with hot oil. . .then remove the cavity debris. . .fill the cavity with mastic & wax [16].
Aelius Cladius GALEN	129 BC to 210 AD age-81-years	Place hellebore & ginger to alleviate pain. . .then opened the pulp & fill the cavity with wax [17].
Zeen Arezener 1 st dental text	1559	The 1 st recorded dental text of 13-editions that reported new surgical & operative techniques to treat people with infirmities of the mouth & teeth [18].
Dr. Giovanni d'Vigo	1450-1525 age-75-years	He recommended to 1 st clean the cavity with vinegar (circa 1500) & to fill the cavity with gall apples & <i>gallanum</i> to stop the pain. . .then remove the cavity debris & clean & fill the cavity with leaves of gold [23].
Dr. Ambrose Paré	1510-1590 age-80-years	Called the "Father of Dentistry" who served as Principal surgeon to several French Kings. He cleaned the cavity as suggested by d'Vigo & then to fill the cavity with cork or lead [24].
Sir Issac Newton	1642-1727 age-85-years	The 1 st to develop (1686) a cold-fusible <i>plastic</i> metal mixture of bismuth, lead & tin, which became a precursor for d Arcet's amalgam filling [31].
Dr. Pierre Fauchard	1671-1761 age-90-years	Wrote in his 1728 "French Dentist textbook. . .the clinician should teach the patient the importance of keeping teeth clean & to show the clinicians how to burn or cauterize & fill the cavity with lead" [19].
Dr. Moulton	1746	A French clinician who practiced the fabrication of plates using the concept of atmospheric suction for maxillary units. He also fabricated & placed gold crowns with enameled surfaces to arrest destruction of teeth [1746].
Dr. Jacques Gardette	1756-1831 age-75-years	Served with the French forces in the US Revolution & provided dental needs & atmospheric dentures for citizens in Phil. PA (circa 1785) [22].
Dr. Antoine-M. Desirabode	1771-1852 age-67years	French dentist who wrote in his 1847 textbook that soft lead (<i>plombage</i> =leading) was a preferred agent to fill a cavity. Gold leaf was just becoming popular to fill cavities [26].
Dr. Jean d'Arcet	1777-1844 age-67-years	Heated bismuth, tin, lead & mercury to 212F & cooled it to then be poured into the prepared cavity (circa 1810). Soon abandoned due to extreme patient pain [32].
Dr. Leonard Koecker	1785-1880 age-95-years	A notable US operative clinician from Germany who used gold leaf for direct pulp capping of exposed vital pulps (circa 1820) [25].
Mr. Marcus Bull	1787-1851 age-64-years	Messrs.' Bull & Abbey manufactured gold foil as a sole business by beating high pure gold <i>Brazilian Johanne</i> coins on granite blocks with leather mallets in Hartford CT [circa 1812].
<i>Plastic</i> terminology	Circa 1830	The term of <i>plastic</i> appeared in dental literature to identify any pliable temporary restorative agents, which could be mixed & immediately placed into a cavity but they soon dried & fell out (circa 1830).
Dr. Lewis	1838	The "Lewis" drill was developed, with a handpiece that could accept various standardized dental burs of steel mill stock [62].
Dr. J. Robinson	1840	He advocated to mix celloidin with asbestos & to then place it as a base underneath metallic amalgam & gold foil fillings to serve as a non-conductor liner (1840) [50].
Dr. J. Robinson	1846	He cautioned in his publication that these 1 st <i>plastic</i> cements should only be considered as temporary restoratives—due to their solubility & fracture [29].
Dr. Leonard Koecker	1785-1880 age-95-years	Recommended the placement of plastic mineral cements to fill a cleansed cavity [25].
Mr. A. J. Watts & J. Barling	Circa 1849	Both clinicians simultaneously developed a new sponge gold foil for being able to condense in the presence of cavity moisture [circa 1849].
Dr. Louis Jack	Circa 1850	Placed small retaining pits in the cavity dentine with small round burs & then used small serrated plugging points for condensing the gold foil into the pits [28].
Dr. Chapin A. Harris	1806-1860 age-54-years	One of 1 st US dentists to advocate for dentistry as a medical-based structured profession. He & Dr. Horace Hayden were co-founders of the 1 st US dental school in 1839 at Baltimore MD. He cautioned that amalgam was misused by many charlatans. His 1849 text recommended replacing lead with crystalline gold & rolled gold pellets. [66].
Messr Sorel	1803-1871 age-68-years	An architect & builder in France developed a zinc oxychloride <i>plastic</i> cement for stuccowork for the building trades in Paris [circa 1856].
Sir Charles S. Tomes	1846-1928 age-82-years	1 st acknowledged amalgam study evaluated 8-amalgam formulations & observed that 7-silver amalgams leaked, while the copper amalgam failed to show any shrinkage or microleakage [73].
Dr. B. Wood	1863	Placed small pieces of bismuth, lead & tin into the cavity & then he fused them together by placing a hot instrument into the fragments [33].
Mr. Thomas Fletcher		The 1 st <i>plastic</i> glass-silicate cement for placement into Class-V cavities was developed in Britain but it was soluble, low durability & long setting reaction compared to other mineral cements & needed 24-hours to set in a cavity (circa 1871) [36].
Dr. J. Buckley	1890	US clinicians began to bathe buccal & occlusal grooves with a 10% silver nitrate to provide an antiseptic treatment against caries & to render the dentine insensitive [52].
Messer's Chevalier & Merry	1891	A modified steel mill stock was developed that allowed the industrial mass production of dental burs to fit into mechanical handpieces (1891)[62].
SS Milte Company		Mass production of uniform standardized steel burs from hardened drill stock (circa 1891) [63].
E.G. Acheson	1856-1931 age-75-years	An industrial silicon-carbide was developed & called carborundum. It was rapidly adapted for coating of dental burs & cutting discs (circa 1893) [64].
Dr. Greene Vardiman Black	1836-1915 age-79-years	Dr. G.V. Black carried out his own laboratory research & defined clinical standards for operative cavity preparation as well as for amalgam composition, trituration & placement into cavities [65].
Dr. Morton		Introduced the use of ether for dental anesthesia to the profession (1842).

Dr. Wells		Introduced the use of nitrous oxide to the dental profession for treating operative treatments (1844).
Dr. Marshall Hickman Webb	1844-1884 age-40-years	A recognized biological researcher as well as a noted US gold foil clinician who improved an electro-mallet for the condensing of cohesive gold foil into well defined & designed cavity preparations. Wrote the "Restoration of Contour and Prevention of Extension of Decay" [66, 67].
Drs. F. McKay & G.V. Black	1874	Their research in Colorado recognized that fluorine had a preventive effect to significantly decrease the caries in human dentitions (1874).
Dr. J. Leon Williams	(1852-1931) age-79-years	Leon contributed research studies on the cause of human dental caries as a matter of external plaque & microorganisms that invaded enamel & dentine. He was the 1 st president of the IADR [74].
Dr. G.V. Black	(1836-1915) age-79-years	The "Father of American Dentistry" who defined amalgam properties as well as standards for preparation & placement in cavities [76].
Dr. Carl Koller	1884	Discovered the analgesic properties of cocaine in which Dr. W. Halsted used a mixture of cocaine for injection anesthesia for operative treatments (1884).
Dr. W. C. Rontgen	1895	The principles of X-rays were discovered & the apparatus was adapted by Dr. C.E. Kells for recording caries in dental tissues (1895).
Dr. E.G. Acheson	1896	The Carborundum company was manufacturing over 1,000,000 pounds of carborundum for industrial use, which provided dental burs with the capacity to prepare cavities with ease & efficiency (1896) [64].
Dr. A. Lufkin		"It is store food that has given us store teeth" (1939) [20].
Dr. Miles Markley	(1903-2000) age-97-years	A noted US clinician who employed engineering principles to design new burs with round pear shaped bases to prevent propagation of cracks & eventual major fracture & loss of cusps [77].
Dr. Einhorn & Uhfelder		Synthesis in a research laboratory in Germany developed procaine with a small amount of epinephrine to gain deep analgesia for dental treatments by local injection (1904). Novocaine surpassed procaine to become more popular with US dentists to achieve profound anesthesia by local injection (1950).
Drs. Rushton, McLean, Kramer, Leader & Blount	1940's	These clinical researchers at Guy's dental Unit worked to develop the newer adhesive resins that were based on the research concepts of the Dr. Hagger GPA polymeric chemistry to advance the newer agents for adhesive treatment of vital dentine [78-82].
Dental researchers in Germany		Resin methacrylate <i>plastic</i> cements were developed in Germany as a hard-set luting & protective base that resisted solubility & breakdown (1937-1945).
Dr. L. Blumenthal Technical Report		A US publication, which described the advances in German research that discussed the developments of resins in the field of plastic dental agents during WW-II (1947) [60].
Dr. Oskar Hagggar	The mid 1940's	Developed & patented a GPA chemistry to modify the cavity interface for placement of a polymer & adhesive system for operative clinicians [87, 89].
Dr. S Kramer & Dr. J McLean		Their histologic staining of polymer treated cavity walls demonstrated a thin blue zone of a continuous resin filled layer—referred to as the hybrid layer of Nakabatashi (1952) [80].
Dr. Nobuo Nakabayashi		In the early 1980's, Dr. Nakabayashi demonstrated the hybridization of dentine with his novel 4-META primer & adhesive
Drs. Brännström Garberoglio, Massler & Kidd		The research publications of these dental Notables demonstrated that microleakage of bacteria into & through the restoration interface was the primary cause of recurrent caries, pulp inflammation, eventual necrosis & recurring patient hypersensitivity to thermal extremes (1969-1976) [41-44].
Professor Takao Fusayama	Publications from the early 1970's to his erudite textbook of the late 1990's. A must read for all operative clinicians!	In the late 1960's, Professor Fusayama & his colleagues began their quest to develop a non-toxic stain to differentiate infected from affected dentine. With that development, he brought forward what clinicians know today as Minimal Reduction & total etching for non-pressure adhesion that has revolutionized Operative Dentistry
Dr. Martin Brännström	(1922-2001)	Dr. Brännström's research demonstrated that bacteria were responsible for pulp necrosis & confirmed the hydrodynamic theory of tooth sensitivity (1969) [55].
Drs. Crisp & Wilson		Patented plastic glass-ionomer cement composed of an alumino-zinc-silicate glass & an aqueous polyacid that set by an acid-base neutralization reaction [patented 1977].
Drs. C. Cox, K. Keal, H. Keal & E. Ostro		Their <i>in vivo</i> pulp biology research demonstrated that Ca(OH) ₂ was NEITHER uniquely necessary nor required for stimulation of reparative or a new dentine bridge directly adjacent to an exposed vital pulp (1987) [53].
Drs. C. Cox, K. White, D. Ramus, J. Farmer, M. Snuggs		Their <i>in-vivo</i> pulp biology research demonstrated that deposition of reparative dentine deposition is not due to any sort of biological or physiological stimulatory effect of the restorative agent --- but is a combination of the cutting effects as well as volume of cavity dentine that was removed (1992) [54].

Transition from oral accounts-to written history-to documented publications

History is often studied by following human cultural growth. This may be seen in many ancient dental treatments—use of cotton or wool fibers dampened in clove oil & plugged in cavities to alleviate tooth pain—which had accumulated through the passage of oral folklore that had been handed down through many generations of storied traditions, long before any sort of written records.

The Ebers Papyrus (circa 3,700 B.C.) were detailed written laws that

specified "to treat diseases of teeth and gums with various prescriptions [but] nowhere mention[ed] prosthetics". Beyond the oral folklore, treatment of dental pain had become entrusted to someone in the community—generally a *Shaman* with high tribal authority—who was supposedly entrusted with curative abilities. When treatment failed, the *Shaman* found reason to extract the offending tooth [1].

Observing the ravages of decay & tooth loss in the skulls of ancient humans

Sir Marc Armand Ruffer, a noted English physician studied

hundreds of human skulls from the Egyptian Iron age (1,000 B.C. to 500 B.C.). He noted that caries was a common disease, which existed throughout all eras of Egyptian history. Skulls from all social classes showed tooth decay, calculus, bone loss, alveolar abscesses & tooth loss. Today, we know that decay, periodontal disease & tooth loss is exacerbated by eating soft sticky sweets that feed microorganisms, leading to pathology, especially in people with little knowledge or concern of oral hygiene. These pathologies cause chronic periodontitis & tooth loss.

In a moment of retrospective reflection, the authors feel that today's dental culture—K through 12 as well as all clinical institutions—should reconsider the recommendations of dentistry's early clinicians e.g. Drs. Thomas Berdmore, Robert Blake, Leonard Koecker, G. Waite, Levi S. Parmly, Solyman Brown & others who stressed the use of toothpicks to remove food debris & develop daily regimens of oral hygiene with tooth-brushing, flossing & calculus removal. Their publications are mentioned not only for historical references, but our profession needs to re-support their recommendations with new emphasis of preventive maintenance for all patients on a daily basis.

The Roman physician Aulus Cornelius Celsus (25 B.C.—50 A.D.) wrote “there is nothing in the world worse than a toothache”. Medieval literature referred to tooth pain as “gout of the teeth” or “flow in the teeth” [2]. The skull of the “Old Man of La Chappelle-aux-Saints cave”—a Neanderthal male who lived sometime between 50,000 to 25,000 B.C.—was found in a caringly buried gravesite in southwest France—leaving a jawbone missing all molars & severe bone loss from chronic periodontitis [3]. In 1930, Dr. Hooten reported that the skulls of Pecos natives (1,000 A.D.), which he had studied from Southwest US stated “most of the native skulls showed heavy occlusal attrition and cusp wear in 97.2% of their molars. . .Caries is present in 47.9% of the teeth. . .Periodontal disease is present in 7.2%” [4].

Drs. Pickerell, Ruffer, Moodie [5-7] reported that attrition & wear was common in agrarian cultures who ate corn, wheat & grains, which had become mixed with silica from grinding in stone bowls. Over time, silica particles in the flour caused severe occlusal wear of enamel, dentine & exposed vital pulps causing pain, inflammation & eventual necrosis. Due to their agrarian diet, decay was much less prevalent than in the teeth of affluent urban cultures that enjoyed the liberal use of sugar in their daily diets.

Sugar is scientifically acknowledged today as a major causal agent for instigating caries & other problematic medical issues

In 1747 Andreas Marggraf (1708-1782) extracted sugar from beets, which made cheap sugar available to all social classes throughout the world. The unlimited accessibility of sugar is acknowledged as causing a rapid rise in tooth decay, pyorrhea, tooth loss as well as medical conditions such as obesity & diabetes amongst affected populations [8]. People of the state of Saxony in 1780 Germany—having none if any concept of oral hygiene, or the importance of cleansing the teeth—called their toothache “the fourth-holiday disease”, since most Saxons over-indulged in their eating of sugared-sweets during Christmas, New Year's & Easter holidays, the heavy use of sweets & high calorie foods brought about high caries rates that resulted in tooth pain & eventual tooth loss that created many dental-cripples as well as medical complications of obesity & organ complications such as kidney, liver, diabetes & other pathologies.

Decades of scientific research have reported hundreds of medical reasons that humans should avoid the use sugar & high fructose corn

syrup (HFCS), which are ½ glucose & ½ fructose. Glucose can be metabolized by most eukaryotic cells, but fructose is non-essential to body metabolism. Fruits have organically occurring nutriment with vitamins, fibers, minerals, & water that contain natural sweeteners, whereas sugar & HFCS are empty calorie foods, which supply non-essential fructose that is only metabolized in the liver. However, when HFCS is transported to the liver & not immediately utilized, it causes fat buildup that leads to non-alcoholic fatty liver disease causing a metabolic syndrome that may lead to heart disease, obesity, diabetes and insulin resistance [9].

Early healing arts were 1st recorded on clay tablets & later on papyrus paper

Sumerian cuneiform tablets (circa 5,000 B.C.) documented social & cultural information for our historical understanding. With the fall of the Sumerian culture (circa 3,000 B.C.), Hammurabi (1,810 B.C.–1,750 B.C.—the Semite ruler of Babylon—instructed laws of medical jurisprudence to be inscribed on tablets, which served as the 1st recorded medical text of that time. His laws established physician fees & proposed punishments for clinical failure due to unskilled treatment [10].

Egyptians developed a written alphabet of hieroglyphics & excavated copper from deposits along the Nile River to fabricate implements to write on a papyrus paper that was produced from reeds that grew along the river marshes. Following the robust influences of the expanding Greek culture throughout Mediterranean regions, priests oversaw the intellectual, medical & scientific life of Egyptian culture. From his travels through Egypt, Herodotus (484 B.C.–430 B.C.) wrote “the country was full of physicians; ones who treat only diseases of the eye; head, teeth, abdomen and internal organs”. Excavations by Drs. Wreszinski (1880-1935), Schmidt (1836-1925), Smith (1822-1906) & Breasted (1865-1935) observed caries & tooth loss from their studies, but no evidence of filled or prosthetic teeth [11-14]. In 1875, Professor George Ebers (1837-1898)—a noted Egyptologist at Leipzig University—purchased, a cache of an ancient 110-page papyri scroll in the winter of 1973 from a temple at Luxor Thebes. That document contained herbal & medical writings from 3,700 B.C. to 1,500 B.C. Today, these Ebers Papyri may be observed at Leipzig University in Germany [15].

Treating tooth pain evolved from extractions to the removal of cavity debris, cleansing & filling the cavity

The Roman emperor Marcus Claudius Marcellus (268 B.C.–208 B.C.)—who thought himself a sort of physician—opposed tooth extraction, even if there was a toothache. His prescribed treatment was “to bathe the cavity with hot oil and various formulations of opium or hyoscyamus (*henbane-nightshade*). . .removing cavity debris with a device followed by filling the cavity floor with *mastic* from tree resin and place a piece of wax into the cavity with a small probe” [16]. The notable Aelius Claudius Galenus [GALEN] (129 B.C.—circa 210 A.D.) who was born in Pergamon Turkey became a noted physician, surgeon & philosopher who followed Marcellus's teachings. Galen advocated placing *black hellebore* (buttercup) & *ginger* into the cavity to eliminate pain. If the pain persisted, he encouraged opening the pulp with a metal drill & to then place ground *chamomile root* & *vinegar* into the cavity to promote healing & to then fill the cavity with wax [17].

The Gutenberg press—perhaps more important than today(s) information technology—promoted knowledge to anyone who craved understanding

Johannes Gutenberg (1398-1468) of Mainz Germany invented the

printing press, mechanical moveable typeset & oil-based ink, which promoted the mass-production of textbooks & communication to the general public & professions. The 1st dental textbook titled *Artzney Büchlein* was published in 1530 in Leipzig Germany by Michael Blum. Two years later, Peter Jordan published the 2nd & 3rd editions in 1532 entitled *Zene Artzney* from Mayence Rhineland in Germany. The following editions were a compilation of surgical techniques & operative procedures to treat teeth of people who were suffering toothache & wanted to save their teeth from extraction. That 1st version ended after 14th editions in 1576 published by Christian Egenolffs in Frankfurt Germany, which continued to augment up-dated treatments of known infirmities of the mouth & teeth in following editions [18].

France—circa 1700—is credited as the 1st European country to embrace **OPERATIVE DENTISTRY** as a separate profession from medicine & surgery. In 1728, Pierre Fauchard (1671-1761) wrote in his 1st textbook “The French Dentist” . . .stating “One should be thoroughly conversant with, and understand the subject upon which one is to pronounce an opinion, and should obtain such a manner and measure of light and insight as to warrant a decision: the more thorough the investigation, the more reliable must be the conclusion. . .The use of a broader education for dentists and in advance to those who might criticize his writings. . .it was my object to write for everybody and in particular for those who desire to learn the part of surgery that I practice. . .The clinician should teach the importance of keeping the teeth clean, how to file them, how to clean them, to burn or cauterize them and to fill them with lead” [19]. As today’s diets continue to move from one type of fashion to another, it is notable at this point to reflect on a 1938 comment by Dr. Lufkin “It is store food that has given us store teeth” [20].

In north america—mechanical dentistry gains popularity due to patients needs

Edentulous patients began to demand replacement for their extracted teeth, which ushered in the initiation of **MECHANICAL DENTISTRY**. Dental treatment in Colonial America in the 1700’s had been almost entirely of extractions with only a few clinicians attempting to fabricate rudimentary dentures with crude ligatures, springs & clasps. A few of the enterprising & skilled clinicians began to provide dentures by recording impressions in wax or Plaster of Paris (calcium sulfate) to fabricate suction dentures for patients who could afford the cost as noted by Dr. Solyman Brown (1790-1876) [21].

In the early 1800’s, Dr. Jacques Gardette (1756-1831) a gifted surgeon who had gained recognition while serving with the French naval troops during the American Revolution began to treat residents of Philadelphia PA who had learned of his dental skills. He is credited as the 1st qualified clinical dentist in colonial North America to extract infected teeth & to fabricate & place an upper denture using atmospheric suction that held the upper denture in place without the use of metal springs or other clasps & attachments, which were less than acceptable by most patients [22].

Toilet of the cavity: its cleansing & disinfection to enhance filling retention & longevity

Many clinicians who had made attempts to fill a cavity with an agent of their choice, had come to realize that if the filling was to remain in service for any amount of time, the cavity debris needed to be removed & cleansed—called “*toilet of the cavity*”—& then disinfected before restoration. Dr. Giovanni d’Vigo (1450-1525) a notable Geneon

clinician of great renown—the principal surgeon to Pope Julius II—recommended in a later edition of *Zeen Arezener* that to treat a painful tooth “the clinician must first clean the cavity with vinegar or similar agent and to temporarily fill the cavity with a mixture of *gall apples*, *gallanum* and *opopanax*. . .when the pain stopped, the cavity could be cleaned again and filled with leaves of gold” [23].

Dr. Ambrose Paré (1510-1590) the noted French surgeon—who served as Principal Operator for several French Kings—is credited as the Father of Dental Surgery. Dr. Paré authored a textbook that was later published in a 1634 edition after his death that promoted cleansing the cavity in a manner similar to that described by Dr. d’Vigo in an earlier edition of *Zeen Arezener* & to then fill the cavity with lead or cork [24].

Part II of Fauchard’s 1728 text was devoted to operative & restorative procedures, writing that “incipient caries may be treated in three ways: *first* is the application of a mixture of essence of cinnamon and cloves, or either of them alone. The *second* is actual cautery, and *third* is filling with lead and the patient may bite upon the instrument and assist in the condensing [procedure]. . .When caries proceeds so far as to cause pain, it must be removed and in the carious cavity, must be placed a little roll of cotton which has been dipped in cinnamon or clove essence. . .placed in [the cavity] with care so as not to cause too much pressure when the cotton is placed. . .After three or four days. . .the carious matter is to be removed. . .if the pain continues, cautery must be resorted to, and sometime afterwards the tooth should be filled with lead. . .All of these operations demand a skillful, steady and trained hand and a complete theory.”

Operative dentistry gains respectability with the placement of lead, tin & gold foils

Celsius (100 B.C) is noted for filling of cavities with lead to prevent tooth fracture during extraction. Until the late 1770’s only highly skilled clinicians attempted the operative & cleansing phase of filling teeth. In 1825, Dr. Leonard Koecker (1785-1880) chided his emerging clinical colleagues “The slight scientific attention that has been paid to this [operative] subject, is particularly proved by the superficial manner in which English, as well as [other] foreign writers, have treated it in their works” [25].

Dr. Antoine-Malagou Desirabode (1771-1851) wrote in his 1847 text, that “soft lead was a preferred clinical filling agent by only a few skilled operative clinicians in Paris who felt they could save a tooth from extraction”. Lead leaves were easily compressible & easily formed into thin ductile sheets to fill tooth cavities. The French word *plombage* translates as “leading” [26]. At that time, a thin lead foil lining was thought to promote a soothing influence to a sensitive tooth. However due to discoloration of the tooth & recurring pathology, lead was soon abandoned & operative dentistry remained static in its clinical treatment, as extractions still held sway for the “easy treatment method”.

To provide a standard gold foil, Mr. Marcus Bull (1787-1851) of Hartford CT began a business in 1812 of beating gold with heavy leather mallets on granite blocks to produce a thin gold foil using gold Brazilian *Johanne* coins—due to their high-grade purity when compared to other gold coinage around the world. In 1815, Messrs’ Bell & his apprentice Charles Abbey, moved to Philadelphia PA where they produced high quality gold foil & sold it as their single specialty to clinicians who demanded their superior product. Some dentists’ rolled gold leaf into cylinders & condensed the roll with a serrated condenser developed by Dr. Cushman of Georgia.

In 1849, Dr. Chapin Harris (1806-1860) reported that small gold pellets were common for those highly skilled & reputable clinicians who practiced in the major cities along the eastern American seaboard, having replaced the lesser suitable lead. Colonial manufacturer's records from 1851 show that the amount of processed gold in the US that had been placed in teeth was a total of 6,600 ounces at a total of \$198,000. Other metal foils of tin, silver & platinum were placed in cavities, but they generally fell to the use of gold foil [27].

In 1853, a new type of crystal sponge gold foil was simultaneously introduced by Messrs' A.J. Watts of Utica NY & J. Barling of Maidstone England. It was "heralded far and wide as the *ne plus ultra* in filling materials". The greatest advantage of crystal gold was its condensability in the presence of moisture or other fluids. Dr. Louis Jack of the University of Pennsylvania Dental School Operative Department made advances in cavity preparation by placing small retaining pits into the dentine & using deeply serrated plugging points for condensation of the gold foil into the pits. By the 1850's, US **OPERATIVE DENTISTRY** was recognized to have taken great clinical strides [28].

Direct placement of pliable *plastic* restorative agents

The term *plastic* as a restorative agent appeared in our dental lexicon—circa 1830—describing any malleable agent, which could be mixed & placed directly into a cavity with the ability to be condensed, molded & formed into a shape that conformed to features of the cavity & tooth anatomy.

Early dental cements were temporary cements of a simple mix of alcohol & mastic resin & called *plastics*. But they dislodged & easily fell out. Early mineral cements were sulphate of lime & oxides of iron mixes, but they crumbled upon drying & fell out. The next generation of a dental *plastic* filling agent was Dr. Jean d' Arcet's (1777-1844) mineral cement of fusible metals of bismuth, lead, tin & some mercury, but it needed to be heated to 212°F & after allowing for some cooling, it was placed into the cavity—supposedly with much care—but even so, it generally caused a great deal of patient pain that led to its rapid disuse. Dr. Leonard Koecker (1785-1880) & other colleagues employed these & other *plastic* cements 150-years before adhesive polymers & composites appeared as dentistry's 1st supposedly *plastic* restoratives [29]. As a caveat of caution to clinicians of his era, Dr. Robinson cautioned that "these terro-metallic [mineral-metal] cements were only suited for temporary restorative purposes and that they should not be considered as permanent cavity restorative agents" [30].

Sir Isaac Newton (1642-1727) is acknowledged to have developed the 1st cold-fusible metal (circa 1686), which was composed of 8-parts bismuth, 5-parts lead & 3-parts tin [31]. For dental purposes to fill a cavity, Dr. Jean d' Arcet heated these 3-agents & then poured the hot mix into the cavity, which became unpopular! He later added a 1/10th part of mercury to speed the fusion process before placing it into a cavity [32]. In the US, Dr. Wood modified the fusion process of these metallic agents by placing small pieces of the 3-metals into the cavity & then attempted to fuse them together with a hot instrument [33].

Permanent *plastic* cements as filling cavities & the cementation of restoratives

In 1856 Messer' Stanislaus Sorel (1803-1871)—an architect & draftsman of some note in France developed a magnesium (Mg) oxide & Mg-chloride & zinc (Zn)-oxychloride type of *plastic* cement in 1867 as a stuccowork façade that was applied as a pliable layer of Mg or Zn-chloride over a base layer of Zn-oxide. His *plastic* mineral—Sorel

cement—was rapidly embraced by a few operative minded dentists & Zn-oxychloride rapidly gained popularity as the 1st *plastic* acidic dental cement [34]. Sorel's *plastic* cement was rapidly modified by clinicians who mixed other mineral oxides with phosphoric acid (H₃PO₄) to promote a controlled chemical setting reaction. These acidic *plastic* cements were used to lute porcelain restorations, gold inlays & onlays as well as to provide a thermal insulation base layer against the heat transfer thru metallic restorations. These *plastic* cements were modified by the addition of copper or Zn-oxides, which were known to have certain antimicrobial properties [35]. Shortly afterwards, methacrylate resin cements—discussed later—were developed in Germany during the 1940's as a hard-set protective base & luting cement that would harden into a dense mass.

The 1st *plastic* silicate glass cement was developed as an anterior chairside restorative in England by Thomas Fletcher in 1871 & soon afterwards its improvement was attempted in 1888 in Germany with the addition other minerals [36]. Silicate cement was introduced to US clinicians in the early 1900's with the addition of fluorine, but was soon found to be the least desirable of all *plastic* glass cements due to their lengthy setting reaction & solubility in oral fluids that resulted in postoperative hypersensitivity & recurrent caries. In an attempt to prevent the surface moisture inhibition during the long gel-set reaction, clinicians would cover the silicate surface with a layer of petrolatum or thick coconut butter. The *plastic* gel-set of the silicate reaction formed an internal solid mass of 60% to 70% of an undissolved powder around each glass silica particle that was surrounded by the gel-set agent following 24-hours in the cavity, at which time, the patient was instructed to return to the clinician for final surface finishing. From a practical patient concern, the H₃PO₄ at the restorative-tooth interface etched the smear debris layer & opened the dentine tubules, which resulted in severe patient postoperative sensitivity & microleakage of pathogenic microorganisms [37].

An improvement to the silicate glass *plastic* cement was the development of an adhesive glass ionomer (GI) cement composed of alumino-zinc-silicate glass & an aqueous & polyacid, patented by Crisp & Wilson in 1977 & marketed by De Tray ASPA. The original GI set by an acid-base neutralization reaction, whereas most of today(s) newer GI's are resin modified, which set by polymerization & neutralization reactions. Due to the reported ongoing chemical reaction at the tooth-restorative cavity interface, GI's today are often described as having a **DYNAMIC** interfacial cohesive bond, to the HAP of enamel & dentine, having the potential to keep redefining its cohesive interface to supposedly provide an enhanced toughness, moisture resistance & fluoride release.

Mineral cements were originally placed as temporary restorations as well as indirect & direct pulp capping & filling of instrumented root canals [38]. Shimada reported a benefit of H₃PO₄ zinc phosphate cement was that it had the potential to form an adhesive bond to the enamel HAP substrate [39]. However, when the same H₃PO₄ zinc phosphate cement was cemented to moist vital dentine, it did not adhere or form an adhesive bond to the dentine interface, other than by VAN DER WAALS forces, which are only known to exist between molecules in a moist environment. After placement in the oral milieu & with open margins of at least 5µm as defined by ADA specifications—with constant bathing in oral fluids caused eventual fluid microleakage, the cement would dissolve & permit microorganisms to invade the opened restorative interface [40]. Loss of the luting cement left a space at the restorative interface, permitting fluids to penetrate into the dentine tubules, resulting in increased fluid flow, sensitivity to cold,

acids & osmotic stimuli as reported by Drs. Brännström (1922-2001) Garberoglio (1923-1996), Massler (1912-1990), Kidd & others [41-44].

Studies by Nakabayashi & colleagues have shown that the H_3PO_4 component of the initial cement mix etches the debris smear layer, the cavity interface debris & opens the dentine tubules & also permitting the collapse of the intertubular collagen & interconnecting protein fibers between the larger collagen fibers that formed the bio-scaffold for HAp crystal mineralization. The collapse of these denatured collagen fibers forms a dense mass, known to interfere with the proper interdiffusion of polymers, which leaves a vulnerable unfilled polymer zone, which ultimately leads to a failed *bacteriometrically sealed* interface as described by Dr. Ruby [45]. That vulnerable nonfilled zone permits microbial penetration into & through the open restorative interface, which inevitably leads to pulp inflammation, necrosis as well as to permit patient sensitivity to thermal stimuli & occlusal forces [46-49].

Anodyne cements to alleviate postoperative tooth hypersensitivity

Mineral *plastic* cements evolved into anodyne-obtundant cements by the mixing of essential oils e.g. clove, eugenol, bay or guaiacol with Zn-oxide powder by clinicians who had learned that folk remedies & treatments with essential oils had anodyne-obtunding properties with the capacity to relieve a person's toothache as well as to stop the carious process. In rural areas of Europe & colonial America, some people had learned that placing a wad of cotton wet in clove oil & then plugging it into a cavity would rapidly relieve the pain & eventually stop the chronic agony.

Dr. Robinson advocated mixing asbestos with celloidin & placing it as a thermal liner underneath metal fillings to serve as a non-conductive liner to prevent patient post-operative sensitivity [50]. In addition, some clinicians began to place anodyne cements into cavities with the thinking that it would serve as a protective-base underneath acidic cements, which some considered would serve as a bactericidal liner [51]. By the 1890's, certain clinicians began to bathe the occlusal & buccal grooves of carious lesions as well as cavity walls with 10% silver nitrate, which was known to provide an antiseptic quality as well as to render the dentine as insensitive [52].

Pulp protection of the vital pulp became popular with placement of cavity varnishes or thin $Ca(OH)_2$ liners

In the US, the issue of pulp protection became a biological consideration in the 1940's as a number of clinicians realized that patient discomfort & pulp injury could result from a rapid thermal change of 15° to 18°C that resulted from the operative cavity preparation procedures using steel burs without proper cooling, as well as to the rapid rise of thermal extremes associated the exothermic setting reactions of various cements. At that time, copal tree-resins were mixed with ether or chloroform as a common protective liner that was placed onto all of the cavity walls in several increments that were intended to seal the dentine tubules & prevent the microleakage of microorganisms into the restorative interface [53].

Calcium hydroxide $Ca(OH)_2$ powder was moistened with sterile water or an anesthetic solution & mixed into a paste & placed on the axial & cavity walls as a supposed pulp protectant liner. Due to a few pulp biology studies, some clinicians began to accept that placement of a thin $Ca(OH)_2$ liner would serve to biologically protect the vital pulp from the supposed irritation of acidic cements. However, just consider that many decades of placing millions of acidic mineral cements on

human teeth using Sorel's acidic cement since the mid-1850's, some clinicians began to speculate that $Ca(OH)_2$ had special biological capacities to actually stimulate the formation of reparative dentine underneath a cavity preparation. A number of commercial agents still remain on the commercial market for clinicians to place as "pulp protectants". However, many published studies have shown since the 1960's that lining a cavity floor with a base of $Ca(OH)_2$ or other similar commercial restorative agents are **not** a factor in the biological stimulation of either reactionary or reparative dentine deposition following placement as a cavity liner & base [54].

Dr. Martin Brännström; gave scientific truth a priority over preconceived speculation & unfounded notions

Dr. Brännström's (1922-2001)—called Martin by many colleagues—contributions are uniquely defined by his research of dentine hypersensitivity that demonstrated—beyond a doubt—that the bi-directional movement of fluid flow within enamel lamella defects & deeper in the dentine tubule complex was the cause of the initial pain response. His research conclusively demonstrated that the hydrodynamic theory, which had been proposed by Dr. John Neill's 1850 publication *Sensibility of the Teeth explained on Hydrostatic Principles* was the initial stimulus. Throughout the 119-year hiatus from 1850 to 1969, many researchers took emotional sides of either supporting the nerve conduction theory or the odontoblastic process theory as being responsible for tooth pain, with the fluid theory running in a distant 3rd place.

Another equally important clinical-research breakthrough of Martin with several of his colleagues, was their demonstration that the primary cause of pulp inflammation underneath restorations was the microleakage of microorganisms at the cavosurface margin to percolate into & throughout the restorative interface, in which to invade the underlying dentine substrate on the way to the vital pulp. His clinical publications with histological support demonstrated that even when an acidic silicate was direct capped onto a vital human pulp exposure, that new odontoblastoid cells had formed a new dentine bridge directly adjacent to the glass particles of the silicate interface, without the placement of a commercial direct pulp capping $Ca(OH)_2$ agent at the site of the mechanically exposed pulp tissue [55].

An important clinical contribution of his in 1964 was the development of an ethylene diamine tetraacetic acid (EDTA) cavity-cleansing agent Tubilicid, which removed the smear layer debris & microorganisms from the cavity walls & tubules. In addition, Martin developed a polystyrene cavity liner Tubilitec that when placed underneath amalgam, gold inlay & onlay restorations, had the capacity to provide a bacteriometric seal along the restorative-dentine interface to prevent microleakage of microorganisms with eventual recurrent caries & eventual pulp pathology [56].

Bacteriostatic & bactericidal *plastic* cements

In an attempt to stop the rapid progression of rampant caries, some clinicians modified acidic cements by incorporating various silver & copper oxides, which resulted in a dense-set bacteriostatic to bactericidal base, which was ideal for placement in cavities of primary & permanent teeth. Placing germicidal cements became a popular agent to halt the progression of caries in young children who had rampant caries, which often saved the tooth from extraction [57]. These silver & copper germicidal cements often stained the dentine tubules with black oxides. Consequently they became aesthetically unacceptable to patients who were concerned with wishing to maintain a "cosmetic look" of white teeth.

In an attempt to cleanse & disinfect the enamel & dentine substrates of the cavity, clinicians of the late 1800's would swab agents such as alcohol, phenol, silver nitrate [58], creosote, formaldehyde, ether or chloroform onto the cavity walls before clinical placement of their provisional or definitive restorative agent in an attempt to provide a germicidal effect [59]. However many of these agents would dehydrate the fluid components of the dentine tubule complex & cause aspiration & disruption of vital odontoblasts & pulp cells into the predentine-dentine complex, leaving a subjacent zone of pulp inflammation & necrosis.

Self-curing acrylic *plastic* resin cements were NOT adhesive

Plastic acrylic resins 1st made their appearance in Germany circa 1936 as noted in the Blumenthal report. They were composed of fine polymethyl-methacrylate powder particles mixed with methyl methacrylate monomer & used to fabricate provisional chairside restorations [60]. In addition, these methacrylate resins were initially placed over Zn-phosphate bases as they were virtually insoluble, but they were not stable when placed on phenolic compounds as they inhibited polymerization that led to microleakage of oral fluids around the margins ultimately causing postoperative sensitivity, bacterial microleakage & recurrent caries.

To solve the acrylic non-adhesive & shrinkage problems that resulted in breakdown & degradation of the restorative interface—known today to result in microleakage of fluids & microorganisms—a number of clinical researchers from Guys Dental unit in London worked diligently during the 1940's to develop acrylic cements that would provide a long-term *bacteriometric seal*.

In the 1940's, the family owned ESPE company in Britain supported development of a low-viscosity epimine resin, which displayed low polymerization shrinkage with lower exothermic heat of polymerization. Their epimine resin was more biologically kind to vital tissues & prevented aspiration of odontoblasts & subjacent pulp cells into the dentine tubules during polymerization. Epimines had better flow properties than acrylic resins, but they rapidly failed as they showed poor impact strength & abrasion resistance to occlusal wear. Acrylic resins were frequently referred to as “restorative *plastics*”, but they were **NOT** adhesive to enamel or dentine. To make these acrylic resins opaque in radiographs—to prevent their acrylic transparency as a mistaken interpretation for recurrent caries—manufacturers filled their acrylic *plastic* cements with oxides (e.g. titanium dioxide) to render them opaque in radiographs—preventing the acrylic transparency as a mistaken clinical interpretation for recurrent caries [61].

Another adhesive *plastic* cement contained primarily a Zn-oxide powder with a polyacrylic acid liquid that when mixed, reacted to form a hard-set crystalline mass upon setting, known as a polycarboxylate dental cement. It was developed initially as a cavity base underneath a metallic filling as well as to lute metal castings to teeth with the potential to bond to the calcium HAP in tooth tissues as well as to base metals contained in various castings.

Samuel Stockton White develops uniform operative burs for cavity preparation

Skulls from the Mayan culture were known to use “bow drills” to prepare cavities for placement of gems into the facial surfaces of teeth in those individuals who held high-ranking nobility & social prominence.

In 1838 the Lewis drill was introduced & a modified drillstock was added to bur manufacturing in 1858 by Messrs' Chevalier & Merry [62]. In 1872 the SS White Company advanced the cavity preparation technology of **OPERATIVE DENTISTRY** by defining manufacturing bur standards to produce file-cut steel dental burs in cylindrical, cone & inverted shapes for the clinical profession that easily fit into the 1871 Morrison foot treadle handpiece. In 1891, the SS Milte Company mass produced the 1st machine-made steel burs [63]. In 1893, an industrial silicon carbide—named carborundum—became available for dental burs in 1896 [64]. By 1891, Dr. G.V. Black had defined clinical guidelines for scientific cavity preparation as well as for amalgam composition, trituration & placement [65].

Dr. Marshall H. Webb: a renowned american preventive & operative dentist

Dr. Marshall Hickman Webb's (1844-1884) 1883 limited edition textbook “Notes on Operative Dentistry” is probably unknown to many generations of academic colleagues. His 175-page text was published by S.S. White Dental Mfg. Co. of Philadelphia PA. shortly before his untimely death at age 39.

During his brief lifetime, dentistry had become a worthy profession almost overnight. Dr. Webb increasingly improved his clinical expertise by blending the rapid advances in biological knowledge of tooth tissues with the rapid developments in operative dentistry. At young age, he had become a respected as a consummate conservative clinician who not only taught preventive dentistry but also he also practiced it every day—literally one of America's 1st artistic renaissance clinician. His article “Restoration of Contour, and Prevention of Extension of Decay” make it obvious why his gold restorations were acclaimed as operative triumphs of technical genius—earning him special prominence & unexcelled respect by his peer colleagues during his short lifetime.

Only those dentists who were committed to spend their clinical efforts to “pay particular attention to detail” as Drs. Webb & Jack professed, were able to place gold leaf foils, which were known to withstand the oral challenges & to last for years. On the other hand, clinicians of lesser attentions who realized the difficulties encountered in the preparation, manipulation & finishing of gold foil restorations looked elsewhere for more simple restorative *plastic* agents [66].

Dr. Webb had few equals amongst US colleagues & his 1883 text defined standards of teaching excellence for students & colleagues with over 70 of his own hand drawings. He proudly credited his contemporary colleagues who had impacted his clinical thinking to honor their teachings. His book challenged the reader to “become a faithful practitioner” suggesting their studies would enable them to “became fully prepared for the prevention & treatment or cure of disease”—he strongly advocated use of a chairside assistant. His 20-chapter text incorporated personal knowledge & skills, in which he felt compelled to share with his colleagues.

Dr. Webb emphasized the use of Dr. Barnum's rubber dam & metal clamp “for every case to isolate the patients teeth in a conscientious and sincere manner—doing nothing but what he would have done for himself”. His following chapters demonstrated that he understood the proper composition, preparation & insertion of restoratives like acidic cements, gutta-percha, amalgam & cohesive gold foil. Dr. Webb was best known amongst his contemporaries as a gold foil operator, becoming extremely accomplished at conservative cavity preparation & their filling within labial & buccal walls & masticating tooth surfaces. He perfected the electro-magnetic mallet for packing of cohesive

gold foil into cavities without damaging the rubber dam or gingival tissues if accidentally displaced. Dr. Webb perfected the placement of pre-formed porcelain pieces into cavities, by 1st disinfecting the walls with phenol, salicylic acid or alcohol & then luted with gutta-percha, Zn-oxychloride or Zn-oxyphosphate cement. The margin between porcelain & enamel was sealed with compacted gold foil & the porcelain trimmed with a fine corundum wheel until occlusion was confirmed. Regarding pulp therapy, Dr. Webb wrote that “every effort ought to be made to preserve the pulp in each case, however if pulp death could not be prevented, the tissue should be removed with fine broaches, small amounts of arsenic placed to devitalize any remaining tissue, the chamber temporarily filled with gutta-percha and the chamber later filled with gold”.

Dr. Webb was a noted author, lecturer, debater, inventor & gold clinician extraordinaire during his 15-year dental career. He was decades ahead of other noted colleagues in forwarding the concept of prevention & was 1st to consider what type of restorative agent would be placed—before he began any operative preparation. Dr. Webb challenged the operator to pay critical attention to proper tooth contour so the complete enamel margin of gold would be properly finished to physiological function, preventing food from being forced between the tooth contours during mastication. In reading his textbook, it is apparent he was a complete clinician, practicing prevention, conservative cavity preparation & placement of long-lasting restorative agents that would exclude the possibility of recurrent caries.

By 1870, Dr. Webb had become one of the most highly regarded clinicians in the world. His pioneering work in preventive dentistry raised the standards of what we call today as **MINIMALLY INVASIVE OPERATIVE DENTISTRY**. Unfortunately, Dr. M.H. Webb is unknown by most of today's academics & students, but his concepts of prevention & tooth preparation are easily applicable for today's adhesive & composite systems [67].

Mixed cold fusible metals & their evolution to the metal plastic of amalgam

Sir Isaac Newton (1642-1727) is credited to have developed the 1st cold-fusible metal composed of 8-parts bismuth, 5-parts lead & 3-parts tin. Dr. d' Arcet added a 1/10th part of mercury to speed the fusion process before placing it into a cavity [68]. He heated these 3-agents & then poured the hot mix into a cavity, which was painful & rapidly became unpopular. In 1860, Dr. Wood modified Dr. d' Arcet's metal by placing small pieces of the 3-metals into the cavity & then fusing them together with a hot instrument filing the plug & mixing with a hot instrument [69]. Dr. Robinson advocated the mixing of asbestos with celloidin as a lining agent underneath metal fillings to serve as a non-conductive agent to prevent patient sensitivity to thermal extremes [70].

In 1816, Dr. Auguste d' Taveau mixed filings of pure silver with mercury, which he called silver paste. He mixed the agent into a *plastic-mass* & expressed the free mercury with pliers before placing it into a cavity to harden. In 1836, the European Crawcour brothers introduced their “Royal Mineral Succedaneum” of silver & mercury to Colonial dentists. However, since many charlatans & some clinicians were looking for a simple agent to replace gold foil—the Crawcour's *plastic* amalgam rapidly became the restorative agent of choice. In 1848, Dr. Thomas Evans of Paris added cadmium to the silver-mercury mix but he soon noted that it contracted & cause tooth discoloration as well as microleakage—its clinical use was rapidly discontinued [71].

Amalgam: an intense 3-year clinical limitation followed by a cautious peace

At his 1840 Commencement address of the Baltimore College of Dentistry's 1st graduating class, Dr. Chapin A. Harris (1806-1860) read “More recently an amalgam of mercury and silver has been highly extolled by a few practitioners, both in this and other countries; but by most of those who have had teeth filled with it, bitterly denounced—so that. . .it has nearly gone into disuse. . .and yet. . .thousands have been induced to try its efficacy”.

Many of so-called clinicians & dentist aspirants simply placed the amalgam mix into large cavities without any debris removal or cleansing—some randomly plugged amalgam into healthy tissue spaces between teeth—resulting in continued carious pathology as well as periodontal inflammation that often resulted in alveolar bone necrosis & loss of teeth. In 1843 The American Society of Dental Surgeons—initiated the amalgam war by declaring the use of amalgam as malpractice. In 1845, that same American Society committee reluctantly voted to permit the infrequent use of amalgam & declared it to be “occasionally admissible” but only by those clinicians who understood the specific scientific clinical cavity preparation & cleansing as well as its mixing & placement as a permanent restorative agent [72].

The 1st important study on amalgam microleakage was carried out by Sir Charles S. Tomes (1846-1928) in 1861 England. He packed 8-amalgam compositions into standardized cavities that had been prepared into ivory & then observed their margins by a microscope. He observed that 7-silver amalgam compositions had contracted after setting with each showing leakage, whereas only the copper amalgam failed to show any shrinkage or microleakage [73].

Dr. James Leon Williams; from the maine wilderness to become the 1st IADR president

James Leon Williams—preferred to be called Leon—was born in the Maine wilderness on April 21st 1852, the oldest of 8-children (6-boys & 2-girls) by the Kennebec River near the village of Solon. His parents were Calvin & Sarah Williams who lived in a crude log home with no neighbors for miles.

Leon's great-grandfather Jacob from England was descended from Oliver Cromwell who rose from low social birth to become a champion of the rights of middle class Englishmen & served as Lord Protector of the English Commonwealth for 10-years—between King Charles 1st in 1649 & King Charles IInd 1659.

Leon's grandmother constantly read to him from *Pilgrim's Progress*, the *family Bible* & several books by the 1st century historian named Josephus. By age-6, Leon walked several miles to a small one-room log schoolhouse. His favorite schoolbook was *Comstock's Philosophy* of 1838 that had a strong influence on his life's work. Living in the wilderness, Leon & his siblings made their own playthings using a wealth of imagination that served to strengthen their love of nature. By age-7 Leon made drawings of nature & since no paints were available, he made his own colors of red, green, yellow, brown from juices & vegetables to color his drawings. Leon had an equal blend of intellectual power & aggressiveness from his parents & his mind was said to have been divided into two activities: one dominated by aggressive intellect, which he used to take things apart to understand their makeup & to then put them back together to make them work better; second Leon was dominated by a love of philosophy & beauty in nature & art, he saw that all life was one harmonious whole.

By the time Leon was 14-years old; his parents moved the family to Skowhegan & 2-years later they moved to North Vassalboro, a small village of 20-families along the Kennebec River. A dentist-druggist named E.J. Roberts owned the only drug store, which contained many books as a circulating library to borrow & return once read. Leon was always seen about N. Vassalboro either reading or carrying a library book. Dr. Roberts noticed that Leon—who was only 17—was very interested in books & asked his parents if Leon could work in the store. Leon soon decided to become a dentist & used all of his spare time to study medical texts such as *Gray's anatomy*, Harris's *Principles and Practice* and Dalton's *Physiology*, etc. At the same time, Leon took formal courses of histology & anatomy from a professor at Colby College about 5-miles away in Waterville.

When Leon reached the age of 19-years, Dr. Roberts sold him the store & dental practice, whereupon Leon entered dentistry as an apprentice under Dr. Roberts & received the courtesy title of "Doctor" when he became a member of the Maine Dental Society. His practice prospered for 20-years. At the Maine dental meetings, Leon learned the society owned a microscope & since none of the local physicians or dentists cared about the microscope, he borrowed the device for several years. At the end of the time he had saved \$100 to purchase his own microscope—many of his colleagues thought him crazy. For the next 7-years Leon used his strong search for knowledge & new microscope for personal research on the development of human teeth. He arranged a research lab in his office with a window to the south so he could focus his microscope mirror towards the daily sun. At age-30 Leon wrote his first of many articles for the May 1880 *Dental Cosmos* entitled *Studies in the Histo-Genesis of the Teeth and Contiguous Parts*, which attracted much attention from colleagues around the world, hearing from those who agreed with him & many who opposed his ideas. In the early 1880's Leon used his embryological & histological knowledge from his Colby College studies for research on thousands of histological microslides of human teeth—completely on his own. Even W.D. Miller—of caries theory fame—encouraged Leon's caries research & by 1882, he had become convinced that tooth decay was caused by external factors. Leon wrote that bacteria directly produced caries in 2-steps; the 1st-step was acid dissolution of enamel & the 2nd-step was penetration of bacteria through enamel defects into dentine, which rapidly spread towards the pulp. Due to Dr. William's outstanding histological studies & demonstration of the nature of caries, the Baltimore College of Dentistry conferred the degree of DDS to Dr. Williams in 1883.

At that time Leon moved to NY he was suffering from a weak heart, whereby a physician advised him to move to Philadelphia PA for a more mild climate. After 1-year, he still suffered from a fragile heart & upon his physicians advice, he moved to a sanitarium in the Swiss Alps for recovery. On his 1887 trip to London, Leon's health had improved—he moved there permanently—& immediately applied for a dental license in Dental Surgery at the Royal College of Surgeons of Ireland. While waiting, he associated with a London dentist at 30 George Street & in 1890 Dr. Williams received his license to practice dentistry.

Perhaps his most notable honor was as the 1st-president of the newly formed International Association for Dental Research (IADR) in recognition for his many research contributions, which our dental profession has benefited. Dr. Williams served as the IADR president from 1921 through 1922 & on its editorial board until 1931. A culmination of his many personal contributions to dentistry, Dr. Williams was honored as the 1st recipient of the Ohio State Dental Society Callahan Gold Medal on Dec 5th 1922.

During his lifetime, Leon became an accomplished artist, photographer, writer & recognized philosopher. A colleague commented to Leon "most of the condemnation of his scientific views seemed to come from older colleagues who felt that if they changed their opinion, it meant a rejection of their own lifetimes work". But, as a measure of his personal philosophy, Leon answered "I regard that as altogether the wrong position. Their condemnation comes, not in having taught error, which was really not error so long as nothing better was known, but in clinging to that error after it has been shown to be such. . .I commend them to the writing of Marcus Aurelius [Roman Emperor 121 A.D.–180 A.D: If anyone can convince me of an error, I shall be very glad to change my opinion; for truth is my business and nobody was ever hurt by it. . .he that continues in ignorance and mistake, it is he that receives the mischief". Dr. Williams died in New York City on Feb 23rd 1931 of heart failure. We are all the better for his life-long search for truths in the sciences, arts & philosophy [74].

Dr. Greene Vardiman Black established amalgam standards & defined operative concepts that gave much needed clinical recognition to operative dentistry

By 1885, Dr. Greene V. Black (1836-1915) was acknowledged as the father of Modern Dentistry by colleagues throughout the world. He cultivated his love of reading, learning, philosophy & logic from his mother Mary & gained knowledge of hand craftsmanship from his father William who made fine cabinetry & furniture when not working the family farm. From his older brother Thomas, he learned human sciences & most fortuitous for our profession Dr. Black acquired a keen love, knowledge & practice of dentistry from his mentor during his civil war service—Dr. J.C. Speer of Mount Sterling IL—before moving to Jacksonville IL, in which he quickly became active in the medical-dental community & rapidly became known as "GV" to his friends. GV was more than a 1-dimensional individual in his approach to dentistry—evidenced by his diverse interests & research efforts. His contributions to dentistry originated from his clinical experience during the war & in Jacksonville where he read & worked in his upstairs research laboratory, whenever he was not treating patients. GV knew that to become well informed in the treatment of the teeth & oral tissues, it was important to understand oral tissues. He assembled a research laboratory above his operative clinic where after family time each evening, he read the past & current literature in original German & French from Erlich, Koch, Pasteur & Schwann. GV purchased a microscope & learned the basics of tissue preparation & built his own sectioning device to prepare teeth & jaw tissues for fixation, processing, sectioning & staining of tissues. GV made his own light source to view glass microslides after daylight faded into darkness & spent hours evaluating his tissues & became accomplished to reproduce precision histology & pathology drawings from his tissue preparations. GV published *The Formation of Poisons by Microorganisms* in 1883 & traveled to Germany & France to deliver lectures on his research—referencing Robert Koch (1843-1910), W.D. Miller (1853-1907), Louis Pasteur (1822-1895) & Rudolf Virchow (1821-1902) noting that microorganisms produced acidic waste products that caused caries, pathology & pulp death [75].

GV developed a unique ability to integrate biological & morphological knowledge of the tooth with his clinical observations & experience. His first dental publication in 1869 was *Gold Foil placement* & its concept of cohesiveness. GV's personal research showed that 15-lbs hand pressure on a 1-mm condenser tip was ideal for proper gold foil condensation. He also collaborated with M.H. Webb in the development of a gold-foil electric mallet. GV standardized operative

procedures to provide uniformity for “Technical Procedures in Making Restorations in the Teeth”, which became part of his 1908 Operative text that became used by most dental schools as a standard teaching text. GV defined Cavity Nomenclature; Cutting Instruments; Adult & Deciduous Teeth; Control of Pain in Cavity Preparation; Use of the Dental engine; Sharpening Instruments; The Use of Water & Air; Positions of Operator & Patient; Keeping the Operating Field Dry; Preparation of Cavities by Classes & Manipulation of Materials for Restoration.

In 1883, GV realized that dimensional instability of amalgam needed focused research if it was to become a reliable operative filling material. In 1895, he constructed a micrometer device precise to 1/1000µm & quickly demonstrated that commercial amalgams had no stable standards. As a result, he devised his own amalgam & discovered that a “balanced amalgam was not related to the individual metals, but was controlled by the condition of the alloyed state”. By 1896, GV discovered the principle of annealing—showing that an alloy of 65% silver, 35% tin in the presence of hydrogen & mercury provided a controlled setting reaction, whereas Zn was unsuitable to maintain dimensional stability. GV selflessly gave his amalgam formula to the US Bureau of Standards in 1919, in which they accepted as governmental amalgam standards.

GV was one of the first researchers to assemble the scientific puzzle regarding the cause of human caries—having ready access to the literature. His personal research & clinical observations gave him a unique perspective on the existing caries science of that day, which many others failed to consider. GV pieced together the complex puzzle of human caries from reading Dr. W.D. Miller's (1853-1907) & others papers—writing that tooth decay would occur when oral fluids were routinely acidic or alkaline & that caries was directly dependent upon lodging of food particles & plaque formation in tooth pits & fissures, followed by fermentation & acid production, which began the demineralization process. GV wrote “what is called fermentation by an organized fermentable agent is but the first step in true fermentation”. Until that time, fermentation was mainly a study of the digested substrates & acidic waste products. GV lectured at the Chicago College of Dental Surgery from 1886 to 1889 & moved to the Dental Department of Iowa University for 1-year, whereupon he was then elected as 1st dean of the Northwestern University Dental School from 1889 to 1915, which he guided to become a leading world dental institution.

GV was a self-taught scholar & remained so throughout his life. His personal research standards still guide many of today's colleagues. GV presented more than 1,300 papers & lectures over his lifetime—without governmental research support, computers, internet, face-book or twitter. GV is known to today's dental students & colleagues throughout world, who have read his biological & clinical contributions, which still have relevance for today's dentists. On Aug 31st 1915, GV passed to The Ages at his family boyhood farm & is buried at Jacksonville IL where he practiced for 35-years [76].

Dr. Miles Markley redesigned operative burs based on engineering principles that ensured minimal cavity preparation

In the 1940's Dr. Miles Markley (1903–2000) applied his undergraduate engineering knowledge—which provided him with unique, understanding, perspective & creative insight—to question & to reevaluate the existing operative practice of sharp line-angle &

point-angle cavity preparation in enamel & dentine tissues. He was an avid reader of clinical & biological research & understood the emerging scientific data, that tooth substrates were composed of unique morphological, biological & physiological diversity, hardness as well as density throughout the tooth's occlusal to pulpal substrate regions.

Dr. Markley applied his engineering concepts to question the clinical problem of placing sharp restorative cavity-angles into the dentine & enamel substrates. He recognized that sharp-line & point-angles encouraged crack formation when irregular occlusal forces were placed onto amalgam restorations. Consequently, Dr. Markley conceived of the #330 & other pear shaped burs, which were smaller than conventional flat-bottom burs. It became immediately apparent that his round-cornered cavities actually diffused the occlusal forces, in which the traditional sharp angled line & point-angle corners promoted crack propagation & catastrophic tooth failure—with fracture & loss of the entire maxillary buccal or mandibular lingual cusps. In addition, Miles modified cavity preparations by reducing the traditional isthmus cavity width, which G.V. Black had previously advocated.

It is significant that Dr. Markley's colleagues rapidly grasped the benefits of his modifications of smaller round-cornered bur shapes & shorter length as well as reduced isthmus width. In terms of today's mantra of outcome analysis—most critically thinking clinicians understand from their own clinical outcome analysis—minimal invasive cavity preparation indisputably preserves normal non-carious tooth tissue. These conservative principles of Dr. Markley have served to preserve the morphological & physiological integrity of the tooth, all the while of maintaining the necessary retention to hold restorations in-place. Those of us who remember Dr. Markley remember that he was a consummate clinician who lived by the axiom: “Pay attention to the details—never be content with what you know—there is always more!” [77].

The emergence of operative adhesive & composite restorative systems

Dental literature from the 1940's to today (2016) continue to prompt differing opinions as to the origin of adhesive dentistry, that quite frankly is often based on ones' geographic perspective as well as their understanding of the scientific perspective. From studying the published literature, it seem obvious to attribute the development of adhesives from the 1940's research efforts to Drs. John W. McLean, Martin Rushton, Ivor Kramer, S.A. Leader & B.K. Blount who were at Guys Hospital Dental Unit in London [78-82].

Others may consider that the adhesive timeline began with the research efforts of Buonocore, Gwinnett (1936-1997) & Matsui at Eastman Dental in Rochester NY [83-85]. Dr. Buonocore's contribution to adhesion bonding initially dealt with H₃PO₄ etching of enamel for placing sealants on children's teeth [86]. However from discussions with several of those Rochester colleagues, they commented that their research ideas could be traced to the group research efforts of the McLean, Rushton, Kramer, Leader & Blount group at Guys Hospital Dental Unit in London. Still, others claim that Dr. Oskar Hagger deserves recognition from his July 21st 1949 Swiss Patent [87].

Dr. L.C. Smith of Amalgamated Dental Co. London UK initiated a new clinical concept to place preformed acrylic resin inlay & onlay restorations on human tooth preparations [88]. Drs. Smith & McLean at Guys Dental Hospital—wished to replace the popular, but supposedly irritating silicate cement with Dr. Smith's new adhesive cement for the epoxy resin crowns that were marketed by S.S. White in the US.

Fortunately, Professor Martin Rushton of Guy's Hospital encouraged Dr. McLean to meet with Dr. Oskar Hagger, the chief chemist at London's Amalgamated Dental office of De Trey Co., Zurich. Dr. Hagger's GPA adhesive solved Smith's search as Hagger's Swiss Patent was first to use a ductile resin layer at the tooth surface to enhance retention [89]. In 1952, Dr. Hagger—along with Kramer & McLean verified that GPA treatment of vital dentine would etch & penetrate into the intertubular dentine to form an intermediate adhesive layer, which stained a dark blue in histological sections. Today, researchers refer to this zone as the hybrid layer of Nakabayashi [90].

During visiting lectures to the Pulp Biology Research Group & Operative faculty at the University of Michigan—Dr. Ostro, Chairman of Prosthodontics at McGill University in Montreal CAN speculated why Haggars commercial acrylic Sevriton Cavity Seal [91] was a swift clinical failure. The clinical problem became obvious soon after placement of Sevriton resin in the cavity—the chemical polarity of the carboxyl group of the acrylic easily permitted water uptake from the fluids of the oral cavity—like a dry sponge taking up water, in which it remained soft & spongy—resulting in the breaking & separation of polymeric acrylic chains that caused their eventual softening & loss of strength of the Sevriton acrylic. In retrospect, why hadn't those individuals that were dealing with the development of Severiton systems not have realized that shrinkage & microleakage would be a clinical & biological hurdle to its success, before it was introduced to the commercial marketplace for placement in patients.

In retrospect, research studies explain how Hagger's GPA adhesive system was successful to etch the smear layer, but its clinical shrinkage revealed why Sevriton acrylic restorations failed, due to the moist mouth environment that resulted in microleakage of fluids, bacteria & sensitivity to cold, which led to its clinical failure on the commercial marketplace. Although acrylic resin restorations originally caused excitement amongst North American dentists, Dr. Ostro said that many of his Canadian colleagues referred to Severiton as “shrink & stink—a clinical disaster” [92].

Whatever your view regarding who was the 1st to consider polymer-adhesion as a dental restorative, Drs. Buonocore, Gwinnett & Matsui at Rochester NY deserve acknowledgement for their modification of Dr. Oskar Hagger's (1949) adhesive patent information. The Rochester group substituted phosphoric acid as an enamel etchant to condition the enamel surface for sealants in primary teeth in-place of Dr. Hagger's glycerophosphoric acid (GPA) that Hagger had 1st suggested to place on vital dentine.

As we consider today's research & publication standards, we might consider that Hagger's 1949 GPA chemistry can be considered suitable as a 7th generation adhesive system by today's standards—well ahead of its 1949 patent. In the 1940's, the scientific odds were somewhat against Dr. Hagger's research efforts, since researchers at that time knew little to nothing about the smear debris layer, dentine physiology, fluid movement through the dentine tubule complex, thermal sensitivity due to the bidirectional fluid flow, collagen degradation, the hybrid layer & bond strength—let alone today's several mechanisms to test the shear bond testing of adhesives to dentine & enamel. Later, Buonocore & Quigley reconfirmed Hagger's earlier GPA data.

Dr. Hagger's research demonstrated that adhesive retention from acid etching of dentine & enamel was a scientific possibility. For a detailed history of adhesives, the interested colleague can spend some time to search the “web” to research the development of the many generations of dentine adhesives that have appeared on today's

international commercial marketplace. Dr. Karl Söderholm stated in 2007 that Dr. Oskar Hagger's research efforts to create a vital dentine adhesive system is recognized as one of the earliest chemists to focus his research towards the development of a dentine adhesive system for direct operative restorations [93].

The adhesive timeline & the hurdles to its success

At this point in our article, it is important to understand that there have been many generations of adhesive bonding systems since their emergence in the 1970's. The scope of discussing the decades of commercial systems is not within the length or scope of this article. Our future writing intentions are to develop a following detailed review article, which chronicles the many adhesive systems that began with total acid etching of the smear layer with phosphoric acid & priming & adhesive polymer bonding to today's 1-step adhesive polymer systems.

In his 1981 textbook, Professor Brännström wrote the following comments: “Seeing implies making ourselves free of prejudices, becoming aware of our being manipulated by old frames of reference, acquiring new ones through the collection of knowledge, giving truth priority over the way we would like things to be, interpreting imaginatively so that development forward becomes visible”.

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