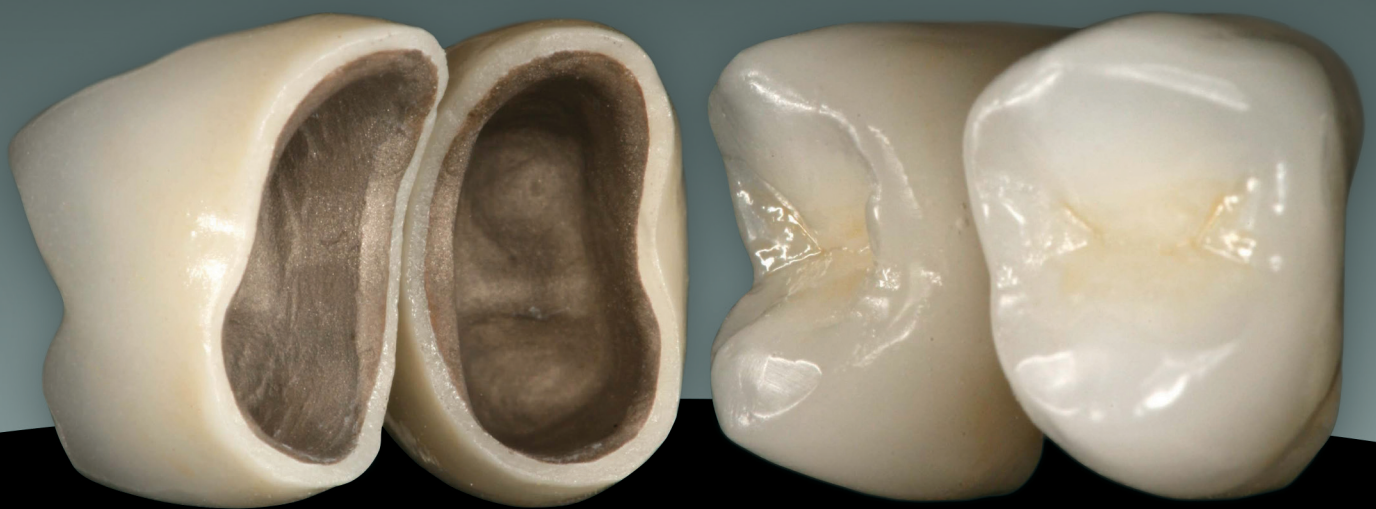


Introduction to
METAL-CERAMIC
TECHNOLOGY

W. Patrick Naylor, DDS, MPH, MS



Third Edition

Introduction to Metal-Ceramic Technology
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Introduction to
**METAL-CERAMIC
TECHNOLOGY**

Third Edition

W. Patrick Naylor, DDS, MPH, MS

Adjunct Professor of Restorative Dentistry

Loma Linda University School of Dentistry

Loma Linda, California

With contributions by

Charles J. Goodacre, DDS, MSD

Distinguished Professor of Restorative Dentistry

Loma Linda University School of Dentistry

Loma Linda, California

Satoshi Sakamoto, MDT

Master Dental Technician

Loma Linda University School of Dentistry

Loma Linda, California

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Dedications

To my dear wife, Penelope, for her skillful reviewing and patience over the many months devoted to the production of this third edition.

And to the memory of my mentor, teacher, and friend, Dr Ralph W. Phillips. As an expert of international renown, his contributions to dental materials science and dentistry in general are immeasurable.

This is a small tribute to a man who left an indelible mark on the dental profession.

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IN MEMORIAM



Arlo Harrison King, CDT

October 28, 1954–November 24, 2013

Arlo King, a dear friend and colleague, died in 2013 at the age of 59. He contributed to the first two editions of *Introduction to Metal-Ceramic Technology*, and his thoughts and suggestions were invaluable as this book evolved from concept to reality.

A true patriot, Arlo provided the United States Air Force (USAF) with more than 20 years of dedicated service. He was a tireless worker and, even when busy with his own commitments, made time to help others. Arlo shared his love of dentistry and dental technology with residents in the USAF Advanced Specialty Education Program in Prosthodontics in San Antonio, Texas. For many years, he mentored these future prosthodontists in the early phase of their education and training. Arlo was later selected to serve with the USAF Dental Investigation Service in San Antonio, where he applied his many talents in research for the benefit of dentists and dental laboratory technicians worldwide.

Following his military service, Arlo joined Dentsply and spent over 21 years with the company. There, his knowledge and expertise in dental technology were well recognized. He went on to become the Director of Technical Services for Dentsply Prosthetics, a position he held until his death.

Arlo was an outstanding teacher, researcher, and lecturer, and audiences across the globe were eager to learn from this soft-spoken but engaging expert. In 2008, he was recognized with the Excellence in Education award from the National Association of Dental Laboratories for his numerous contributions to the dental laboratory profession.

Arlo's impact on me, other USAF veterans, and the dental profession will not be forgotten by those who had the pleasure of knowing him.



PREFACE

Introduction to Metal-Ceramic Technology was first published 25 years ago, at a time when metal-ceramic restorations served as the foundation of fixed prosthodontics. In 2015, Ben-Gal et al¹ surveyed the 58 North American dental schools about the teaching and materials of fixed prosthodontics. Of the 36 institutions that responded, every one reported that metal-ceramic restorations were part of their teaching curriculum, whereas only a third were teaching ceramic-based crowns.¹ Dental schools have the unenviable responsibility and added challenge of balancing the teaching of established, evidence-based treatment modalities without neglecting new and evolving technology.

At the same time, a paradigm shift is underway as dental schools and technical programs strive to prepare their graduates for the eventual transition from an educational institution to that of actual clinical and laboratory practice settings, where the data indicate that usage of all-ceramic systems has steadily increased (see appendix A). And these learning institutions must pursue such an outcome without necessarily abandoning the predictability and longevity that is well documented for metal-ceramic technology.

Today more than ever, it is likely that newer generations of dentists and dental laboratory technicians are more familiar with the various all-ceramic systems than they are with the range of applications for a metal-ceramic restoration. The evolution, refinement, and expansion of all-ceramic products, coupled with the increased advertising focused on esthetics and cost, continue to influence the types of materials dentists recommend to their patients and dental laboratories must provide for their clients. Consequently, this third edition has been revised not only to update the original nine chapters but also to include a tenth chapter devoted to the porcelain-margin metal-ceramic restoration—a potential alternative to an all-ceramic crown or fixed partial denture.

As in the first two editions of this book, the extensive technical data on dental porcelains and metal-ceramic alloys remain so that this text can continue to serve as a reference for an array of dental products, materials, and instruments. Every chapter has been updated and revised, and the nature and extent of the major chapter changes and revisions for this third edition are described briefly as follows:

- Chapter 1. Additional details and new information have been added to the history of the metal-ceramic restoration.
- Chapter 2. The chemistry of dental porcelain and explanations of the contributions of key dental pioneers in the development of metal-ceramic technology have been expanded.
- Chapter 3. The most recent American Dental Association classification system for dental casting alloys is provided along with the expanded classification based on composition. Additional physical property data have been added to the descriptions of the elements generally found in dental casting alloys.
- Chapter 4. New illustrations are provided to aid in the creation of the proper dimensions and location of interproximal contact areas reproduced in metal or dental porcelain.
- Chapter 5. The terminology section has been updated with additional terms and expanded definitions. The explanation of the buttonless casting technique has been simplified to a four-step process.
- Chapter 6. Although the theories that explain the nature of the porcelain-metal interface remain the same, the explanations of how dental porcelain “attaches” to a metal substructure have been reexamined with a fresh analysis of our traditional reference to porcelain “bonding” mechanisms.
- Chapter 8. The porcelain application process is now easier to understand and follow, especially for individuals who are still learning these techniques.

- Chapter 10. Perhaps the single most significant enhancement is the addition of this final chapter focused on one topic—the metal-ceramic crown with a porcelain margin. This chapter was added for the benefit of dental students, dental technology students, recent dental graduates, and dental laboratory technicians, as well as dental educators and clinicians who recognize the longevity of metal-based restorations but may not have seen or be aware of actual patient outcomes illustrating the full esthetic potential of metal-ceramic technology. The goals of chapter 10 are to illustrate not only that the porcelain-margin metal-ceramic restoration is a viable treatment option but also how clinicians and laboratory technicians can partner, expand their armamentarium, and address the unique functional demands of each patient while meeting esthetic expectations. In the hands of skilled clinicians and ceramists, a metal-ceramic restoration with a porcelain margin can rival all-ceramic materials in terms of esthetics, functionality, predictability, and longevity. It is important to bear in mind that the appearance and the long-term success of a restoration is often influenced more by *how* a material is used rather than *which* material is selected. Therefore, the true challenge for chapter 10 is to illustrate how well-made porcelain-margin restorations can serve as alternatives to all-ceramic restorations and how metal-ceramic technology remains relevant today.

The cited materials for the entire book have been reviewed, not only to confirm existing content but also to determine if other information might be of value to include in this revision. Relevant new articles have been identified, and research pertinent to the topics in each chapter has been added. Because providing evidence-based information for the topics under discussion is a priority, readers will be able to identify the source publications for important content cited in each chapter. Therefore, readers are encouraged to review the provided reference materials as well as to access the annotated reference lists online to expand their knowledge of the subjects and findings mentioned in this text.

Acknowledgments

I wish to thank Dr Charles J. Goodacre for preparing the new graphics in chapter 4 and sharing photographs of his clinical cases on the cover of the book and in chapters 1 and 10. Additional thanks also go to Satoshi Sakamoto, whose skills as a dental ceramist are highlighted in those laboratory and clinical photographs. The before and after photographs of patients treated by the team of Dr Goodacre and Mr Sakamoto provide evidence of the potential to achieve function, longevity, and esthetics with existing metal-ceramic technology.

Additional thanks are extended to Sam Sadanala, whose artistic talents are reflected in the new illustrations created for chapter 10.

Finally, I would be remiss if I did not acknowledge the leadership and staff of Quintessence Publishing for allowing me to update this book and for providing editorial and graphic support throughout the publication process. In particular, I wish to thank several individuals: Bryn Grisham for her painstaking editing and numerous suggestions, Erica Neumann for her wonderful cover design, and Kaye Clemens for the internal layout for this third edition.

Reference

1. Ben-Gal G, Herskowitz HD, Beyth N, Weiss EI. Teaching new materials and techniques for fixed dental prostheses in dental schools in the United States and Canada: A survey. *J Prosthodont* 2015;24:598–601.

History and Overview

One of the more interesting facets in the annals of dental technology is how the centuries-old artistry of making porcelain evolved into processes that continue to revolutionize modern-day dentistry. The creation of porcelain works of art and fine china were stepping stones in a journey that literally took thousands of years before a few pioneers envisioned potential dental uses for these simple ceramic materials. In fact, it was not until the 19th century that applications for porcelain in dentistry were created in what would eventually emerge as metal-ceramic technology.

From the late 1800s until today, the pace of change has been extraordinary, thanks in large part to the continued introduction of new products and techniques. You need only examine the origin of dental porcelain to gain an appreciation of just how far ceramic technology has come. At the same time, it is important to recognize the contributions of nations, cultures, and select individuals responsible for the advancements now enjoyed by patients, dental laboratory technicians, and clinicians the world over.

From Earthenware to Stoneware to Porcelain

In his historical account of the development and evolution of dental ceramics, Jones¹ described the role of Chinese artisans in transforming crude fired clay objects into delicate and functional pieces of transparent porcelain. The earliest traces of the origins of ceramics were porous fragments of mud and clay fired at low temperature. These rudimentary products, described as *earthenware*, were estimated to date back to approximately 23,000 BC.¹ Firing in primitive kilns at temperatures up to 900°C only allowed the clay particles to fuse at points of contact, which yielded

a rather porous final result.² And while functional, earthenware items were found to have significant physical limitations. For example, they were not ideally suited for holding and storing liquids because of their porous structure.

Thousands of years later, around 100 BC, the Chinese discovered how to produce more refined ceramic pieces. This next generation of fired objects, referred to as *stoneware*, was not only stronger than earthenware, but the pieces produced were impervious to water due to improvements in the sintering process.^{1,2} Such an advancement in manufacturing was achieved by firing stoneware at temperatures *higher* than those used to produce earthenware. This significant change to the sintering process resulted in glass formation with sealing of the ceramic surface.²

Anyone who has ever attempted to chronicle the history of ceramics knows that the Chinese also are credited with the subsequent development of porcelain as early as 1000 AD.¹ So refined was this “China stone” or “China ware” that strong, functional, and transparent containers were crafted with walls only a few millimeters thick.¹ Even to this day the terms *china* and *porcelain* are used interchangeably when referring to high-quality ceramic items.

Key European Contributors

Despite repeated attempts, European artisans were unsuccessful in their efforts to unravel the secrets of Chinese ceramic technology. In fact, the best that German researchers could do was to produce materials akin to Chinese stoneware. While this outcome was an improvement over porous and crude earthenware, these early European ceramic products reportedly failed to approach the quality, strength, and translucency of fine oriental porcelains.

Father Francis Xavier d'Entrecolles

In what Jones described as “an early example of industrial espionage,” Francis Xavier d'Entrecolles, a Jesuit priest, ingratiated himself with Chinese potters sometime around 1717 in order to learn the porcelain manufacturing process.¹ Father d'Entrecolles lived in what was considered China's porcelain center, a city named King-te-tching. It was in this industrial region of the Kiangsi Province where he was able not only to obtain Chinese porcelain products but also to acquire essential descriptions of the Chinese manufacturing methods of the day.² With the help of French scientist Réne-Antoine Ferchault de Réaumur, the composition of Chinese porcelain was found to consist of approximately 50% clay (hydrated aluminum silicate, or *kaolin*), 25% to 30% feldspar (sodium aluminum silicate, or *soda*, and potassium aluminum silicate, or *potash*), and 20% to 25% quartz (silica).² Within a few years, Europeans also began producing fine translucent porcelains of their own.³ Yet despite d'Entrecolles' achievements, ceramics were not immediately recognized as a material of potential value to dentistry in the early 18th century. But in less than 60 years, that would change.

Alexis Duchâteau and Nicolas Dubois de Chémant

There is evidence in the late 18th century to indicate that an edentulous French apothecary by the name of Alexis Duchâteau was troubled by stained and odiferous dentures with teeth made from Walrus ivory,⁴ a condition probably not uncommon among the general population of that time.¹ Armed with his skills as an apothecary, Duchâteau attempted to make a set of porcelain dentures for himself. Much to his dismay, those initial efforts were less than successful.⁵ It was not until he teamed up with Parisian dentist Nicolas Dubois de Chémant around 1774 that the two were finally able to construct complete dentures from a material they referred to as “mineral paste.”³⁻⁵ Satisfied with the improved fit of his new dentures, Duchâteau returned to his apothecary shop. But Dubois de Chémant became intrigued by his experimentation and went on to reformulate the original mineral paste. He focused his efforts on enhancing the color, increasing the dimensional stability, and improving the attachment of the “mineral teeth” (ie, porcelain teeth) to the denture base.⁶

Dubois de Chémant eventually patented his porcelain formulation and in 1788 published a pamphlet on his work. Yet it was not until 1797 that his more definitive text, *A Dissertation on Artificial Teeth*, appeared in print. Dubois de Chémant's “mineral paste dentures” came to be known as “incorruptible teeth” or more simply as “incorruptibles.”^{5,7} Dubois de Chémant's porcelain formulation was said to have enabled denture wearers to have “clean and hygienic dentures,”⁷ but, not everyone hailed Dubois de Chémant's decision to patent the porcelain paste. It was said that some of his contemporaries regarded his actions as nothing more than the theft of Duchâteau's original invention.¹

Pierre Fauchard—The father of modern dentistry

As it turns out, the work of Duchâteau and Dubois de Chémant may have been preceded by another French dentist, Pierre Fauchard, who is generally recognized as the father of modern dentistry.¹ Evidently, Fauchard and others reported using what they referred to as “baked enamel” prior to 1760, perhaps as early as the 1720s.¹ Fauchard's writings described the use of porcelain for the construction of dentures in 1723, but 5 years passed before he actually published his philosophy on dentistry in a 1728 book entitled *Le Chirurgien dentiste, ou, Traité des dents (The Surgeon Dentist, or, Treatise on the Teeth)*.⁵ Then in 1746, some 18 years later, Fauchard released an expanded second edition of his book. His two-volume work was 863 pages in length and contained additional subject matter and improved illustrations. According to Ring,⁵ Fauchard's writings and philosophy influenced dentistry well into the next century.

Giusseppangelo Fonzi

Another notable advancement occurred around 1806 when Italian dentist Giusseppangelo Fonzi is said to have devised a method to mass produce individual porcelain denture teeth. He also is credited with devising a technique for placing platinum pins in the back of the porcelain teeth, so the pins could be soldered to a metal denture base.^{1,3} However, Fonzi did not publicize this achievement until 1808.¹ His individualized porcelain teeth were referred to as “terro-metallic incorruptibles”³ or “terrometallic teeth.”¹

Claudius Ash

In 1837, English goldsmith Claudius Ash is reported to have begun manufacturing fine porcelain denture teeth.⁵ Ash later created an artificial tooth that could be secured over a metal post in either a complete denture or a fixed partial denture. The “tube tooth,” as it was called, went on to enjoy wide popularity in its day.

Arrival of Porcelain in America

Accounts describing the path taken by porcelain technology through Europe and across the Atlantic to the United States differ slightly among dental historians.^{1,5,8,9} Nonetheless, it is generally agreed that like their European counterparts, the American artisans' first use of porcelain in dentistry was also in the fabrication of complete dentures.

Antoine A. Plantou and Samuel W. Stockton

Credit is due to French dentist Antoine A. Plantou for introducing individual porcelain teeth to America in 1817.^{1,6} Yet, it was Philadelphia jeweler Samuel W. Stockton who envisioned the widespread potential of this application

in approximately 1830 and became the first American to mass-produce porcelain denture teeth in the United States.¹

Creation of Translucent Porcelain with Enhanced Color

Dr Elias Wildman

Even by the early 19th century, the porcelain used to fabricate complete dentures was seen as an opaque white material with the appearance of commercial ceramic products used in industry.¹⁰ But in 1838, American dentist and Philadelphia native Dr Elias Wildman revamped the formula for dental porcelain, which brought improvements in translucency and produced tooth colors “similar to natural teeth.”^{3,11}

Dentists Supply Company and vacuum firing

It took more than 100 years to achieve the next major milestone. In 1949, the Dentists Supply Company (now Dentsply Sirona) developed porcelain denture teeth that were dense, porosity-free, and translucent; all these welcomed changes were attributed to their use of vacuum firing during the sintering process.^{3,11,12}

Evolution of Modern Applications

Looking back, the road from porcelain dentures and denture teeth to the contemporary metal-ceramic restoration was also a long and winding journey, often littered with disappointments and outright failures. Historical accounts have singled out and credited several key individuals with achieving additional technologic milestones. This evolutionary process reflected the combined talents of many inquiring minds and very determined researchers.^{1,5,10,13–17} It is not possible to identify all those responsible for the development of metal-ceramic restorations and pay tribute to their individual contributions. Nonetheless, it is important to highlight the achievements of a select few early pioneers and mention some of the significant articles they published in leading scientific journals of their time.

Contribution of Dr B. D. Wood

According to an article by Capon, entitled “Enameling Plugs and Restoring the Contour of Defective Teeth by the Application of Enamelled Caps,” Dr B. D. Wood is reported to have “presented an article” in 1862 that described a technique for “enameling of a metallic cap for badly broken down teeth.”¹⁷ Capon acknowledged that Wood did not provide any details of his technique, and there was no mention of where Wood made this presentation or if his article was ever published.¹⁷ Nonetheless, Capon was of the opin-

ion that Wood’s work should be recognized as “practically the basis of our porcelain jacket of today.”¹⁷

In the nearly five decades that followed Wildman’s improved formulation, dental porcelain remained a material for use primarily in complete denture prosthodontics.¹⁰ That situation eventually changed, and dental porcelain entered the realm of restorative dentistry thanks, in large part, to the creative mind of a single individual—Detroit dentist Dr Charles H. Land.^{1,5,13,14}

Contributions of Dr Charles H. Land

The idea of fusing porcelain to a thin platinum foil matrix is credited to Land, who reportedly patented the process sometime between 1886 and 1888.^{1,5,13,14} Around this same period, Land also published articles in the dental literature describing a technique for fitting what he referred to as “enamel fronts” to prepared teeth.¹⁵ These prefabricated porcelain “fronts,” or *facings*, were ground to fit a 30-gauge platinum foil matrix adapted to prepared teeth. Land also described using a low-fusing porcelain he developed to make restorations for a maxillary anterior tooth for which a porcelain facing was attached to the “prepared base” of a platinum and iridium alloy (Fig 1-1).^{15,16} The facings were then fused to the foil matrix with body porcelain in a “Land’s Gas Furnace.”¹⁵ The resulting restoration, composed of a platinum foil and porcelain facing, was described by Land as an “enameled metallic coating” or “metallic enamel coating.” Shortly after the turn of the 20th century, Land published another article in which he again referred to different types of restorations: “enameled metallic caps” and “enameled caps or jacket crowns.”¹³

Capon acknowledged that Land’s method of burnishing platinum foil to prepared teeth and using the adapted foil as a substrate onto which dental porcelain was fused in a gas furnace was entirely different from any techniques recognized up to that time.¹⁷ It also is necessary to point out that although the designations “enameled metallic caps” and “enameled caps” appear similar, the restorations themselves apparently were quite different.

Enamelled metallic caps: Early metal-ceramic crowns

Unlike porcelain facings ground to fit a foil matrix of pure platinum, *enameled metallic caps* consisted of a metal substructure fabricated from an *alloy* of platinum and iridium. Land actually veneered these platinum-iridium substructures with a low-fusing porcelain he developed.¹³ The porcelain would be placed on one of these substructures, built up (ie, stacked), fired (ie, sintered), and once cooled, shaped to final contour (see Fig 1-1a). Re-creations of the drawings Land published in 1886 (with color added) actually resemble the designs of modern-day metal-ceramic restorations (see Fig 1-1b)

Perhaps what is most important to note is that when Land used the word *metallic* in a name, as in *enameled metallic cap*, he was describing a primitive metal-ceramic restoration. But Land is said to have had a great deal of difficulty with his low-fusing porcelain.¹ According to Jones,¹

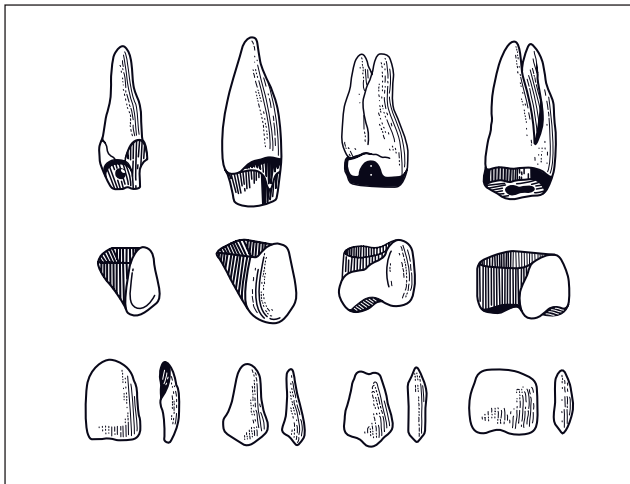


Fig 1-1a This is a rendition of the drawings that originally appeared in one of Land's 1886 articles.¹⁵ Note the use of facings (what Land referred to as "fronts") on platinum foil, much like contemporary cast metal-ceramic substructures.

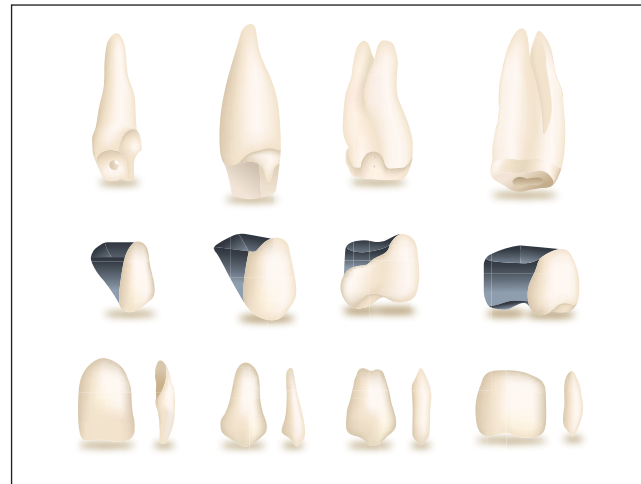


Fig 1-1b Land's restorations as shown in Fig 1-1a have been colored by the author in an attempt to portray what the ceramic veneers may have looked like in their day.

the high levels of borax and pulverized glass reportedly rendered Land's fired ceramic restorations susceptible to breakdown in the oral cavity.¹

Enameled caps: Early porcelain jacket crowns

The enameled caps Land mentioned actually referred to all-porcelain jacket crowns. These restorations relied on a platinum-foil matrix simply to provide a foundation on which to place dental porcelain during the fabrication process. In other words, the porcelain was applied to the platinum matrix, shaped to the desired contours, and then sintered. Once the porcelain portion of the restoration had been built to final form, the foil matrix was removed, leaving what Land described as a "complete coat of artificial enamel."¹³ In other words, the final restoration produced with this technique was nothing more than a "hollow veneer or shell" of dental porcelain, intended to replicate a natural tooth. So the designation *enameled cap* appeared to be Land's way of describing an all-porcelain restoration replacing the natural enamel (ie, coronal) structure of a tooth.

Land portrayed this treatment approach to the dental profession and his fellow clinicians as a way to offer patients a "much better artistic effect" coupled with "the preservation of a large amount of tooth structure."^{15,18} This same technique served as the basis for the platinum foil-porcelain, pin-retained inlays he also advocated in lieu of large metallic intracoronal restorations.^{13,14,16}

In addition to seeking improved esthetics, Land had a remarkable appreciation for the differences in thermal conductivity between metal restorations and "metallic coatings." Perhaps of even greater importance was that Land understood the clinical implications of these differences.¹⁶ For example, in 1886 he wrote that vital teeth with large, all-metal restorations were found to undergo greater thermocycling (ie, alternating hot and cold changes) than were teeth with his metallic coating restorations. Land let it be known that such temperature fluctuations potentially

could be harmful to healthy pulpal tissues. He also noted that nonvital teeth with large metal restorations were more prone to root fracture.¹⁶ Land's published observations even extended to an appreciation of the periodontal health of teeth when he stated that "inflammation of the membrane"—likely a reference to the periodontal ligament—can occur and lead to tooth loss.¹⁶ Land published a subsequent report as part of his continuing effort to bring what he described as "this new mode of practice to the notice of the dental profession."¹⁹

By promoting the use of enamel coatings for complete crowns in addition to partial veneer restorations, Land effectively became a strident advocate of conservative dentistry. His writings could be interpreted as a plea to the dental profession to preserve as much healthy tooth structure as possible, appreciate the importance of maintaining pulpal health, and then design and fabricate porcelain restorations for complete or partial coverage. As far back as 1887, Land is quoted as stating, "in nearly all the modern systems of crown-work there seems to be too much good tooth material cut away, and I think a careful investigation will demonstrate this new process to be far superior, making it possible to save the greater portion of the crown, it not being necessary to cut beneath the gum."¹⁹ In that same paper, Land not only promoted his new porcelain process, but he also offered the unrestricted use of his patented discovery to advance the dental profession.

A few years later in an 1889 presentation before the First District Dental Society of the State of New York, Land reportedly stated that he had been restoring teeth with porcelain for 5 years and shared his findings with this group.¹⁸ Again, instead of removing the entire clinical crown, he advocated for retaining coronal tooth structure when restoring teeth with restorations made by fusing porcelain to metal. Land felt this approach to treatment was especially valuable when restoring teeth in children. It is noteworthy that these early writings not only reflected an astute awareness of esthetics and dental materials science (eg, the potential

damaging effects of thermal changes on vital and nonvital teeth) but also raised awareness of the importance of conservative tooth preparation along with the need to maintain periodontal health. Land went on to publish other articles in which he reported that the enameled caps he placed in his patients had survived clinically for 8, 10, and 12 years.¹³

The “father of porcelain dental art”

Nearly two decades after Land described his enameled metallic caps, another Detroit dentist, Dr Edward D. Spalding, reported that there were two prevailing techniques at that time to replace human enamel: (1) bake porcelain on a platinum foil matrix (0.001 inch thick), remove the foil, and cement the porcelain restoration to the tooth; and (2) grind a “vulcanite tooth” (ie, denture tooth) to create a facing (or veneer) that was then baked to a platinum foil matrix with the aid of body porcelain.²⁰ Spalding clarified that the first technique was used for premolar and molar teeth, whereas the second method involving a facing was popular when restoring incisors and canines. Clearly, Land’s plea to the dental profession to use enameled metallic coatings was heard and had gained popularity.

Then in 1905, Canadian dentist Dr H. Zeigler published a tribute to Land in which he characterized Land as the “father of porcelain dental art.”²¹ He noted that “Dr Land has not only outgrown, but outrivalled any other claims as to the origination of porcelain art.”²¹

While Land’s discoveries and technical procedures were precursors to the development of the modern-day porcelain jacket crown, he stood largely alone in his day as the one individual who guided the dental profession toward wider applications for porcelain, preservation of tooth structure, improved esthetics, and the need to protect and preserve periodontal tissue.

Recognizing limitations

Land’s discoveries and technical procedures involving enameled caps clearly foreshadowed the modern-day porcelain jacket crown. But his promotion of enameled metallic caps was a frank acknowledgment of the need for a restoration with a metallic foundation veneered with dental porcelain. As early as 1886, Land described the use of a “platinum overcoat” to cover prepared anterior and posterior teeth that received porcelain facings (see Fig 1-1).¹⁵ Land detailed how he mechanically fitted a piece of thin, 30-gauge “platinum plate” to a prepared tooth to create what he described as a “hollow shell.”¹⁵

Interestingly, it was apparent that Land also held an appreciation for the limitations of a platinum foil matrix as evidenced by his understanding that dental porcelain would not bond to a high noble metal. Later in 1903, he stated this fact quite clearly when he wrote, “we must realize that a vitreous mass, like all our porcelain bodies, does not strongly adhere to nonoxidizable metals and will readily peel off.”¹³ Despite this inherent limitation with the technique, in his private practice Land continued to fabricate the restorations described and illustrated in his publications. His drawings depicted crowns that combined a metal foundation with

a porcelain facing as well as posterior restorations with a porcelain occlusal surface (see Fig 1-1).^{13,15,16} Land even referred to patient situations in which he treated both anterior and posterior teeth with crowns using these different designs.

Clearly, Land’s achievements and contributions laid the groundwork for the eventual development of methods to bond porcelain to metal. But what may be even more remarkable about Land’s work is what is captured in the illustrations of the rudimentary metal and porcelain restorations he placed in the late 1800s (see Fig 1-1b). Note how the metal foundations of those restorations are strikingly similar to the designs of metal-ceramic substructures fabricated today. As a result, Land’s metal and porcelain crowns should be considered precursors to the modern-day metal-ceramic restoration—a fact not generally recognized.

It remains for dental historians to determine if credit for development of the porcelain jacket crown remains with Land or if sufficient evidence exists for that honor to be shared by Land and Wood. But with respect to the early development of metal-ceramic technology, Land was a pioneer who clearly led the way. He wrote about his technologic advancements, described his use of various types of porcelain restorations over many years, and acknowledged the challenges he encountered in his clinical practice. Land’s achievements and experiences are sufficiently well documented in the dental literature to leave no doubt as to the significance of his many contributions to porcelain art as well as conservative dentistry in general.

Evolution of the Metal-Ceramic Restoration

After numerous refinements of the early formulations of low-fusing dental porcelain and countless trials and tribulations over many decades, improvements to the metal-ceramic restoration eventually emerged. However, it was not until the mid-1950s that reports appeared in the literature revealing the successful pairing of porcelain to gold for fixed restorations.^{22,23}

Foremost among the 20th-century publications on metal-ceramic technology was Dr S. Charles Brecker’s 1956 article, “*Porcelain Baked to Gold—A New Medium in Prosthodontics.*”²² Published in the *Journal of Prosthetic Dentistry*, this single article by Brecker has likely been more widely read than any of the reports by Land that appeared in respected 19th century journals, such as the *Independent Practitioner* and *Dental Cosmos*. However, even today, not everyone is aware that Brecker merits recognition for the role he played in the evolution of contemporary metal-ceramic technology.

Contributions of Dr S. Charles Brecker

Brecker’s landmark article remains one of the most widely referenced publications on the emergence of a “new medium in prosthodontics” which is what we now refer to as a *metal-ceramic restoration*.²² But in his 1956 publication, Brecker described the process as “porcelain baked

to a gold” alloy to create a “porcelain-fused-to-gold” restoration or what he also referred to as a porcelain-fused-to-metal restoration.²² These different designations may have been warranted because Brecker considered there to be three types of porcelain-fused-to-metal crowns in use at the time. There were restorations with dental porcelain fired to: (1) an iridium-platinum alloy, (2) a palladium alloy, and (3) a gold alloy. All three of these suggested substructure alloys are based on a noble metal (refer to chapter 3 for more information on alloys for dental casting).²² It is important to point out that in the ensuing years, the term *porcelain-fused-to-metal (PFM) restoration* emerged to describe the pairing of metal and dental porcelain. In fact, the term *PFM crown* remains deeply embedded in the terminology of dental technology as opposed to the more contemporary term, *metal-ceramic restoration*.

Of these three alloys used by Brecker, he contended that a gold-alloy restoration provided a superior foundation for porcelain compared with either an iridium-platinum alloy or a palladium-alloy alternative. Yet Becker recognized that porcelain would not fuse to a nonoxidizable noble metal like gold, so he resorted to the use of a metal bonding agent of red cadmium compound—what he described as a “refractory wetting agent”—to chemically bond dental porcelain to the metal foundation.

The fabrication technique described in Brecker’s article differed from Land’s methodology in that Brecker actually cast a gold “crown or thimble” to a 0.001-inch platinum matrix burnished to a die. On the other hand, Land mechanically adapted the foil to the prepared tooth. And with the Brecker technique, the platinum foil–gold substructure also had to be returned to the prepared tooth for adjustments to ensure a proper fit. Brecker described that desired fit as being one that allowed the substructure to “slip on and off with strong finger pressure,” or what today might be described as a *nonbinding* or a *passive* fit. Once back in the dental laboratory, the casting was cleaned with water and dried in a porcelain furnace to rid the surface of any contaminants. Then a bonding agent was mixed with water, applied, placed in a furnace, and heated to 982°C (1,800°F).

Next, opaque porcelain was applied to the metal in two separate, thin applications, reportedly with each layer able to bond to the treated substructure to mask the color of the underlying metal foundation. With the Brecker technique, the first layer of opaque was fired to 982°C (1,800°F), and the second opaque application was heated to 872°C (1,602°F). Body porcelain was applied, shaped, and “carved with fine knives or small spatulas” to achieve the desired tooth form.²²

The porcelain buildup was dried slowly to drive off excess liquid, after which the restoration was fired to 982°C (1,800°F), resulting in what Brecker described as “the biscuit bake.”²² After each firing was completed, Brecker cautioned readers to “cool the biscuit bake slowly,” a technique still recommended today. The porcelain application and firing processes were repeated with the second bake heated to a slightly lower high-temperature setting, 968°C (1,774°F).

In his 1956 article, Brecker stated that the ceramic he used was a medium-fusing porcelain, and he described the shrinkage of the ceramic as “minimal” and “not noticeable.”²² Once cooled, the porcelain was adjusted, and additional firings, if needed, were carried out at reduced high-temperature settings until the desired contours of the restoration were achieved. Following any final contour reshaping, a clear glaze was applied to the external surface of the porcelain and sintered to 954°C (1,749°F).²² It is important to point out that even by traditional methods for classifying dental porcelain, ceramics would have to have a fusing temperature in the 1,093°C to 1,260°C (2,000°F to 2,300°F) range to be classified as *medium-fusing porcelains*.²⁴ So the veneer porcelain Brecker used was likely a low-fusing dental porcelain and not a true medium-fusing porcelain (see Table 2-2). Using contemporary product descriptions and dental porcelain classifications systems can be confusing. It is quite likely Brecker was working with a dental porcelain that had to be sintered in the upper fusion-temperature range (ie, high fusing) for modern-day low-fusing porcelains (see Tables 2-2 and 2-3).

When introduced to the dental profession, this porcelain-fused-to-gold restoration was deemed new and destined to replace the “acrylic-faced gold crown” so popular at that time.²² Brecker also suggested using a porcelain-fused-to-gold restoration when a patient’s occlusion would not permit the placement of a porcelain jacket crown. Sensitive to the need for esthetics, Brecker illustrated a case where a porcelain-fused-to-gold restoration with a facial porcelain veneer was fabricated without displaying a facial metal collar. To achieve this more esthetic result, he adapted the platinum foil over the facial margin of the die, making it possible to “butt the porcelain against the bared shoulder like a porcelain jacket crown.”²²

Brecker did acknowledge that the combination of platinum with 10% iridium “added for stiffness” was an alloy combination used in dentistry for some time.²² That statement is consistent with Land’s mention of the use of a “telescope cap of platinum and iridium” in 1903.¹³ But the early platinum-iridium and palladium alloys mentioned by Brecker were difficult to cast, and the resultant substructures reportedly left much to be desired in terms of fit.¹ Such outcomes may help to explain why Brecker preferred a gold-based metal-ceramic alloy.

Remarkably, the technical descriptions and terminology used by Brecker remain largely a part of modern-day metal-ceramic technology. For example, opaque porcelain is still applied in a similar manner (two applications); a porcelain buildup is slowly heated (to drive off moisture); sintered porcelain is slowly cooled (to prevent crack formation and crack propagation); and the high temperature setting is reduced for each subsequent porcelain firing cycle to avoid overheating and loss of form. Even the fired but unglazed porcelain, described as a *bisque bake*, is akin to Brecker’s “biscuit bake.”²²

Table 1-1 Factors affecting esthetics in prosthodontics

Type of treatment	Level of control	Comments
Complete denture prosthodontics		
Tooth form (mold)	Maximum	Wide selection
Tooth color (shade)	Maximum	Wide selection; can mix shades
Gingival form	Maximum	Can create natural contours; can modify at try-in
Gingival characterization	Maximum	Can characterize (stain) denture base acrylic resin either internally or externally
Dental materials	Maximum	Many types of denture base acrylic resins
Removable partial denture prosthodontics		
Patient expectations	Reduced	A priority
Prosthesis design	Reduced	Balanced with esthetic requirements
Dental materials	Reduced	Important to select most appropriate materials
Fixed prosthodontics		
Patient requirements	Limited	Treatment options driven by patient needs
Controllable factors	Limited	Clinical requirements dictate selection of shade, outline form, surface texture, size, occlusal plane, and tooth position
Dental materials	Limited	Select materials best suited for each patient situation

Metal-ceramic restorations in contemporary dentistry

It was some 130 years ago that Land wrote of his use of a metal foil matrix as the foundation for porcelain. More than 60 years have passed since Brecker published his frequently quoted article describing the possibility of porcelain fused to metal and the creation of a porcelain-fused-to-gold restoration involving a cast metal substructure.^{15,16,22} From 1956 to 1962, improvements were made in ceramic materials and the technical procedures required to produce a porcelain-fused-to-gold restoration.¹ Largely, the development of gold alloys and compatible porcelains resulted in the harmonious relationship of a veneering material (ie, dental porcelain) on a rigid metallic foundation cast in a high noble or noble alloy that was not only ductile but strong and tough. By 1962, L.K. Weinstein, S. Katz, and A.B. Weinstein patented an improved porcelain system for gold-based alloys, followed by a second patent by A.B. Weinstein and L.K. Weinstein in that same year.^{25,26}

It may have required centuries to introduce porcelain to dentistry, but it took mere decades to transform a rudimentary metal-ceramic restoration into what it is today.²⁷⁻²⁹ The dental marketplace is inundated with a variety of dental porcelains and an array of ceramic casting alloys with a wide range of compositions and costs. Appreciating subtle differences in handling characteristics among the various porcelains as well as the different types of ceramic alloys is no simple task. In fact, dental-alloy formulations vary so widely that classifying them has become quite complex (see chapter 3). Likewise, success in contemporary dental technology requires both a refinement of artistic skills and an understanding of biomaterials science. Clinicians and dental laboratory technicians have an even greater array of materials and systems from which to choose for complete crowns, fixed partial dentures, and implant-supported

restorations. Nonetheless, lifelike restorations can be produced with metal-ceramic technology when dental art, science, and biomaterials are fully understood and skillfully combined (see chapter 10).

Art and Science of Dental Technology

Dental technology, like clinical dentistry, has evolved from the image of a trade or craft to a profession with its own unique demands and challenges. Those who excel in this field do so because of an ability to understand the theoretical aspects of dental technology and to acquire the visual acuity and manual dexterity required to apply these theories in practice. Such individuals not only master the technical procedures that are now a part of dental care but also develop an understanding of the materials science and fabrication techniques they use routinely. Highly skilled dental ceramists are able to transform simple ceramic powders into lifelike restorations that mirror natural teeth in every physical sense; in many instances, metal-ceramic materials rival newer all-ceramic systems. Such talent is acquired over many years thanks to dedicated training, practice, experimentation, and life-long learning.

Esthetics with complete denture prosthodontics

For a better understanding of how art and science are intertwined in dental technology, consider the important issue of esthetics. In complete denture prosthodontics, the dentist and dental laboratory technician generally have maximum control over the techniques required to produce lifelike prostheses (Table 1-1).



Fig 1-2 (a) Complete maxillary and mandibular wax trial dentures with denture teeth of an appropriate mold (ie, size and shape) and shade. (b) Note how the high value of the pink baseplate wax strongly suggests the need for custom characterization of the denture base resin so the dentures are less obvious. (c) The appearance of the definitive maxillary and mandibular complete dentures, following custom characterization of the denture base resin, illustrates the possibility of maximum control over materials and techniques.



Fig 1-3 (a) These maxillary and mandibular complete dentures have short, severely worn acrylic resin denture teeth and a poor occlusal relationship. (b) The dentures were remade in the correct occlusal relationship with new teeth and properly contoured denture bases. (c) The postoperative appearance of the patient with definitive prostheses looks more natural. Compare with Fig 1-3a to see the appearance before and after treatment.

When replacing existing complete dentures, clinicians and technicians generally have some latitude with tooth shade and mold selection as well as the positioning of teeth because they are restoring an entire dentition (Fig 1-2). In these patient situations, the denture base acrylic resin can be shaped to replicate actual gingival contours and even characterized with a custom blend of hues and color patterns to recreate a realistic appearance in harmony with the patients' actual gingival tissues. After all, the entire dentition is being replaced. Sometimes, patients want their new dentures to be similar to their existing prostheses, so their outward appearance is not dramatically different or noticeable to the casual observer.

At other times, change is warranted because the existing dentures are ill-fitting and their overall appearance

leaves much to be desired (Fig 1-3). In these situations, the dentures must be remade but not replicated. Here too, clinicians can select the denture teeth shade and shape, and the acrylic resin denture base can be shaped to replicate actual gingival contours (see Figs 1-3b and 1-3c).

Esthetics with removable partial prosthodontics

The same techniques required to produce natural-appearing complete dentures also can be applied in removable partial prosthodontics. When providing patients with a removable partial denture (RPD) to restore only a portion of the natural dentition, the clinician and laboratory technician have



Fig 1-4a Preoperative appearance of a patient missing the maxillary right canine and lateral incisor.



Fig 1-4b Postoperative appearance of the same patient with a characterized transitional partial denture replacing the maxillary right canine and lateral incisor.



Fig 1-5a The mandibular bilateral distal removable partial denture (Kennedy Class I) was designed to minimize the display of the metal retentive clasps by using infrabulge clasps. Denture teeth had to be selected of an appropriate shade and mold to blend with the surrounding natural teeth.



Fig 1-5b Lateral view of the same patient illustrating how the removable partial denture was carefully designed and constructed for esthetic requirements.



Fig 1-6a Preoperative view of a patient with a maxillary complete denture opposing a mandibular RPD.



Fig 1-6b Postoperative view of the same patient showing a new maxillary complete denture and RPD with characterization of both prostheses. New tooth molds were chosen (with a new size and shape), and the orientation of the occlusal plane was corrected. Infrabulge, rather than suprabulge, clasps were used for the mandibular RPD.

reduced control in the fabrication process due to increased patient demands and the need to balance proper prosthesis design with the esthetic requirements of each individual (see Table 1-1). A patient's remaining natural teeth and gingival tissues dictate features such as tooth length, width, and shade as well as the color and appearance of the denture base material. As a result, compromises are more common because of the reduction in controllable factors, be they in the design of the prosthesis or the selection of materials. The different patient situations depicted in Figs 1-4 to 1-6 illustrate the functional and esthetic challenges faced by clinicians and laboratory technicians when treatment planning RPDs.

Replacing only a portion of the natural dentition with an RPD is more challenging than providing a complete denture because the selected tooth shade and mold must

blend with the surrounding natural dentition, as seen in Fig 1-4b. In other cases, denture tooth shade is important, but there are the added challenges of transitioning the appearance of the denture base resin with the surrounding soft tissue and minimizing the display of the retentive clasps when attachments are not being used (see Fig 1-5).

Even when replacing an existing RPD opposed by a complete denture, the level of control is also reduced, but the treatment options are more manageable if both prostheses are to be replaced (see Fig 1-6). Again, the remaining natural dentition guides tooth shade and mold, just as healthy gingival tissues should guide denture base shade, contours, and characterization. After all, the goal for the two new prostheses is not only to restore function but also to enhance the patient's appearance.