Introduction to Metal-Ceramic Technology
Third Edition

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Introduction to METAL-CERAMIC TECHNOLOGY

Third Edition

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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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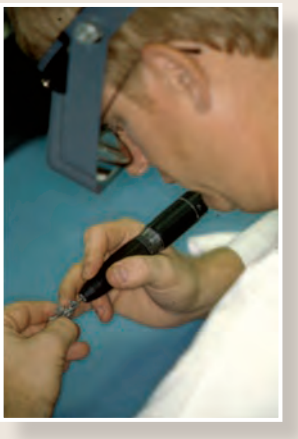
IN MEMORIAM

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

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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 al[1] 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.

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- 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.

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Chapter 1

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, Jones[1] 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.

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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

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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 Enameled 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 opinion that Wood's work should be recognized as "practi 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.

Enameled 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]

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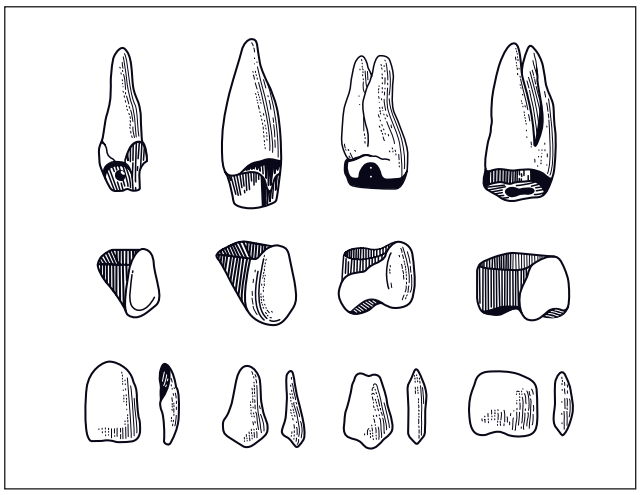

Fig 1-1a This is a rendition of the drawings that originally appeared in one of Land's 1886 articles.[15] Note the use of facings (what Land referred to as "fronts") on platinum foil, much like contemporary cast metal-ceramic substructures.

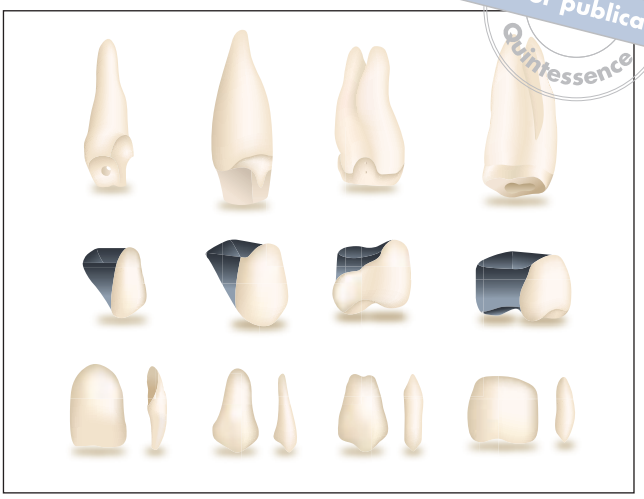

Fig 1-1b Land's restorations as shown in Fig 1-1a have been colorized by the author in an attempt to portray what the ceramic veneers may have looked like in their day.

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

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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 outrivaled 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 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

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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 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]

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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).

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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

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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.

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Fig 1-7a Facial view of a metal-ceramic crown with a porcelain labial margin on the maxillary left central incisor.

Fig 1-7b Lingual view of the metal-ceramic crown. It was designed to restore the lingual surface in metal yet retain interproximal porcelain. (Ceramics by Mr Larry Costin.)

Fig 1-8a Example of a metal-ceramic restoration with a highly visible and unesthetic facial metal margin before retreatment. (Courtesy of Dr Charles J. Goodacre and Mr Satoshi Sakamoto.)

Fig 1-8b Note the porcelain margin and healthy marginal tissue 2 years after retreatment. (Courtesy of Dr Charles J. Goodacre and Mr Satoshi Sakamoto.)

Esthetics with fixed prosthodontics

Fabricating one or two anterior crowns adjacent to unrestored natural teeth is an example of one of the most exacting professional challenges in fixed prosthodontics (Figs 1-7 and 1-8). By any measure, both clinician and technician have limited control of the variables involved in this type of patient situation (see Table 1-1). Patient requirements for esthetics, cost, and time dominate, while the number of factors under the control of either the dentist or dental laboratory technician are reduced significantly when compared to complete and partially edentulous patient situations.

The very choice of materials used to fabricate individual crowns imposes increased limitations from a purely technical standpoint. Therefore, determining the most appropriate restorative materials for each individual is critical. Careful consideration should be given to the selection of the type of restoration best suited for any given set of clinical variables. As will be discussed in chapter 10, all-ceramic crowns may not be advisable for all patients or every clinical situation. Despite their limitations, metal-ceramic restorations have been enormously successful for some time (Fig 1-9 and 1-10). What is remarkable is that most technicians fabricate metal-ceramic restorations without the benefit of seeing the patient for whom their work is intended. Dental laboratory technicians—who, by virtue of their training and experience, have mastered the technical skills needed to manipulate dental porcelain—are frequently identified as *ceramists* or *dental ceramists*. Designations such as these are bestowed with a mixture of reverence and envy because they set these individuals apart from their coworkers. What makes a skilled ceramist unique is an ability to transform dental porcelain materials into vital-looking restorations that replicate natural teeth using either all-ceramic or metal-ceramic technology. Chapter 10 includes laboratory and clinical examples of metal-ceramic restorations fabricated by ceramists to these exacting standards.

The common thread to the previously mentioned clinical cases (see Figs 1-2 to 1-8) is an ability to recreate the position, form, texture, and color of the surrounding oral tissues. Such outcomes reflect the artistic skills of the dental technician and dentist (ie, the *art* of dental technology). However, artistic talent alone is no guarantee of success and is best used when accompanied by a working knowledge of dental materials (ie, the *science* of dental technology). Blending the *art* and the *science* of metal-ceramic

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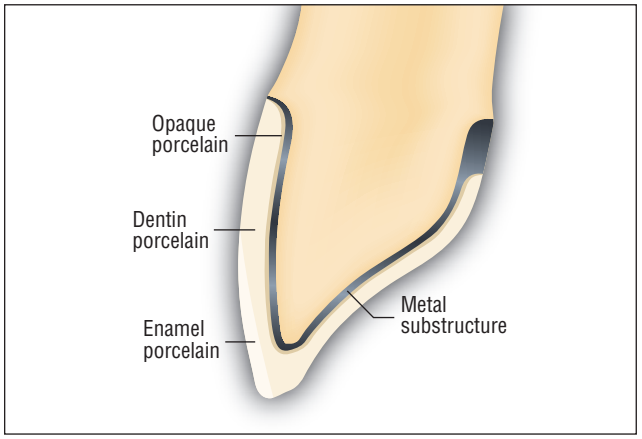

Fig 1-9a The components of a complete porcelain veneer metal-ceramic restoration include the metal substructure (often referred to as a *coping* for single-unit restorations), the oxide layer (present but not visible), the opaque layer, the dentin veneer, the enamel veneer, and the external glaze (present but not visible).

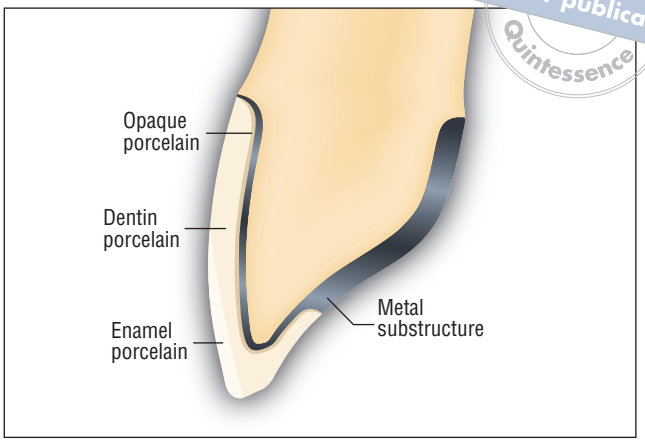

Fig 1-9b A partial porcelain veneer metal-ceramic crown consists of all the components of a complete porcelain veneer restoration but relies on more metal to restore the occluding surfaces (lingual/occlusal).

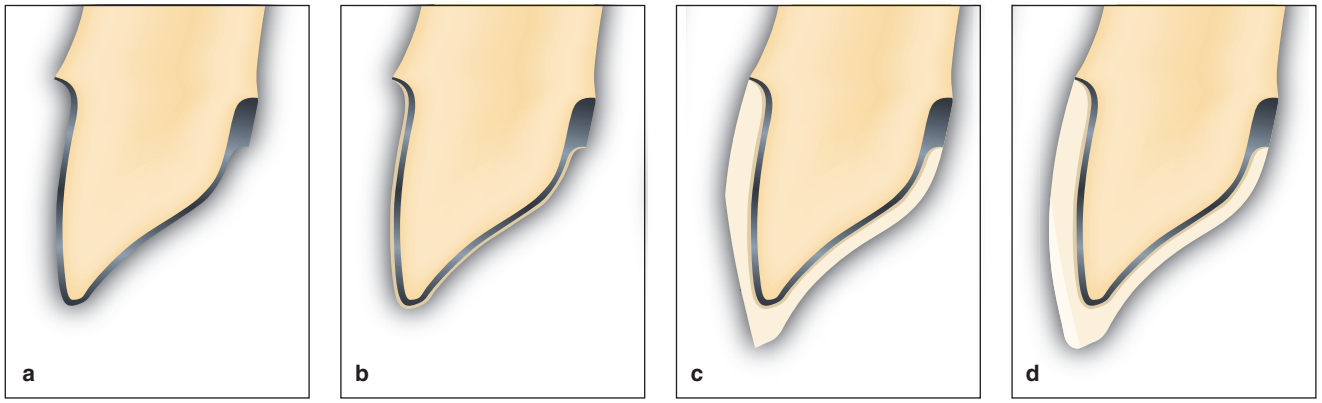

Fig 1-10 *(a)* A metal coping has been fitted (internally) and finished (externally), oxidized, and returned to the master die. *(b)* The opaqued metal substructure. *(c)* The dentin porcelain has been cut back for the application of a layer of enamel porcelain. *(d)* The final buildup of the enamel porcelain, which has been applied and contoured. Note: The amount and extent of the enamel cutback is based on the appearance of the tooth to be restored and, ideally, should be described in the laboratory work authorization and/or discernible in high-resolution digital photographs provided by the prescribing dentist.

technology can result in successfully planned and fabricated metal-ceramic restorations and fixed partial dentures. Therefore, the initial chapters of this text focus on the technical and scientific foundations that are key to the practical applications and skills that are covered in the later chapters.

Metal-Ceramic Terminology

You may find that some of the descriptions and instructions in the following chapters require an expanded vocabulary of technical terms unique to the materials used or the procedures described. A working knowledge of this terminology will help readers avoid confusion and potential misunderstandings. An even more extensive glossary of technical terms can be found in the back of the book. In some instances, pertinent terms have been defined at the beginning of certain chapters. Where appropriate, the *Glossary of Prosthodontic Terms*[30] has been used as a reference to ensure that the descriptive terminology in this text is consistent with the terms used in the specialty of prosthodontics.

Instances may arise when you detect differences in the interpretation of terminology used in this text as compared with other publications, including the *Glossary of Prosthodontic Terms*.[30] In these cases, an attempt will be made to identify those distinctions. The selected interpretation will be explained and used as consistently as possible. It is for you to weigh the merits of both explanations, make a personal interpretation, and select the definition that you believe best describes the term in question.

As mentioned previously, opinions differ on how to properly identify the restorative combination of metal and porcelain. Several popular designations include: *PFM restoration*, *ceramometal restoration*, *porcelain-bonded-to-metal* (PBM) *crown, porcelain veneer crown* (PVC), and finally, the term used in this text, the *metal-ceramic restoration*.[30] Although all these terms describe the same restoration and often are used interchangeably, the designation *metal-ceramic* is preferred to describe either a single crown or a fixed partial denture, just as the term *all-ceramic* has been chosen

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to identify single ceramic crowns and fixed partial dentures with nonmetallic substructures.

Some additional preliminary terminology follows:

- **Metal-ceramic restoration** A fixed restoration that employs a metal substructure veneered by a ceramic material.
- **Porcelain-fused-to-metal (PFM) crown** A popular and widely used alternative designation, synonymous with the term *metal-ceramic crown (MCC).*
- **Porcelain attachment mechanisms** The ways in which dental porcelain attaches to a metal foundation, be it chemical or physical (see chapter 6), also known as *porcelain bonding*.
- **Coping** The individual metal substructure of single-unit crowns to be veneered by dental porcelain; copings are made for individual units or attached to pontics to create a fixed partial denture.
- **Framework** A fixed partial denture with a one-piece substructure composed of either several copings attached to a pontic or multiple single units joined to one another as a single structure.
- **Oxidation** Process by which a metal substructure is heated in a porcelain furnace to elevated temperatures (980°C to 1,050°C), generally in a reduced atmosphere (ie, vacuum), to produce an oxide layer for porcelain bonding as well as to cleanse the porcelain-bearing areas of any volatile surface contaminants (*see* chapter 7), also known as *oxidizing*. Replaced the misnomer *degassing*.
- **Substructure** Foundation for a metal-ceramic or all-ceramic single-unit crown or fixed-partial denture.

Components of the Metal-Ceramic Restoration

In its simplest form, an MCC or fixed partial denture consists of two major components: *(1)* a metal substructure and *(2)* a dental porcelain veneer. A surface oxide layer lies between the metal and the porcelain veneer that could be considered a third component, but it actually is more an integral part of the metal substructure. Even the dental porcelain veneer, with several discreet layers, functions as one mass. Consequently, the metal-ceramic restoration is best considered a composite entity with a metal substructure (ie, coping or framework) masked by a discreet film of opaque porcelain (in the porcelain-bearing areas) that is veneered by layers of different dental porcelains (dentin, enamel, and effect porcelains for characterization) covered by a rather thin external surface glaze (see Fig 1-8).

Metal substructure

Conventional low-fusing dental porcelain alone lacks the strength required of an all-ceramic restoration. Therefore, an underlying metal substructure is needed to support the porcelain veneer for a single crown or a fixed partial denture. Depending on the type of casting alloy used and the amount of tooth structure removed by the dentist, the thickness of substructure can range from 0.2 to 0.5 mm in the porcelain-bearing area (see Fig 1-10a). As a general rule, substructures for high-density, high noble alloys are often at the high end of this thickness range (at or close to 0.5 mm) compared to the lower-density, base-metal alloys at the opposite end of this range (0.2 mm). An increased thickness is required of some high noble alloys with poor high-temperature strength (ie, poor sag resistance) to prevent framework deformation—especially with fixed partial denture frameworks—during processing as well as later when the finished restoration is under function in the mouth.

Oxide layer

Metal-ceramic alloys typically are subjected to an oxidation firing cycle after the porcelain-bearing area of the restoration has been properly finished and cleaned. As a result of that heat treatment, metallic oxides form on the alloy's surface and later play a key role in the chemical bonding of opaque dental porcelain to the underlying metal substructure. Noble elements, by their very nature, do not oxidize, so an alloy's base metal constituents are principally responsible for forming the oxide layer. Due to differences in alloy composition, oxidation protocols (ie, time, temperature, environment, and the postoxidation management of the oxide layer itself) are alloy specific.

Theoretically, the desired outcome of the oxidation process for all metal-ceramic alloys, irrespective of compositional differences, is an oxide layer that is no more than a discrete, monomolecular film on the porcelain-bearing surface (see Fig 1-10a). However, the chemical nature, color, and thickness of that film will differ significantly among different alloy systems, as is discussed in chapter 3. In addition, the role these oxides play in bonding dental porcelain to metal is explained in chapter 7. That said, there are alloys available that do not need to be oxidized in a reduced atmosphere. In fact, manufacturers of a few base metal alloys claim that oxidizing castings is optional, but this recommendation is not typical of all alloys. Consequently, it is vital to read and follow each dental alloy manufacturer's instructions for all phases of processing.

Opaque porcelain layer

Because dentin and enamel porcelains must possess some degree of translucency to mimic natural tooth structure, they lack the ability to mask the dark color of the metal substructure. Porcelain manufacturers provide a compatible, color-matched opaque for each body porcelain, with some opaques matched to multiple dentin shades.

The opaque porcelains are formulated to serve three major functions: *(1)* to establish the porcelain-metal bond, *(2)* to mask the dark color of the metal substructure, and *(3)* to initiate the development of the selected dentin porcelain shade.

The precise dimension of a fired opaque layer differs among brands of dental porcelain and in combination with the color of the oxidized metal substructure to which it is applied.[31–33] A uniform thickness of 0.2 to 0.3 mm is regarded as ideal (see Fig 1-10b).[33,34] Furthermore, all

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brands of opaque porcelain are vacuum fired on the metal substructure in a dental porcelain furnace (see chapter 8). Typically, opaque porcelains appear high in value (or relative brightness) if not covered by an adequate thickness of dentin porcelain. Furthermore, opaque porcelain is rough and cannot be glazed should the opaque layer be exposed from overadjustment of a metal-ceramic restoration.

Dentin porcelain veneer

Although shade development begins with the opaque layer, the major color contribution is derived from the pigmented metal oxides in the dentin porcelain (see Figs 1-9 and 1-10c). In fact, this first application of body porcelain is responsible for creating the dentin shade associated with, but not confined to, the gingival two-thirds of a tooth. In the initial buildup of a metal-ceramic restoration, this first layer of dentin porcelain should be overbuilt slightly (generally by 10%) and condensed to remove excess free liquid (ie, distilled water or a slow-drying special buildup liquid). Then the dentin porcelain is cut back and overlaid with a layer of enamel porcelain. The location and extent of the dentin cutback is based on where greater translucency is needed as well as the desired final appearance of the restoration.

Most porcelain manufacturers add organic dyes to distinguish between the various porcelain powders. For example, typically a pink colorant is incorporated with the dentin powders, and the addition of a light blue colorant distinguishes enamel porcelains from other types of porcelains (eg, opaque porcelains, shoulder porcelains, body modifiers). These pink versus blue color distinctions allow the ceramist to "visualize" the desired zones of the dentin and enamel porcelains in the unfired state.

For more accurate shade duplication, estimates of the combined thickness of fired dentin and enamel porcelains range from a minimum of 0.5 to 1.0 mm[34,35] to a maximum thickness of 1.5 to 2.0 mm,[34,35] depending on the location of the restoration being measured. By some estimates, the minimum total thickness of porcelain ranges from 1.2 to 1.3 mm at the middle one-third of the restoration and from 1.5 to 1.6 mm at the incisal edge.[35] The occlusal surfaces of posterior restorations may approach 2.0 mm in porcelain thickness. More material is needed for the occlusal table not only to ensure proper coverage and mask the underlying metal but also to provide sufficient thickness of the ceramic veneer to permit the development of ideal dental morphology. Teeth prepared with an insufficient amount of occlusal reduction (well below 2.0 mm) and their corresponding metal substructures may prevent the creation of lifelike definitive restorations because of inadequate secondary anatomy. In addition, the high-value opaque layer may be visible if there is only a thin veneer of overlying dentin porcelain.

From a purely structural perspective, free-standing porcelain that is built and fired above this 2.0-mm maximum height is considered unsupported by metal and more prone to fracture.[35] Potentially harmful stresses can form in thick, unsupported sections of a restoration (eg, incisal edges, cusp tips, and marginal ridges), thereby increasing the risk of crack formation, crack propagation, and subsequent fracture within the porcelain veneer itself.[35] But to replicate the desired shade in the fired porcelain achieve maximum strength, it is highly desirable, whenever possible, to have a uniform thickness of porcelain covering the metal substructure.

Enamel porcelain veneer

The enamel porcelain veneer has intentionally not been labeled the *incisal layer* to avoid implying that these porcelains must be restricted to the incisal third of a buildup. That is because it is appropriate to place mixed blue enamel porcelain wherever natural enamel translucency is required, even if that placement is outside the incisal third of an anterior crown or the occlusal third of a posterior metal-ceramic restoration.

In general, enamel porcelains are used largely in the incisal and interproximal areas, but they need not be limited to these regions in every porcelain buildup (see Fig 1-10c). The desired final esthetic outcome of a restoration is what actually determines the amount and the boundaries of the cutbacks for enamel veneer.

To create the appearance of natural translucency and the vitality of natural tooth structure, an underlying layer of dentin porcelain should support incisal edges, individual cusp tips, and for some patients, even the marginal ridges. The enamel layer is applied, condensed, dried slowly, and vacuum fired with the dentin buildup. It is unwise to fire the dentin and enamel layers separately because the blending of shades will not be as subtle and realistic as when these two materials are sintered together (see Fig 1-10d). This is why the pink and blue colorants are so important. They permit the ceramist to visualize the location and depth of the dentin layer in relation to the overlying enamel porcelain.

Firing procedures

The two opaque porcelain applications and the multiple body porcelain buildups of dentin and enamel porcelains are all fired in a porcelain furnace under vacuum as per the porcelain manufacturer's recommended processing steps for time and temperature (see appendix B). Typically, the firing cycles begin with a drying stage to allow the distilled water or modeling liquid mixed with porcelain powders to evaporate slowly before the furnace door is sealed for vacuum firing. If the wet porcelain is heated too rapidly, the water (or modeling liquid) in the mix can be transformed from its liquid state to steam rather than slowly evaporated. Steam production can cause the porcelain buildup to "pop off" the substructure as the restoration is being introduced inside the porcelain furnace and before a vacuum is even created, in which case processing must be stopped and the buildup repeated.

External glaze

The surface luster of an intact and unrestored natural tooth is best reproduced by the development of a sheen over the external surface of the fired porcelain (see Figs 1-7a and 1-8b). The final processing step in the fabrication of a metal-ceramic restoration is to heat the completed work

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to a temperature (recommended by the porcelain manufacturer) sufficient to produce what is often referred to as a *natural glaze, autoglaze*, or *self-glaze*. An alternative glazing method, and one that is perhaps used more often, involves applying and firing an artificial glazing porcelain (called an *overglaze*) to recreate this desired natural sheen and seal the exterior ceramic surface in the process.

The most common practice for both techniques is to air fire, not vacuum fire, when glazing and hold the work at a prescribed high temperature for a specified period of time (called the *hold time*) until the desired degree of sheen and maturation are attained. Details of the step-by-step procedure of glazing a metal-ceramic restoration are included in chapter 9 and appendix B.

With most glazed restorations a simple mechanical polishing on a high-speed lathe using a wet rag wheel with a fine diamond paste or other polishing agents (eg, Brasso [Reckitt Benckiser] mixed with flour of pumice) can transform a metal-ceramic restoration with a glassy porcelain surface into a lifelike restoration with a more natural-appearing luster, as described and illustrated in chapters 9 and 10.

Summary

A brief history of ceramics, a discussion of metal-ceramic versus all-ceramic technology, the definition of key terms, and an introduction to the components of the metal-ceramic restoration have been presented in this chapter. It is now appropriate to take a closer look at dental porcelains.

What's Next?

Chapter 2 provides an overview of the chemistry of metal-ceramic porcelains as we know them today. The various types of porcelain powders are identified and described in terms of composition, classification, use, and optical properties, and representative firing schedules are provided in appendix B.

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