Orthodontic Treatment of Impacted Teeth

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Fourth Edition

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Preface to the First Edition

There can be little question that the treatment of impacted teeth has caught the imagination of many in the dental profession. The challenge has, over the years, been taken up by the general practitioner and by a number of dental specialists, including the paedodontist, the periodontist, the orthodontist and, most of all, the oral and maxillofacial surgeon. Each of these professionals has much 'input' to offer in the resolution of the immediate problem and each is able to show some fine results. However, no single individual on this specialist list can completely and successfully treat more than a few of these cases without the assistance of one or more of others of his/her colleagues on that list. Thus, the type of treatment prescribed may depend upon which of these dental specialists sees the patient first and the level of his/her experience with the problem in his/her field. Such treatment may involve surgical exposure and packing, orthodontic space opening, perhaps autotransplantation, or a surgical dento-alveolar set-down procedure, or even just an abnormally angulated prosthetic crown reconstruction.

Experience has come to show that the orthodontic/surgical modality has the potential to achieve the most satisfactory results in the long term. Despite this, many orthodontists have ignored or abrogated their responsibility towards the subject of impacted teeth to others, accounting for the popularity of other modalities of treatment. The subject has become something of a Cinderella of dentistry.

Within the orthodontic/surgical modality, much room exists for debate as to what should be done first and to what lengths each of the two specialties represented should go in the zealous pursuit of its allotted portion of the procedure. The literature offers scant information and guidance to resolve these issues, leaving the practitioner to fend for him/herself, with a problem that has ramifications in several different specialist realms.

This book discusses the many aspects of impacted teeth, including their prevalence, aetiology, diagnosis, treatment timing, treatment and prognosis. Since these aspects differ between incisors and canines, and between these and the other teeth, a separate chapter is devoted to each. The material presented is based on the findings of clinical research that has been carried out in Jerusalem by a small group of clinicians over the past 15 years or so, at the Hebrew University – Hadassah School of Dental Medicine, founded by the Alpha Omega Fraternity and from the gleanings of clinical experience in the treatment of many hundreds of my patients, young and old.

An overall and recommended approach to the treatment of impacted teeth is presented and emphasis is placed on the periodontal prognosis of the results. Among the many other aspects of this book, the intention has been to propose ideas and principles that may be used to resolve even the most difficult impaction, employing orthodontic auxiliaries of many different types and designs. None of these is specific to any particular orthodontic appliance system or treatment 'philosophy', notwithstanding the author's own personal preferences, which will become obvious from many of the illustrations. These auxiliaries may be used with equal facility in virtually any appliance system with which the reader may be fluent. The only limitation in the use of these ideas and principles are those imposed on the reader by his/her own imagination and willingness to adapt.

The orthodontic manufacturers' catalogues are replete with the more commonly and routinely used attachments, archwires and auxiliaries, which are offered to the profession with the aim of streamlining the busy practice. These items have not been tailored to the demands of the clinical issues that are raised in this book. These issues, by their very nature, are exceptional, problematic and often unique, while occurring alongside and in addition to the routine. Among the more common limitations self-imposed by many orthodontists has been the disturbing trend to rely so completely upon the use of preformed and pre-welded attachments that they have forgotten the arts of welding and soldering and no longer carry the necessary modest equipment. This then restricts one's practice to using only what is available and sufficiently commonly used to make it commercially worthwhile for the manufacturer to produce. By consenting to this unhealthy situation, the orthodontist is agreeing to work with 'one hand tied behind his/her back' and treatment results with inevitably suffer.

I acknowledge and am grateful for the help given me by several colleagues in the preparation of this book. An excellent professional relationship has been established, and has withstood the test of time, with two senior members of the Department of Oral and Maxillofacial Surgery at Hadassah, with whom a *modus operandi* has been developed, in the treatment of our patients. Professor Arye Shteyer, Head of the Department, and, subsequently, Professor Joshua Lustmann have educated me in the finer points of surgical procedure and care while, at the same time, have demonstrated a respect and understanding of the needs of the orthodontist at the time of surgery. I am grateful to them for their collaboration in the writing of Chapter 3.

Dr Ilana Brin read the original manuscript and made some useful suggestions, which have been included in the text. I am grateful to Dr Alexander Vardimon for his

comments regarding the use of magnets and to Dr Tom Weinberger for the discussions that we have had regarding several issues realised in the book. My wife, Sheila, read the earlier drafts and made many important recommendations and corrections. More than anyone else, she encouraged me to keep writing during the many months when other and more pressing responsibilities could have been used as justifiable excuses for putting the project aside.

My colleagues Dr Monica Barzel, Dr Yocheved ben Bassat, Dr Gabi Engel, Dr Doron Harary, Dr Tom Weinberger and Professor Yerucham Zilberman, and my former graduate students Dr Yossi Abed, Dr Dror Eisenbud, Dr Sylvia Geron, Dr Immanuel Gillis, Dr Raffi Romano and Dr Nir Shpack, have provided me with several of the illustrations included here and I am indebted to them.

I am grateful, too, to Ms Alison Campbell, Commissioning Editor at Martin Dunitz Publishers and to Dr Joanna Battagel, Technical Editor, for their constructive and professional critique of the manuscript, which contributed so much to its ultimate format. I also thank Naomi and Dudley Rogg, of the British Hernia Centre, for the computer and office facilities that they placed at my disposal during my short sabbatical in London in the latter stages of the preparation of the work for publication.

Permission to use illustrations from my own articles that were published in various learned journals was granted by the publishers of those journals or by the owners of the copyright, as follows:

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Figure 6.35 was reprinted from Kornhauser, S, Abed, Y, Harary, D, Becker, A, The resolution of palatally-impacted canines using palatalocclusal force from a buccal auxiliary, *Am J Orthod Dentofac* Orthop 1996; 110: 528–534, with kind permission of Mosby-Year Book Inc., St Louis, MO, USA.

I am very thankful for their cooperation and for their agreement.

Adrian Becker
Jerusalem

Preface to the Second Edition

In the nine years that have elapsed since the publication of the first edition of this book, much has changed in the field of orthodontics in general and, perhaps even more so, as it relates to the treatment of impacted teeth. The advances in imaging, particularly cone beam computerized tomography, have made accurate positional diagnosis of an impacted tooth virtually foolproof, enabling the application of appropriately directed traction to resolve even the most difficult cases. Temporary orthodontic implants have provided the opportunity to resolve the impaction, in many cases without the need for an orthodontic appliance and before orthopaedic treatment *per se* is begun. They have opened up a whole new area to exploit for mechanotherapeutic solutions to many of the problems we face.

The first edition was based on the findings of clinical research that was carried out over a long period of time in Jerusalem during the 1980s and 1990s. In much the same way, this second edition documents the findings of ongoing and evidence-based studies carried out by largely the same small group of clinical investigators, since then. Most of these published articles were the product of an excellent working collaboration with Dr Stella Chaushu, a former student of mine and now Senior Lecturer in the Department of Orthodontics. Her industrious and intellectual qualities have contributed to the output of a large number of valuable published studies in just a few short years.

Under the leadership of Professor Refael Zeltser, chairperson of the Department of Oral and Maxillo-facial Surgery at the Hebrew University – Hadassah School of Dental Medicine in Jerusalem, a whole generation of young surgeons has grown up who exhibit the ability to appreciate and value the finer points of cooperation with the orthodontist. Dr Eran Regev and Dr Nardi Casap in Jerusalem, Dr Gavriel Chaushu, the chairperson at the parallel department of the Sourasky Hospital in Tel Aviv, and Dr Harvey Samen in private practice, have worked closely with me in the treatment of our patients. Many of these cases are illustrated in the pages of this book. I derive considerable satisfaction from seeing the surgical expertise learned from and handed down by Professors Arye Shteyer and Joshua Lustmann being practised by these highly professional colleagues, on a day-by-day basis. Their awareness and perception of the significance of their work in determining the long-term outcome have helped me to aim for the highest quality results and the well-being of the patient. They deserve my gratitude.

In the preparation of this book, I have called upon and am grateful for the expertise of a small number of people, who have provided me with authoritative and essential information that has permitted me to make the text more comprehensive and more complete. In particular, I mention Dr James Mah and Dr David Hatcher in California, with regard to cone beam CT imaging and Dr Joe Noar in London, with regard to the use of magnets.

I have given and continue to give courses and lectures on the subject of impacted teeth in many places all over the world which, in the past few years, have been presented in collaboration with Dr Stella Chaushu. It is at these meetings that I come across some of the most interesting and rare material. I am indebted to several individual members of these audiences who frequently approach us during a coffee break, radiograph in hand, with some truly remarkable conditions, several of which have been included in this book, together with appropriate recognition.

My colleagues in the Orthodontic Department in Jerusalem have often become the sounding board for many of the ideas that are presented herein and I am thankful to them for the discussions that we have had. I appreciate their taking the stand of devil's advocate in these situations, forcing me to justify or to discard. Nevertheless, none of this would ever have been published had I not spent so many years teaching the students on our postgraduate orthodontics specialty course. These future orthodontic standard bearers are privileged to learn from the various individual teaching preferences of mentors who rely on years of experience in practice, particularly when it comes to this bracket or that, this treatment philosophy or that and this orthodontic guru or that. Additionally, they have learned to look for and even demand clinical ideas and treatment policies that have a proven evidence-based, track record to commend them and to justify their use. I know of no other postgraduate orthodontic course, worldwide, in which the subject of impacted teeth is explicitly taught in a comprehensive and integrative manner, including a designated weekly clinical session. It was this more than any other factor which encouraged me to embark on this mammoth task.

The future of our profession and the long-term superior care of the even younger generation of our patients is in the hands of these aspiring orthodontists. I am grateful to them for having, perhaps unwittingly, cajoled me into writing this text. I hope that it will be a source of information for them as they undertake the challenge of some of the more difficult, unconventional and unusual cases that they will inevitably come across in practice and for which they will be expected to find appropriate therapeutic answers.

I wish to thank the following publishers of two articles, as follows:

Several of the illustrations comprising Figure 7.8 were reprinted from the *World Journal of Orthodontics. Vol. 5. The*

Role of Digital Volume Tomography in the Imaging of Impacted Teeth, by Adrian Becker and Stella Chaushu. 2004. with permission from Quintessence Publishing Co, Inc.

Several of the illustrations comprising Figure 11.9 were reprinted from *Healthy periodontium with bone and soft tissue regeneration following orthodontic-surgical retrieval of teeth impacted within cysts*, by Adrian Becker & Stella Chaushu, in *Biological Mechanisms of Tooth Movement and Craniofacial Adaptation*. Proceedings of the Fourth International Conference, 2004, pp. 155–162. Z Davidovitch and J Mah, editors. Sponsored by the Harvard Society for the Advancement of Orthodontics. Reproduced with permission.

Adrian Becker
Jerusalem, Israel

Preface to the Third Edition

Only 14 years have passed since the publication of the first edition of this book and much has changed in orthodontics, in general and in the context of the treatment of impacted teeth, in particular. The subject material that appeared in that small monograph has developed several fold, in the light of research and the advent of new technology. These two factors have encouraged the orthodontic specialist to be more discerning in the diagnosis of pathology and more innovative and resourceful in the application of directional traction. Mistaken positional diagnosis and surgical blunders have become less common and consequent failure to resolve the impaction less frequent. At the same time, they have permitted the orthodontist to become more adventurous and to successfully apply his/her knowledge and experience to the treatment of cases where previously the tooth would have been scheduled for extraction. If this third edition may yet contribute to the furtherance of this favorable trend in any way, I will consider that my mission will have been accomplished.

It was the aim in each of the earlier editions of this book to present reasoned principles of treatment for tooth impaction, illustrated by examples from real life. Following these principles to their logical conclusion, Chapter 15 has been added in the present edition to illustrate how some extreme examples or cases with concurrent complicating factors may be resolved, several of which involve the expertise of colleagues in our sister specialties. Oddities, such as the "banana" third molar, with its impacting influence on its immediate neighbor, are also new to this edition.

Failure has intrigued me for a long time and, while Chapter 12 was new to the second edition, it has been enlarged now in the third. The recognition and importance of invasive cervical root resorption (ICRR) as a cause of failure to resolve an affected impacted tooth seems to be hardly known within the profession. There is a section added herein which discusses the etiology of this pathological entity, its disease process, its potency as a factor for failure and speculates on accepted standard procedures that may predispose to its occurrence.

To write a textbook or to update an edition may take several years. Once it is finished, it has to go through the many months of the publishing process, with questions and corrections, proofreading and amendments. In the meantime, what was written becomes progressively obsolete – new ideas are put forward in the journals, some are disciplined studies and others just innovative clinical methods learned in the very singular one-on-one situation in the orthodontic operatory between orthodontist and patient. In order to provide at least a partial answer to this, I have set up an internet website at www.dr-adrianbecker. com, in which regular updates on clinical research and technique, vignettes describing individual conditions or just a customized approach to the treatment of a specific case, are published with the aim of complementing the book. The site also features a "troubleshooting impacted teeth" page for individual clinical consultations – open to anyone, whether orthodontist, patient or concerned parent. Details of the patient and his/her condition will need to be filled in and existing radiographs, CBCT and other relevant information uploaded. A report is returned to the sender within a few days with suggestions and recommendations for treatment.

The clinical research on which this text is largely based has been the product of long-term cooperation with Professor Stella Chaushu, PhD, DMD, MSc, Chairperson of the Orthodontic Department in Jerusalem, to whom are due my special thanks. I am grateful to my co-authors who have advised me in my writing of several of the chapters herein and to a number of my colleagues who have sent me illustrative material which I have included, with their permission. I would also like to recognize Mr. Israel Vider, director of the Dent-Or Imaging Center in Jerusalem, for his CT imaging expertise, his assistance in granting me access to his technical laboratory and for his work on several of the illustrations that are published in this edition.

Adrian Becker
Jerusalem, October 2011

Preface to the Fourth Edition

As the fourth edition of this book goes to print, I am happy to present a much-enhanced text, both in terms of the verbal discussion and the illustrated figures, which is offered in a similar pattern to its predecessors. The third edition of *Orthodontic Treatment of Impacted Teeth*, published in 2012, had 15 chapters. This new edition comprises 21 chapters, of which several are completely new and, together with the significant additions and improvements, the overall content is now approximately 60% larger.

Video clips and other 3D illustrations cannot be published in book form, thus preventing the printed literature from matching the advances in the recording of radiographic imaging that is now commonplace in dental schools, in radiographic imaging centres and in private dental offices. This is particularly so in relation to orthodontics, in general and to accurate positional and pathological diagnosis, that are so essential in the resolution of tooth impaction, in particular. In order to overcome these serious illustrative limitations, I have included a Companion website adjacent to the text, to enhance the orthodontist's ability to use the existing presentation modes (secondary reconstructions), to extract the maximum information that is available in a cone beam CT scan. A number of 3D video clips are presented, to illustrate how to refine the diagnostic know-how, which can only be to the benefit of the patient. These are embedded in PowerPoint presentations, with concise accompanying comment to highlight the salient points at issue. This should assist those who still have 3D comprehension difficulty in accurately locating the impacted tooth.

There are many new areas in the present text that feature aspects that have not been fully described in the literature to date. There are also a number of supposed truths that are shown to be spurious and contrary to our understanding of the biological process.

Just to mention a few of the many examples that the reader will find in this edition:

- Did you know that hooked roots are not a reason that teeth do not erupt (see Chapter 13)?
- Unerupted incisor teeth that have been severely damaged by trauma inflicted in infancy remain high in the maxilla adjacent to the nasal floor, neither growing their roots nor showing any signs of ever erupting into the mouth. Can these teeth be mechanically erupted? Will they develop roots of a sufficient length that will contribute to the tooth surviving into adulthood? Will the eruption of these teeth generate new bone that could naturally rehabilitate the formerly deficient alveolar ridge (see Chapter 6)?
- Instead of developing a long straight root, the severely traumatized central incisor in a 2-year-old child may develop a root that continues to grow at an acute angle to the calcified portion of the tooth, to form a tightly curved or angled dilaceration. The root continues to grow in the wrong direction, necessitating root canal treatment and root amputation to enable the orthodontist to re-align the majority portion of the tooth. Perhaps there is a way to correct the direction of the further root growth and thereby achieve a normally apexified vital tooth with a perfect crown, indistinguishable from and aligned with its beautiful adjacent counterpart (see Chapter 6).
- There appears to be a cut-off age of 9 years for the maxillary lateral incisor to develop at least half its normal root length. If there is less than a half root at this age, as seen in a small or peg-shaped tooth, the chances that the unerupted canine will become the victim of eruption disturbance become notably exaggerated (see Chapter 6).
- Conventional wisdom has it that mandibular second and third molars are sometimes impacted because their roots are being 'held down' by entanglement with the inferior alveolar canal (mandibular branch of the trigeminal nerve). We maintain that this view is unfounded (see Chapter 13). It is more likely that another factor, such as invasive cervical root resorption (ICRR), enlarged dental follicle, crowding of adjacent teeth and even possibly pre-eruption intra-coronal resorption, represents the primary aetiology that prevents eruption (the 'cause'). With the root apices then growing in cramped circumstances, in close proximity to pathological entities or anatomical limits, the further erratic development of the root ends inevitably results in entanglement with the nerve and vascular bundle (the 'effect').
- You have just finished the phase 1 treatment of a child, for the treatment of a cross-bite or an impacted incisor or for maxillary anterior crowding, and he is now 8 years old. As the final flourish, you have aligned the incisors and paralleled their roots into their final adult orientation. The four incisors look beautiful and the parents are happy. In order to hold on to this delightful result, a fixed or removable retainer will need to be placed, until the child is ready for phase 2 treatment in 3–4 years' time. The question that needs to be asked is: Will the 'attention to detail' at this early stage and the apparently laudable 'intention to fully exploit the capabilities of an existing orthodontic appliance' be to the patient's overall

benefit, or will they raise the spectre of iatrogenic damage in the long term, by potentially disturbing the eruption of the canine (see Chapters 6, 7 and 18)?

A word about the tooth-numbering convention used in this book. For the most part, the narrative in this volume refers to the individual teeth by their full descriptive title. Thus, we may refer to an impacted maxillary left permanent canine tooth or an infra-occluded deciduous mandibular second molar tooth – a six-word definition for a very small entity. However, for the sake of brevity and particularly for the annotation of teeth in an illustration, an author will prefer to use a shortened code for each tooth. The numbering system we have used here is the Fédération Dentaire Internationale (FDI) numbering system. This system has been widely accepted in many parts of the world, being easy to understand, logical and adaptable to the various tooth groups. It is compatible with computerized representation and uses the same description of the teeth on either side and in either jaw in a symmetrical and rapidly recognizable manner.

The method assigns a two-number code to each tooth. The first number defines the quadrant in which the tooth is found. Thus, the right maxillary quadrant, from midline to last molar, is given the number 1. The left maxillary quadrant is number 2; the left mandibular quadrant number 3; and the right mandibular quadrant number 4. The individual teeth are then numbered from 1 to 8, beginning from the midline and proceeding to the last molar. In this manner, all impacted canines will be recognized by the second number 3: a right maxillary canine would be denoted 13; a left mandibular second molar would be assigned 37; and a mandibular right lateral incisor 42. All four canines are rarely impacted in the same individual, but when this occurs, it will be appreciated that 13, 23, 33 and 43 will be more easily recognizable than the 6, 11, 22 and 27 of the so-called 'universal' numbering system, which seems to have achieved acceptance largely in the USA. (We have occasionally used the hash sign # in front of the number, in order to clearly differentiate the tooth number from other numbers in the text.)

Similarly, numbering the deciduous teeth employs the quadrant system in the same order, labelled from 5 to 8 and the teeth numbered 1 to 5. Thus, the maxillary deciduous right central incisor is defined as 51 and an infra-occluded mandibular right deciduous second molar is numbered 85.

I am grateful to each of my co-authors for having enthusiastically responded to my invitation to write a specific chapter in this volume and for having submitted their finished manuscripts ahead of the deadline I set for them. The chapter on biomechanics as it relates to impacted teeth was written and illustrated by Dr Ulrich Kritzler, who is in private practice in Warendorf, Germany and a regular contributor to the international orthodontic literature. The rapidly expanding popularity of clear aligners in orthodontics prompted me to invite a discussion of their use, suitability and the limitations of their application to the treatment of cases with impacted teeth. This has been authored by Prof. Dror Aizenbud, Chair of the Unit for Orthodontics and Craniofacial Anomalies in Haifa, Israel.

For the past several years, I have availed myself of the expert services of Mr Amnon Leitner, perhaps the most knowledgeable and skilled master radiographic imaging technician I have ever had the good fortune to meet and to work with. I invited him to enlarge and update the chapter on diagnostic imaging, specifically with regard to cone beam computerized tomography. Several of his highly informative secondary reconstructions, 3D screenshots and video clips appear in that chapter and additional examples of his work may be seen in a number of other chapters.

I am grateful to Dr Athina-Maria Mavridou of KU Leuven (University of Leuven) in Belgium, a trained endodontist and an accomplished research scientist, who provided helpful comment on the histopathological aspect of my description of invasive cervical root resorption. ICRR is a specific pathological entity in its own right and is discussed in Chapter 10. The positive diagnosis of ICRR has serious repercussions in relation to the treatment of impacted teeth, yet it is substantially uncharted territory and rarely recognized by orthodontists.

As in the second and third editions, I acknowledge the contribution to several chapters in the book, of Prof. Stella Chaushu, Chair of the Department of Orthodontics at the Hebrew University–Hadassah School of Dental Medicine, Jerusalem, Israel. For the past 25 years, our academic collaboration has achieved much in terms of basic and clinical research, particularly in the area of eruption disturbance. Tooth impaction has also been the subject of the many invited lectures and courses that we have conducted together internationally and this book largely represents the culmination of those years of endeavour, even from as early as 1964. It reflects many of the fruits of our joint academic collaboration.

Writing a text on the subject of impacted teeth involves filtering out the relevant and appropriate conclusions of published studies from the mass of orthodontic literature in general, and specifically honing in on those evidence-based investigations published in the leading international, peer-reviewed orthodontic journals. The treatment decisions made in individual cases or in small case series of the treatment of rare conditions cannot, by virtue of their small numbers, be founded on evidence that is other than anecdotal. This does not necessarily negate the validity of the decision to treat the next patient with the same condition in a similar manner. However, it must be understood that the decision can be justified on an empirical basis only and is likely to be dependent on careful patient selection; and it does obligate this and any other author to report the possibility of bias. I have tried to comply with this and hope that

I have been successful in my diligence in the examples of treatments elaborated in the text.

In my efforts to produce a readable and understandable narrative, I managed to persuade my brother Laurence (Shmuel) Becker to be responsible for the editing and proof-reading of this work. He is a lawyer and is the first to admit that he knows absolutely nothing about orthodontics. His theory was that if he could understand what I have written in this volume and could follow the ideas and the logical sequence, then any orthodontist should be able to read, follow and understand the text and the ideas that I have tried to portray easily and painlessly. And so he has corrected, amended, shuffled words around, relocated sections and substituted my words for others that only a lawyer can produce. (He is probably the only other person who will have read the entire book at least five times over.) For all this, I am greatly in his debt.

The wondrous workings of today's desktop computers have provided me with the means to write this text, which would never have been possible using the steam-propelled typewriter. However, my computer has also given me a false sense of security, learned from bitter experience. Many times in the past three years I lost material that I had spent days writing, either because I had failed to save it or because I had 'copy-pasted' these sections into other files, which I promptly and unintentionally deleted. I cannot count the number of times that I called my son-in-law, Asher Cohen (also a lawyer), setting him the task of rediscovering them and putting me back into the business of writing. He found them every time, at break-neck speed. I salute his alacrity and his digital skills!

I closely identify with the legendary Danish pianist and comedian who, at the same advanced age as I am now, was still appearing on stage before large live audiences. At the end of one of his solo performances, Victor Borge acknowledged: 'I wish to thank my parents for having made this possible and I wish to thank my children for having made it necessary.'

Adrian Becker
Jerusalem, Israel
June 2021

About the Companion Website

This book is accompanied by a companion website.

www.wiley.com/go/becker/orthodontic_treatment_impacted_teeth

The website includes a series of Power Point presentations mainly of CBCT interpretation work-ups and particularly in relation to diagnosis of impacted teeth. They contain embedded video clips illustrating methods for refining accurate positional identification or analysis of the teeth in 3D and in improving the qualitative recognition of pathologic entities.

Each online resource is called out in the text by number for ease of location.

View all animations in full screen by clicking the square button under the bar at the bottom right of the animation window.

1

General Principles Related to the Diagnosis and Treatment of Impacted Teeth

Adrian Becker

Orthodontic Treatment of Impacted Teeth, Fourth Edition. Adrian Becker.

Companion website: www.wiley.com/go/becker/orthodontic_treatment_impacted_teeth

In order for us to understand what an impacted tooth is and whether and when it should be treated, we must first define our perception of normal development of the dentition as a whole and the time-frame within which it operates.

The development of a child has many components. In assessing the developmental age of a child, it is necessary to consider and correlate these components and there is a hypothetical mean for each, though the overall development rate rarely falls exactly on this mean. A child's growth and development rate may also be different for each of the developmental components.

- *Somatic age*: A child may be tall for his or her age, so that his or her somatic age may be considered to be advanced.
- *Skeletal age*: By studying radiographs of the progress of ossification of the epiphyseal cartilages of the bones in the hands of a young patient (the carpal index) and comparing this with average data values for children of his or her age, we are in a position to assess the child's skeletal age.
- *Sexual maturation age*: The sexual age of a child is related to the appearance of primary and secondary sexual features.
- *Mental age*: This is assessed by intelligence quotient (IQ) tests.
- *Behavioural age*: This is an assessment of a child's behaviour and his or her self-concept.

These are among the indices complementing the *chronological age*, which is calculated directly from the date registered on the child's birth certificate. All these parameters are essential in the comprehensive assessment of a child's developmental progress.

Dental age

Dental age is another of these parameters and is a particularly relevant and important assessment used in advising as to the timing of proper orthodontic treatment. The tables and diagrammatic charts presented by Schour and Massler [1], Moorrees et al. [2, 3], Nolla [4], Demirjian et al. [5], Koyoumdjisky-Kaye et al. [6], Willems et al. [7] and Liversidge et al. [8] demonstrate the stages of development of the teeth, from initiation of the calcification process through to the completion of the root apex and the average chronological ages at which each stage occurs. Normal and healthy tooth buds develop from initial calcification to root apex closure at a given rate for each of the teeth groupings. That is to say that incisors, canines, premolars, first, second and third molars, in the mandible and in the maxilla, differentiated between males and females, all have their individual specific time at which they reach the various developmental stages. These stages are empirically defined in the above classic works. Schour and Massler [1] produced an atlas from *intra utero* to adulthood, consisting of 21 consecutive drawings, which feature annual development schemes up to age 12 as well as 3 more schemes up to age 35 years. Nolla [4], on the other hand, used a radiographic assessment of tooth development at 10 different developmental stages, starting from the presence of the crypt through to root apex closure (apexification).

Estimating the stage of development based on the eruption time of teeth is an unreliable method of assessing dental age. Although eruption of each of the various groups of teeth normally occurs at a particular time (when there is half to two-thirds of the final root length), nevertheless this may be influenced by local factors, which may cause premature or delayed eruption with a wide time-span discrepancy. This may be true even when root development may be proceeding unhindered.

In contrast, examination of periapical or panoramic X-rays is a far more accurate tool for dental age assessment. With few exceptions, mainly related to frank pathology, root development proceeds in a fairly constant manner and usually regardless of tooth eruption or the fate of the deciduous predecessor.

Let us take the case of a child of 11–12 years of age who has four erupted first permanent molars and only the permanent incisors, with deciduous canines and molars completing the erupted dentition. If practitioners were to refer only to the eruption chart, they would note that at this age *all* the permanent canines and premolars should have erupted. They may then conclude that the 12 deciduous teeth had been retained beyond their due time. The treatment that would appear to be the logical sequel to this observation would be the elective extraction of all the deciduous teeth!

This, however, is an overly simplistic diagnosis, since indeed there are two possible conclusions to the practitioner's observations. It is of paramount importance to carefully study the radiographs in order to distinguish between these two possibilities and thereby avoid unnecessary harm being inflicted on the child and the parents.

The initial conclusion to which the practitioner came would indeed be correct if the radiographs were to show that the unerupted permanent canines and premolars had completed most of their expected root length, showing that the child's dental age corresponded with his chronological age. In the present case (Figure 1.1), the deciduous teeth had not shed naturally, presumably due to insufficient resorption of their roots constituting an impediment to the normal eruption of the permanent teeth. Their permanent successors must then strictly be defined as having delayed eruption. The logical line of treatment would be to extract the deciduous teeth on the grounds that their continued presence defines them as over-retained.

However, there is a second possibility, where the radiographs reveal relatively little root development, more closely corresponding on the tooth development chart

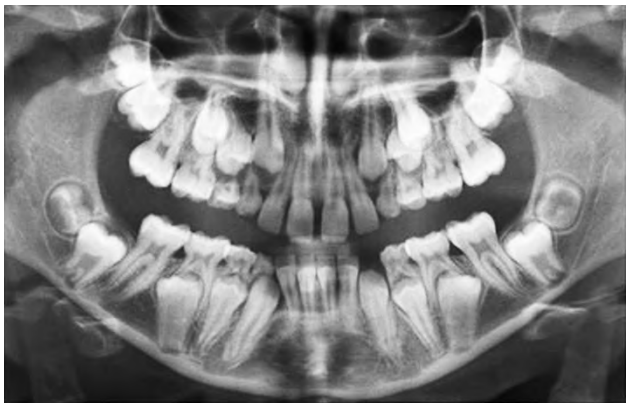

Fig. 1.1 The advanced root development of the canines and premolars indicates a dental age of 12–13 years, despite the presence of 11 deciduous teeth in this 10-year-old child. This defines the deciduous teeth as over-retained and extraction is their appropriate treatment. A note should be made and follow-up is needed regarding the relatively slow eruptive progress of the second permanent molars.

Fig. 1.2 A 12-year-old patient with root development indicating the late dental age of 9 years. Extraction of deciduous teeth is contraindicated

(Figure 1.2) to the picture of a 9-year-old child. The child's birth certificate has indicated the age of 12 years and this may well be corroborated by body size and development and even by intelligence level. Nevertheless, her dentition is that of a child three years younger, thus determining *dental age* as 9 years. Extraction of deciduous teeth in these circumstances would be the wrong line of treatment, since it is to be expected that these teeth will shed normally at the appropriate *dental* age. Early extraction may lead to the undesired characteristic consequences of early extraction, performed for a completely different reason.

An additional parameter of teeth development must also be considered. Although on average, central incisors, canines and first and second molars in the maxilla show identical rates of development of one side of the mouth compared to the other, this may not be true for certain specific teeth. There may be a marked variation between right and left sides in the development rate of maxillary lateral incisors and mandibular second premolars and, less commonly, of maxillary second premolars.

In the same way that we may determine the patient's overall dental age, these identical principles also serve to enable us to diagnose the dental age of the patient's individual unerupted permanent teeth. However, because developmental variation is found within these different groups of teeth, the developmental stage of a single tooth cannot be used as an indicator for overall dental development and dental age must be evaluated employing a comprehensive, all-round assessment. Only then can a definitive determination be offered.

Accurate assessment of dental age is critical in deciding when to treat a patient in general and in regard to the treatment of impacted teeth in particular.

We are now in a position to define the terms that we shall use throughout this text, as follows:

- *Retained deciduous tooth*: This term has a positive connotation and refers to a tooth that remains in place beyond its normal, chronological shedding time due to the absence, or retarded development, of the permanent successor. A radiograph of the permanent successor is required in order to determine the presence and developmental status of the unerupted permanent tooth.
- *Over-retained deciduous tooth*: In contrast, this term has a negative connotation and refers to a tooth whose unerupted permanent successor exhibits root development in excess of two-thirds of its expected final length (Figure 1.3). Here too, a radiograph of the permanent successor is required in order to determine the status of the deciduous tooth and its implied treatment.

Fig. 1.3 The mandibular left second deciduous molar is retained (extraction contraindicated), since the root development of its successor is inadequate for normal eruption. The right maxillary deciduous canine, in contrast, is over-retained (extraction advised), since the long root of its successor illustrates delayed eruption.

- *Permanent tooth with delayed eruption*: This term refers to an unerupted tooth whose root is developed in excess of two-thirds of its expected final length and whose spontaneous eruption may nevertheless be expected within a reasonable time.
- *Impacted tooth*: This refers to a tooth whose root is developed in excess of two-thirds of its expected final length, but which is not expected to erupt in a reasonable time.

When assessing the dental age of the patient, it is important to emphasize that one should not include the maxillary lateral incisors, the mandibular second premolars and the third molars in this calculation. The development timetable of these teeth is not always in line with that of the patient's other, ontologically more stable teeth [9, 10]. These are the same teeth that are most frequently congenitally missing in cases of partial anodontia (hypodontia) or oligodontia. Indeed, reduced size, poorly contoured crown form and late development of these teeth are all considered microforms of congenital absence [9–12]. The variation in their timing is, however, always expressed as *lateness* and they are never seen in a chronologically more *advanced* state of development than the other teeth. If the individual dental age of any of these variable groups of teeth is advanced, then so too is the dental age of the entire dentition in which they are to be found.

In summary, therefore, we may assert as follows:

- All orthodontists must have at their fingertips the ages at which the permanent teeth normally erupt.
- Permanent teeth normally erupt when approximately two-thirds of their final root length has developed.
- The remainder of the root reaches apexification approximately 2½–3 years after eruption.
- Determining the closed apex of the tooth on a radiograph is usually an easy and accurate parameter to establish.
- Determining the completed proportion of the root of a tooth, whose final completed length is unknown, is not an assessment that can be performed accurately. It rather falls into the realm of informed guesswork.

Having now set out the principles upon which dental age may be assessed, we must turn to the practical side of translating these principles into clinical terms in a logical, systematic and didactic manner. The simplistic way of adopting the above principles would be to take the panoramic radiograph or full-mouth periapical survey and then work around each dental arch from one tooth to the next, individually and from left to right, upper to lower, evaluating each tooth in turn. This would then require coordinating all the individual results and computing a final figure that is the dental age of the patient. The resulting conclusion would have to be compared against the values seen on an idealized chart of the norms for a given population [1, 4, 13]. Although this method delivers accuracy, it requires a considerable time and it is likely to take an hour or so to reach the final conclusion. It is an arduous and tedious endeavour, which does not lend itself to the conditions that are present in a busy clinical orthodontic practice.

What is recommended is a simple, logical but systematic approach that can be employed chairside to reach a similar conclusion in just a few minutes, even at the initial orthodontic consultation visit. This method will rely on the same criteria of establishing the development of crown and root, but must do so in a step-by-step manner, starting from a different point of departure. The 'starting point' of this systematic approach has, for reasons that will be explained in the following paragraphs, been set at the cut-off dental age of 9 years.

Assessing dental age in the clinical setting – the Jerusalem method

There are several criteria that are appropriate to the appraisal of tooth development when using full-mouth periapical radiographs or a panoramic film. The information that is available regarding the ages at which the various stages of dental development occur is based on the classic random studies that have been carried out over many decades of the local populations of the researchers involved. The figures for the mean ages at which these stages occur, in the hypothetical child, are as follows:

1 The first signs of the presence of a tooth are discernible radiographically with the initiation of calcification of incisal edges and cusp tips. Thereafter, one may observe the formation of the completed crown as well as progressive degrees of root formation (usually expressed in fractions), and thence the fully closed root apex. Since orthodontic treatment is largely performed on a relatively older section of the child population, the stages of actual formation of the root become the only relevant factors.
2 The accuracy with which one may assess fractions of an incomplete, immeasurable and merely 'expected' final root length is not reliable and is very much a matter of individual observer variation.
3 The stage of tooth development that is easiest to define with confidence and with accuracy is that which relates to the closure of the root apex. So long as the dental papilla at the root end remains discernible, the apex is open and Hertwig's root-forming, epithelial sheath is in an active stage of increasing root length. However, once fully closed, the papilla disappears and a continuous lamina dura will be seen on a periapical radiograph, closely following the root outline. These are the specific diagnostic signs of that landmark event. Apexification is therefore the most important single factor upon which a

system of assessment may be faithfully and easily made of the dental age of a given patient in the clinical environment.

4 From population studies, we learn that the first permanent tooth to erupt in the mouth is the mandibular central incisor, closely followed by the first permanent molars, and this occurs at the age of 6 years.

5 Root development of the permanent teeth is completed approximately 2.5–3 years after their normal eruption [4]. This allows us to conclude that, at the age of 8.5–9 years, the child's mandibular incisors will be the first teeth to exhibit closed apices and will usually be closely followed by the four first permanent molars. This being the case, it is clear that the age of 9 years must be the basic starting point from which to commence the evaluation of the child's dental age. If mandibular incisors or molars demonstrate root closure, then the tentative diagnosis would be that the patient has a dental age of *at least* 9 years. If the apices are still open, then the conclusion would be that the child has a lower dental age.

It should be emphasized, however, that the exercise is aimed at ranking a specific child's dental development vis-à-vis the above hypothetical mean. Whether or not the evaluated tooth has actually erupted is entirely irrelevant to this equation.

Let us examine the progressive diagnostic path in its correct order (see also Table 1.1):

1 If the mandibular central incisor roots are complete, we may presume that the patient is at least 9 years old (dental age), i.e. this figure is derived from 6 years (the normal age of eruption as determined by two-thirds root length development), with the addition of 2.5–3 years to apexification.

2 We may then proceed and check for closed apices of the first molars (9–9.5 years).

3 At 9.5 years, the mandibular lateral incisors roots will have completely developed.

4 The next teeth in the expected eruption series are the maxillary central incisors, whose closed apices would indicate a dental age of 10 years.

5 Because their rate of development is variable, it would be wise to bypass the assessment of the maxillary lateral incisors at this point in the diagnostic process and move on to examine the later teeth.

6 Apexification of the mandibular canines and first premolars (12–13 years).

7 Thereafter, the maxillary first premolars (13–14 years).

8 In common with the maxillary lateral incisors, the mandibular second premolars are also developmentally variable teeth and their assessment should also be bypassed for the present calculation.

9 Next there are the maxillary canines (14–15 years).

10 The final stage of development relates to the four second molars (15 years).

Table 1.1 Apexification age of individual tooth types.

9 years	Mandibular central incisors
9–9.5 years	First molars and mandibular lateral incisors
10 years	Maxillary central incisors
11 years	Maxillary lateral incisors
12–13 years	Mandibular canines
13–14 years	Maxillary first premolars
14–15 years	Second premolars and maxillary canines
15 years	Second molars

This stage-by-stage apexification determination will lead us to the last tooth in this sequence with a closed apex (Figure 1.4), which indicates the dental age of the patient. Once the determination is completed, it is valuable to return to the maxillary lateral incisor and the mandibular second premolar. If these are developing normally, then their age of eruption would be 8 years and 11 years, respectively, with an apexification date of 11 and 14 years, respectively. Retarded development of these individual teeth may be age assessed according to the above criteria for calcification. An illustration of this situation would be where the overall dental age assessment is diagnosed as 12 years, yet the right maxillary lateral incisor might match a 9-year-old child and the left mandibular second premolar might even be characteristic of someone 8 years of age.

In contrast to the above process of examination and assessment and in the case of a dental age less than 9 years, none of the permanent teeth will have completed their root development. Here clinicians will have no choice but to rely on their own estimation of the degree of root development, of the degree of crown completion and, in the very young, of the stage of initiation of crown calcification (Figure 1.5). This is most conveniently carried out by working backwards from the expected development at age 9 years and, with this as a base, comparing the dental development

Fig. 1.4 Root apices are closed in all first molars, all mandibular and three of the maxillary incisors, excluding the left lateral incisor. Canine and premolar apices are open.

Fig. 1.5 No closed apices. Dental age assessment 7–7.5 years.

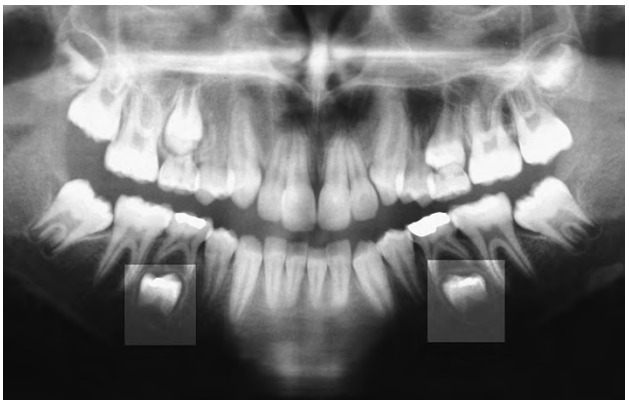

Fig. 1.6 Late-developing second mandibular premolars with retained (*not* over-retained) deciduous second molars in a child with a dental age of 11–12 years. The contrast and brightness of this poorly contrasted picture have been adjusted in the relevant areas to clearly show the stage of development of these tooth buds.

status of the patient, beginning with the mandibular central incisors and the first permanent molars.

By way of illustration, at a dental age of 6 years the length of the roots of the mandibular central incisors and the first permanent molars will be seen to be one-half to two-thirds developed. Confirmation of this will come from a comparison, which may be made with the development stage reached by the other teeth, where one would anticipate that unerupted maxillary central incisors will have reached one-half root length, mandibular canines one-third root length, first premolars one-quarter root length, and so on.

As already noted, however, variations do occur, particularly with maxillary lateral incisors, mandibular second premolars or third molars. This may lead to certain apparent contradictions. It is therefore recommended to exclude consideration of these teeth when making the relevant assessments and thereby not only simplifying the process, but also contributing to the accuracy of the resulting assessment.

In addition, as stated above, *early* development of these teeth in relation to the development of the remainder of the dentition does not appear to occur. Indeed, individual variability is expressed only in terms of degrees of *lateness*. Accordingly, the developmental status of these teeth is available as corroborative evidence for the determination of dental age, but only if their own developmental stage is shown to be in line with the remainder of the dentition.

In a similar way, one should not incorporate abnormal features in the calculation process of the assessment of dental age. Unusually small teeth, coniform premolars, mandibular incisors and peg-shaped lateral incisors are all wont to develop very much later than normally shaped and sized teeth of the same series; indeed, sometimes as much as three or four years later. Thus, in diagnosing dental age for a patient with an abnormality of this nature, a general determination of the dentition should point out that this abnormal tooth may display a much lower dental age. A 14-year-old patient who has a complete permanent dentition, including the second molars, may yet exhibit a mandibular second deciduous molar. The radiographs (Figure 1.6) show the apices of the first molars, central and lateral incisors, mandibular canines and premolars to be closed, while the maxillary canines and the second molars are almost closed. However, the unerupted mandibular second premolar has an open root apex and presents a development stage equivalent to about a quarter of its expected eventual length, or even less. Correspondingly, although we may assess the dental age of the dentition as a whole to be 11-12 years, we would have to point out that the dental age of the unerupted second premolar is approximately 7 years. The conclusion here, in the context of this terminology, is clearly that the second premolar, *individually*, does not exhibit delayed eruption and the deciduous second molar is not over-retained. Thus, it would not be appropriate to extract the deciduous tooth at this point, but rather to wait for at least a few years, during which time the tooth may be expected to shed normally.

In summary, there are four different parameters that can explain the existence of certain deciduous teeth that are inconsistent with the chronological age of the patient. Each of these parameters has clinical repercussions and labelling a patient as one particular grouping will in fact dictate the nature of the treatment required:

1 *A late-developing dentition*: In this condition the dental age of the patient has developed slower than his chronological age. This is evident radiographically by a lesser root formation in the entire dentition than that which is expected at the chronological age. Typically, this is accompanied clinically by the continued and symmetrical presence of all the deciduous molars and canines on both sides of the jaw. Here, the extraction of deciduous teeth is contraindicated, since the teeth are expected to exfoliate normally when the appropriate *dental* age is reached.