Color Atlas of Dental Medicine

Editor:
Herbert F. Wolf

Orthodontic Therapy

Fundamental Treatment Concepts

Andrea Wichelhaus
with the assistance of Tena Eichenberg

Thieme

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3922 illustrations

Thieme
Stuttgart • New York • Delhi • Rio de Janeiro

Library of Congress Cataloging-in-Publication Data

Names: Wichelhaus, Andrea, author. | Eichenberg, Tena author.

Title: Orthodontic therapy: fundamental treatment concepts / Andrea Wichelhaus; with the assistance of Tena Eichenberg.

Other titles: Kieferorthophadie—Therapie. English

Description: Stuttgart; New York: Thieme, [2017] | Series: Color atlas of dental medicine | Includes bibliographical references and index. | Identifiers: LCCN 2017023011 (print) | LCCN 2017024687 (ebook) | ISBN 9783132008618 | ISBN 9783132008519 (hardcover: alk. paper) | ISBN 9783132008618 (eISBN)

Subjects: | MESH: Malocclusion—therapy | Orthodontics—methods | Atlases

Classification: LCC RK521 (ebook) | LCC RK521 (print) | NLM WU 417 | DDC 617.6/43—dc23

LC record available at https://lccn.loc.gov/2017023011

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Translator: Angela Trowell, Radstock, UK

Thieme Publishers Stuttgart
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+49 [0]711 8931 421, customerservice@thieme.de

Thieme Publishers New York
333 Seventh Avenue, New York, NY 10001 USA
+1 800 782 3488, customerservice@thieme.com

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A-12, Second Floor, Sector-2, Noida-201301
Uttar Pradesh, India
+91 120 45 566 00, customerservice@thieme.in

Thieme Publishers Rio de Janeiro,
Thieme Publicações Ltda.
Edifício Rodolpho de Paoli, 25º andar
Av. Nilo Peçanha, 50 – Sala 2508
Rio de Janeiro 20020-906 Brasil
+55 21 3172 2297 / +55 21 3172-1896

Cover design: Thieme Publishing Group
Typesetting by DiTech Process Solutions Pvt. Ltd., India

Illustrations: Anja Günter, Munich, Germany; Adrian Cornford, Reinheim-Zeilhard, Germany
Cover illustration: Anja Günter, Munich, Germany

Printed in China by Everbest Printing Ltd 5 4 3 2 1

ISBN 978-3-13-200851-9

Also available as e-book:
eISBN 978-3-13-200861-8

We look forward to the future as reflected in the curiosity in the eyes of this world's children.

Andrea Wichelhaus
Tena Eichenberg

Contents

Preface

Practical application of science was our motivation for writing this book. Our desire to present orthodontics in a practical manner—without purely philosophical considerations but based on scientific background—posed a constant challenge during the development phase. Georg Thieme Verlag offered us a unique opportunity to record our own therapeutic concept, rather than trying to describe and evaluate all conceivable therapeutic approaches. The atlas enables fellow practitioners to refer to a treatment concept that has been technically proven and scientifically scrutinized. One of our main objectives was to provide our colleagues with feasible therapeutic targets and the requisite basic principles of biology, mechanics, and biomechanics. The clear structuring of the book into sagittal, transverse, and vertical anomalies is intended to provide clear guidance.

This book is the product of many years of research, practical experience, and further training and reflects our therapeutic concept in orthodontic treatment with extensive illustrations. It was fascinating to analyze our own therapeutic approaches, current literature, and scientific studies resulting from many years of work at the universities of Ulm, Basel, and Munich. Modernity is an ongoing process in the debate with colleagues and current literature concerning various key areas of orthodontics and related medical fields. What matters to us is developing orthodontics in dialog, not insisting on our own point of view.

Our thanks go to all those who have made this book possible through their support—the universities of Ulm, Basel, and Munich, the professors, senior physicians and training assistants, scientific laboratory staff who work there, and, in practical terms, the secretarial assistants, photographers and graphic designers as well as dental assistants at the hospitals and polyclinics. In particular, we would like to thank Dr. Uwe Baumert, Dr. Andrew Boryor, Ms. Birgit Bartl, and Ms. Anja Günter. At this point, we would also like to remember and express our gratitude to our teacher Prof. Dr. Franz Günter Sander (†March 10, 2012), for whom scientific and critical analysis in the field of orthodontics was an essential part of life.

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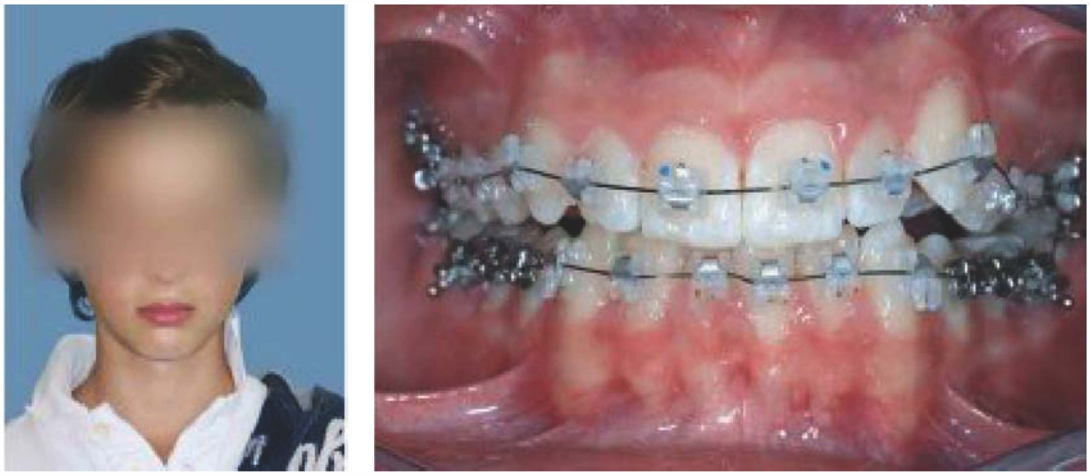
1 Fundamental Problems in Orthodontics

Successful orthodontic treatment of anomalies requires a fundamental knowledge of orthodontic tooth movement itself, together with its biomechanical parameters. The kind of tooth movement, intrusion, extrusion, and rotation as well as tipping versus bodily tooth movements must be continuously adjusted to suit the particular patient in terms of the magnitude of force used during the individual treatment phases. Biological knowledge of tooth movement has led to the current concept of the light wire technique in orthodontic treatment. Genetic factors may play a part in the orthodontic tooth movement itself and the orthopaedic effects of the anomaly. The therapist must be aware that most orthodontic treatment involves patients who are still growing. Stability and retention planning are closely linked to the growth parameters of the particular anomaly. In orthodontic therapy, side effects in the form of decalcification, attachment loss, and resorption may occur, which, in many cases, can be avoided by means of appropriate diagnosis and patient selection.



1 Patient-specific individualized therapy

As individual responses differ, each stage of development in the individual anomaly group must also be dealt with differently. In young patients, in whom tissue responses are expected to be good, orthodontic treatment can be performed successfully in most cases if the fundamental problems of orthodontic therapy are taken into consideration.

2 Patient-specific individualized therapy

Treatment in adult patients requires a different approach because of altered conditions in terms of biomechanics, bone response, and additional dental and other diseases as well as altered attachment. In many cases, the biomechanically and biologically altered conditions also require a different treatment technique.

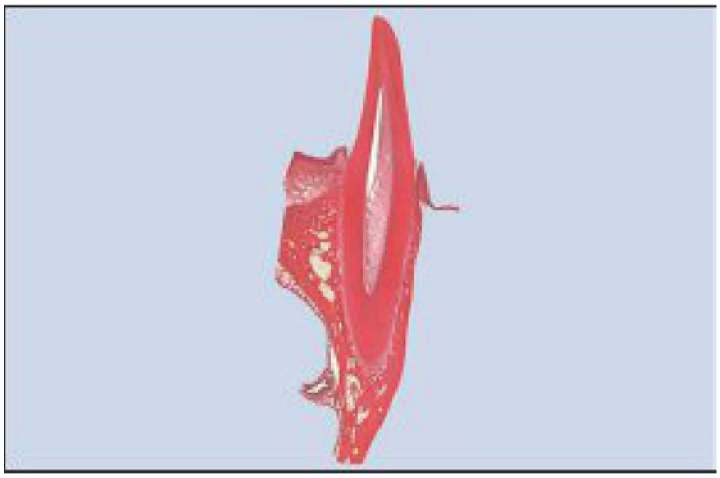
1.1 Biomechanical Factors

Orthodontic treatment is a combination of the orthopaedic impact on the bone, or to be more precise, the maxilla and the mandible, and the orthodontic effect on the teeth. The biomechanical response is dependent on factors such as the magnitude of force, direction (force vector), and frequency (Roberts 2012). Orthopaedic effects presuppose modulation of the bone and sutures. Dental effects require an intact periodontal ligament (PDL) and bone modeling and remodeling processes (**Fig. 1**, **Fig. 2**).

The structure, bone density, and extent of bone coverage of the individual teeth are important for the biomechanics of the resulting tooth movement. From an anatomical perspective, the maxilla—unlike the mandible—is directly linked to the cranium so that less compact bone is sufficient to distribute the stresses that affect the jaw as a result of masticatory forces (Roberts 2012). Accordingly, the maxilla is composed of more finely structured trabecular bone and the mandible of more compact bone (**Fig. 3**).

3 Bone structure of maxilla and mandible

The masticatory forces are transferred to the bones of the maxilla and mandible. As the maxilla is connected to the cranium anatomically, the bone is less compact, unlike the structure of the mandible. The trabeculae in the maxilla are therefore much more gracile and there is less compact bone than in the mandible. This must be taken into account when considering movement of the teeth and orthodontic anchorage. (Modified from a slide by Prof. Waschke, Anatomical Institute LMU Munich, Germany.)



4 Histological section: mandibular anterior tooth

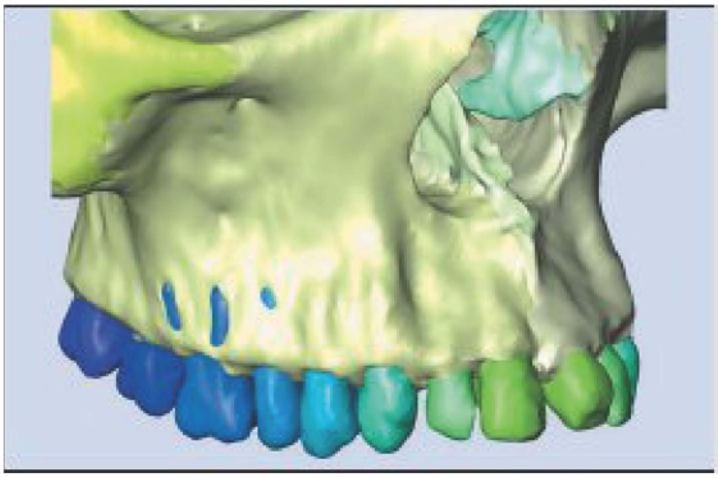
Bone coverage is not the same on all tooth surfaces. In the mandibular anterior tooth shown here, there is dense and sufficient lingual bone coverage from a lingual aspect. From a buccal aspect, the proportion of bone is thin. In the case of uncontrolled labial tipping, the risk of losing bone and attachment is high. Knowledge of the limits of anatomical structures is a prerequisite for successful orthodontic treatment.

Courtesy of Prof. Bartels, Anatomical Institute LMU Munich.

The structure of the bone is important for orthodontic tooth movement. High bone density and compact bone lead to less response in tooth movement. This affects not only the speed of tooth movement, but also the response of the tissue itself. Thus, the proportion of hyalinization is greater for oro-vestibular movements than for sagittal tooth movements (von Böhl et al 2004a, 2004b). This aspect must also be taken into consideration with regard to anchorage. While molars in the mandible migrate more slowly in a mesial direction due to the bone morphology and density, this movement is significantly faster in the maxilla. Biomechanically, given the same amount of sagittal tooth movement or gap closure, anchorage is unproblematic in the mandible, whereas in the maxilla the position of the molars has to be monitored in most patients. In our treatment concept, we therefore use Roth attachments as a straight wire concept for the maxillary molars and, if necessary, we add a transpalatal arch with and without anchorage bends. Micro-screws are required for maximum anchorage in extraction patients and/or adults.

In addition to the differences in the structure of the bone between the jaws, within one jaw the bone is not isotropic but anisotropic. Thus, molars in the mandible may move at different speeds in response to exactly the same biomechanics. Biomechanically, a certain amount of room for maneuver is therefore highly desirable for certain tooth movements in our treatment concept.

Buccolingual and buccopalatal bone coverage varies in individual tooth segments (**Fig. 4**). In particular, this is the case for the area comprising the incisors and the canines, the first premolars and first molars in the maxilla (Thilander 2012). In individual cases, fenestrations may even be found here (**Fig. 5**). Studies by Fuhrmann (1996) show that the buccal bone lamella is only 1 to 2 mm in histological sections. Based on these aspects, expansion of the dental arches in the permanent dentition using orthodontic appliances is only possible to a limited extent in our treatment concept. In many clinical cases, a rapid palatal expander (RPE) is indicated before insertion of the orthodontic appliance. The same is true for the buccopalatal axis adjustment of the posterior teeth to improve articulation and avoid balancing contacts. Buccal root torque in the maxilla is only possible if there is sufficient bone.



5 Buccal bone coverage

The cone beam CT of a patient shows the bone coverage of the teeth in the maxilla and mandible from the buccal aspect. The density of the cortical laminae varies in the individual areas. In particular, the bony covering of the incisors and canines and also of the premolars and first molars in the maxilla is thin from the buccal aspect. Fenestrations in the molar area are common. In many cases, an RPE is therefore indicated.

6 Mesial migration of the second molars in the maxilla and mandible

Following extraction of the first molars, the mesial migration tendency of the second molars is different in the maxilla and mandible. In the mandible, mesial tipping occurs when the second molars erupt and this makes further treatment mechanics difficult.

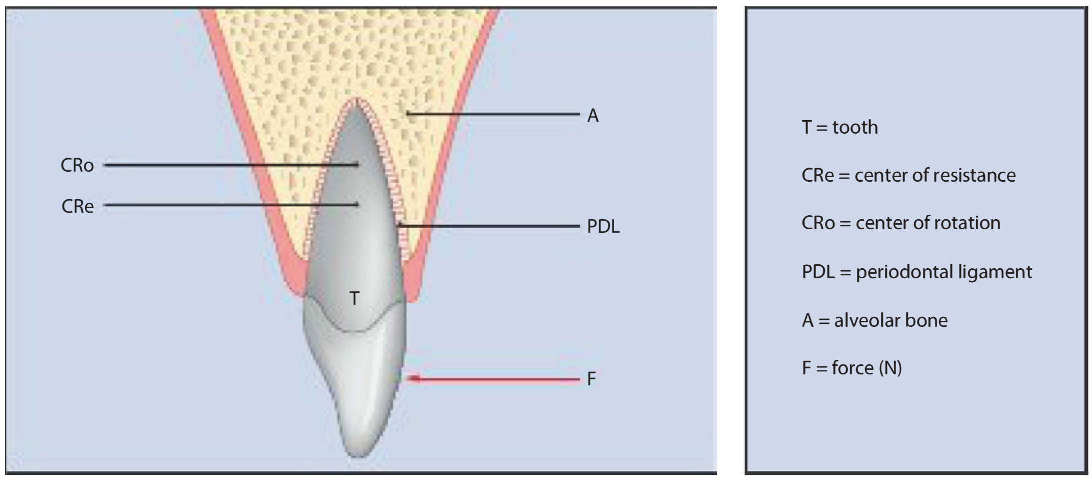
Left: With unfavorable maxillary sinus development, tipping can also be expected in the maxilla.

Radiological studies by Fuhrmann (1996) show the same critical situation in mandibular incisors. Given uncontrolled labial tipping, as may occur in the leveling phase with NiTi archwires, there is a high risk of losing attachment during orthodontic treatment (**Fig. 4**). A detailed spatial analysis to correct existing crowding and monitoring of arch length during leveling are therefore important parameters of orthodontic therapy.

The movement of the maxillary molars in a mesial direction is faster than that of the mandibular molars. Following extraction of the first molars in the mandible, there is clinically no bodily mesial movement, but tipping of the tooth occurs in most patients (**Fig. 6**). In the maxilla, the second molars tip less and migrate almost bodily in a mesial direction. This is related to the more favorable bone structure for root movement, and makes closure of the gap in a distal to mesial direction easier in clinical terms. However, favorable maxillary sinus conditions are a prerequisite. In the case of tooth movement that is not orthodontically induced, mesial movement may thus be made more difficult (**Fig. 6**).

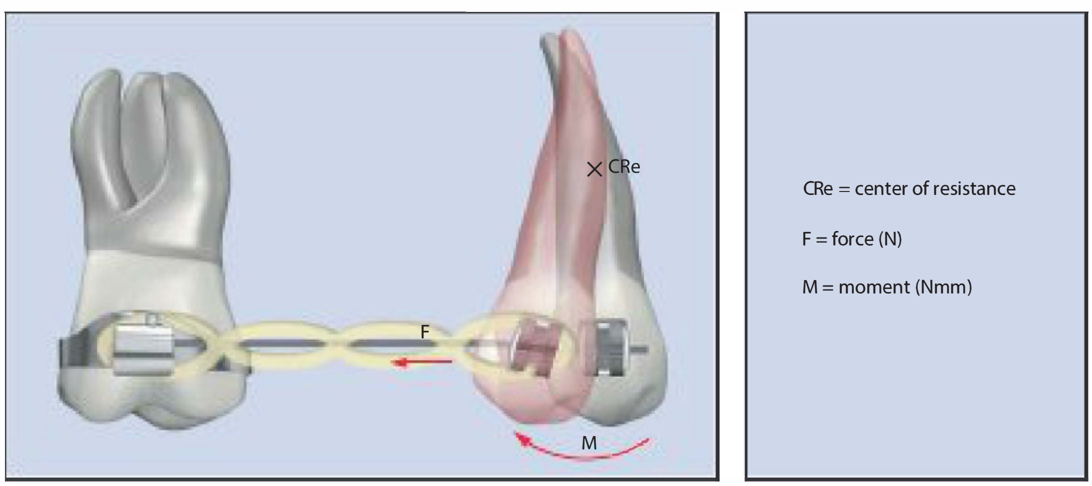
1.1.1 Tipping Tooth Movement

Biomechanically, a distinction must be drawn between a tipping and a bodily tooth movement. Force may be applied or transmitted via spring elements or screws on removable appliances and, in the case of fixed orthodontic appliances, via wires or tensile and pressure mechanisms. In the biomechanical consideration of tooth movement, in addition to the movement of individual teeth, the movement of groups of teeth is of interest. In terms of the movement of teeth, there is always a unit consisting of tooth, PDL, and adjacent alveolar bone (**Fig. 7**). A center of resistance (CRe) and a center of rotation (CRo) can be defined for the movement of individual or groups of teeth. The location of the CRe depends on the tooth and the associated root geometry. For a single-rooted tooth, the CRe is assumed to lie between the cervical root third and half of the root length; for a multi-rooted tooth, it lies 1 to 2 mm apically of the bifurcation or trifurcation (Pedersen et al 1990). The CRe is not a really constant value as it may move its location in an apical direction during tooth movement as a result of a change in the unit comprising tooth, PDL, and bone attachment.



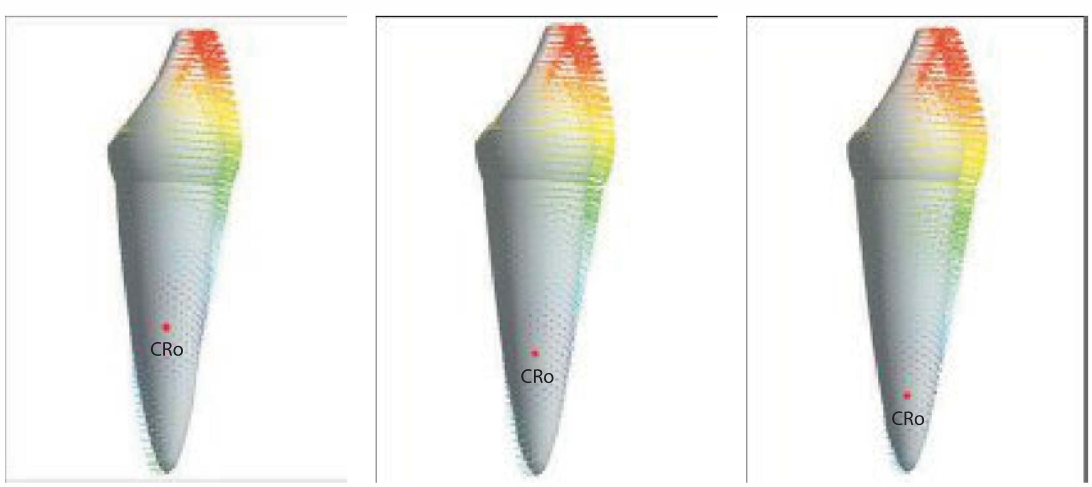
7 Biomechanical factors involved in tooth movement

In terms of tooth movement, a distinction must be drawn between the movement of individual teeth and the movement of groups of teeth. A CRe and a CRo can be determined for the movement of individual teeth and groups of teeth. The biomechanical unit always consists of tooth, PDL, and surrounding alveolar bone. The CRe depends on the attachment.



8 Tipping tooth movement

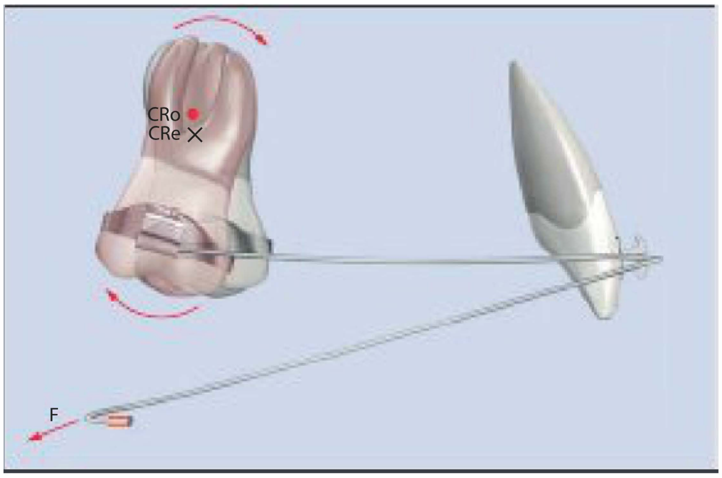
In the case of tipping tooth movement, force is applied coronally. In orthodontic therapy, it can be applied via chains or NiTi tension springs. The force acting (eccentrically) beneath the CRe produces moment, which leads to tipping of the tooth. The amount of moment is dependent on the magnitude of force of the chain or spring and the distance of the force application point from the CRe.



9 Center of rotation

The CRo is determined by the force application point and the magnitude of force. The CRo is represented by missing arrows as there is no movement here. The simulation shows the CRo as a function of force transmission, magnitude of force, and M/F ratio (moment/force ratio). The CRo is apical with an M/F ratio of 8 (right). If the M/F ratio is smaller, the CRo migrates in the direction of the CRe (center and left).

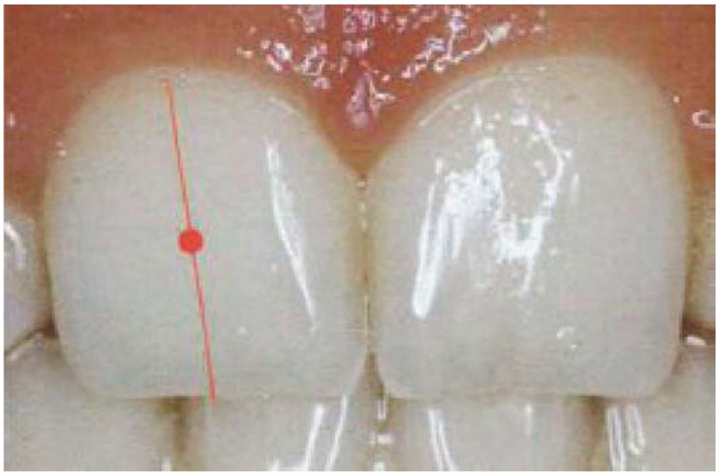
A tipping tooth movement is produced as a result of eccentric transmission or application of force, the vector of which does not run through the CRe. Due to anatomical conditions, this is usually in a coronal direction (**Fig. 8**). The resulting clinical effect is tipping of the tooth as the transmitted force acts as torque on the tooth. If the force is too great or the transmission of force is too far in a coronal direction (in the case of headgear due to excessive angulation beyond the crown), the CRo migrates in the direction of the CRe (**Fig. 9**, **Fig. 10**). In the worst-case scenario, the tooth is then moved in the opposite direction not only with the crown, but also in an uncontrolled way with the root. With headgear, this can lead to loosening of the tooth without a clinical distalization effect. In orthodontic treatment, when the incisors are retracted, a small sagittal apical base and uncontrolled application of force may give rise to an unwanted vestibular movement of the roots (**Fig. 11**, **Fig. 12**). These are critical movements, in particular in the orthodontic treatment of Class II/1 anomalies with thin vestibular bone coverage.



10 Biomechanics: headgear angulation

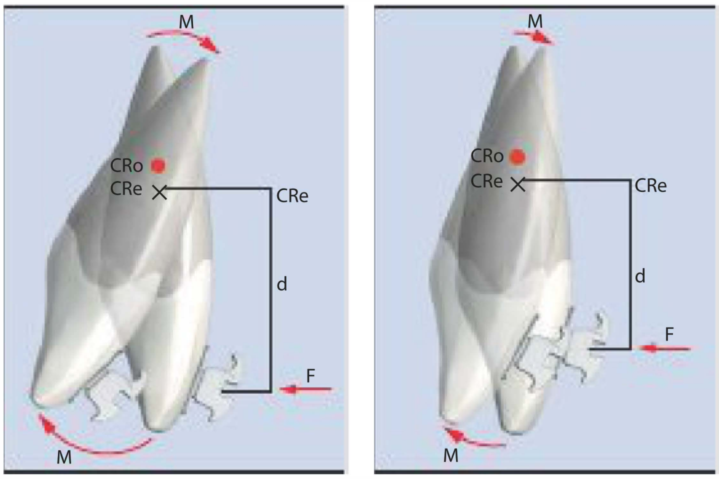
If the angulation of the headgear is too far in a caudal direction, the CRo migrates in the direction of the CRe and the tooth is only loosened, but not moved in a distal direction.

In the first phase of distalization of the molars with headgear, the external arm of the headgear is therefore not angulated in the case of low pull, so that the CRo is located apically and only the crown is moved in a distal direction.



11 Biomechanics: bracket positioning

If a bracket is positioned too far in a coronal direction, a more propalatal tipping of the anterior teeth is to be expected due to a longer lever arm (distance of bracket to the CRe). To guarantee precise, targeted force and moment application, the center of the clinical crown is therefore a reproducible and acceptable bracket position. Greater deviations result in undesirable clinical side effects.

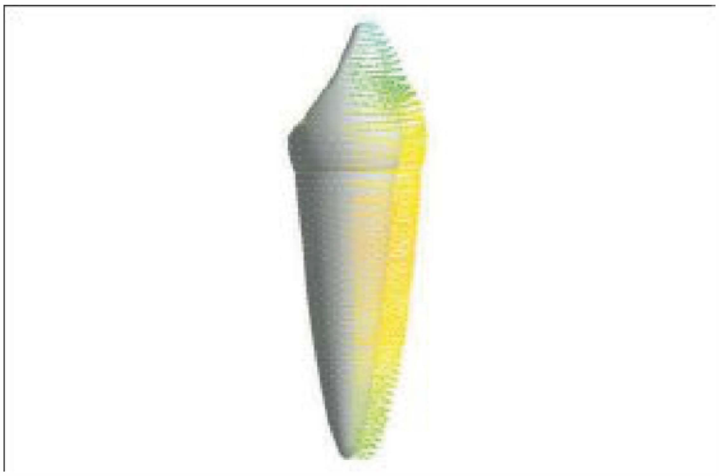


12 Biomechanics: magnitude of force and bracket positioning

Where eccentric forces are too great and a bracket is wrongly positioned, tipping is greater in a palatal direction. In addition, the CRo migrates in the direction of the CRe (left) and moment is also transferred mesially to a root movement that is usually undesirable. This is an effect to be avoided, especially in patients with a small apical base.

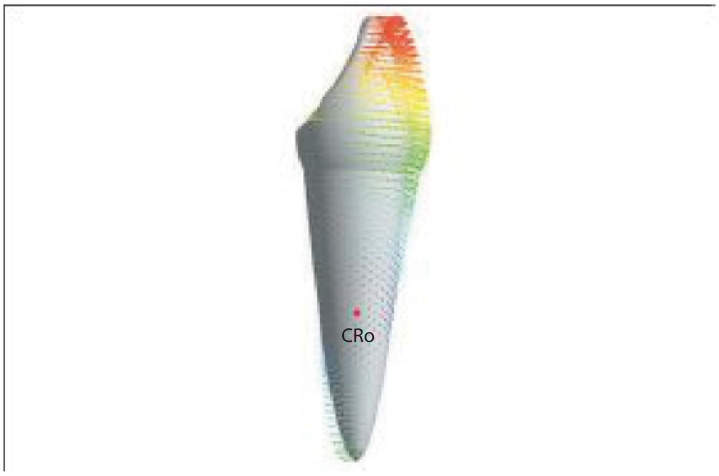
1.1.2 Bodily Tooth Movement

The bodily movement of individual teeth or groups of teeth is the best form of tooth movement in biological terms. The tension arising in the tissue due to the force applied is evenly distributed in the periodontium, alveolar bone, and tooth. Fewer or no stress peaks occur in individual areas (**Fig. 13**, **Fig. 14**). Clinically, this is true for sagittal movement, but not for intrusive moments; even bodily intrusion movements can lead to stress peaks at the root tip. With a simulated tipping tooth movement, the individual stress peaks in the tooth are evident (**Fig. 14**). In biological terms, it is a less favorable form of tooth movement. Biomechanically, a bodily tooth movement can only be obtained if the force runs through the CRe of the tooth to be moved (**Fig. 15**, right). Clinically, however, this is not possible for anatomical reasons. Translation of the tooth can only be achieved by means of the combined application of forces and moments (**Fig. 15,** center). During sagittal tooth movement with orthodontic appliances, moment is transmitted by means of the angulation in the bracket.



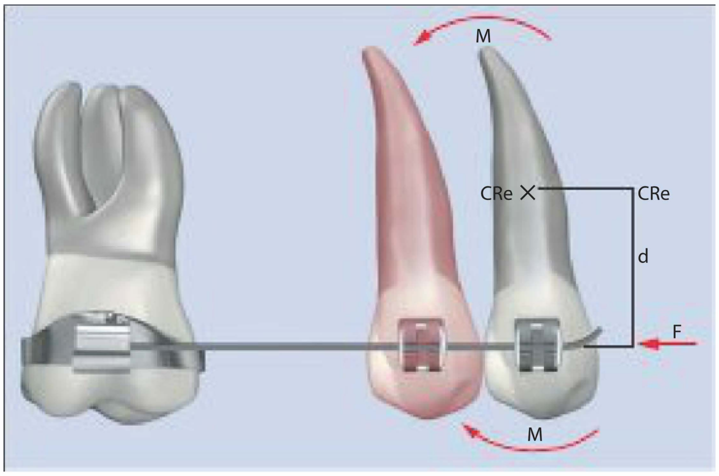
13 FE simulation: translational tooth movement

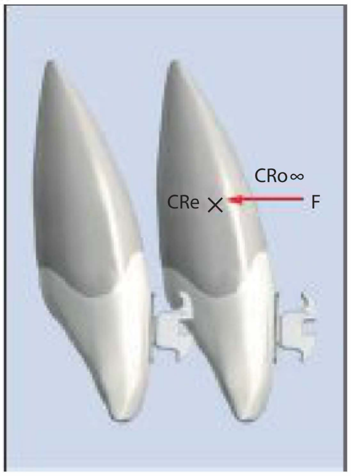
A purely translational movement of the tooth is a bodily movement. The stresses produced by the forces are distributed over a wide area on the surface of the tooth, PDL, and bone. As a result, no local stress peaks that compress the periodontal gap too much and result in orthodontic side effects occur in individual areas.



14 FE simulation: tipping tooth movement

In the case of a tipping tooth movement, tension peaks occur in the coronal-apical area and the root in the area of the apex. As a result, the stresses are not distributed over an entire area and the risk of excessive compression in individual areas is high.



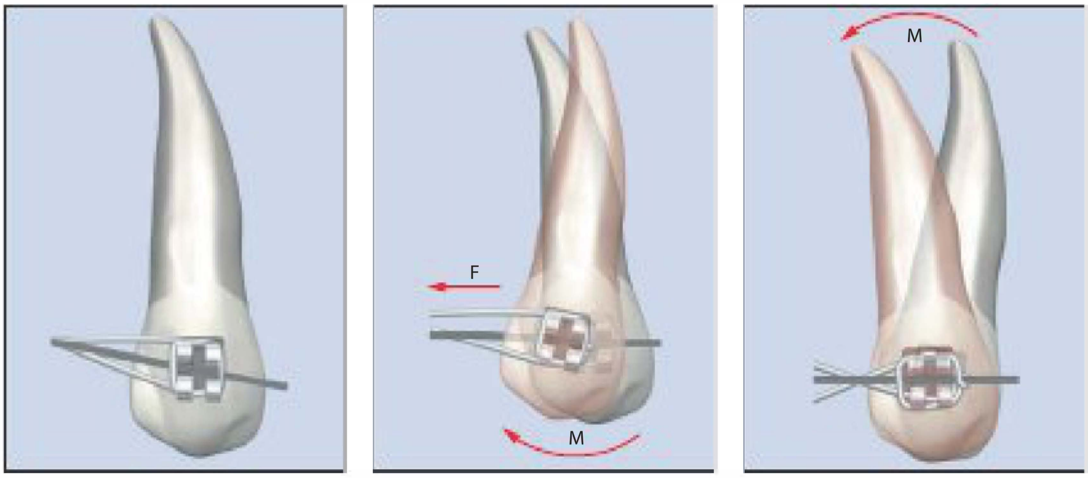


15 Biomechanics: bodily tooth movement

A bodily tooth movement may take place biomechanically through the combination of force (F) and moment (M). Ideally the M/F ratio should be 10 (left).

Right: A bodily tooth movement can take place as a result of force being transmitted directly through the CRe. However, this does not occur clinically due to anatomical circumstances, while the CRo is located in infinity.

Clinically, crown tipping precedes root movement. Using today's straight wire technique, a tipping tooth movement rather than a bodily movement is thus performed biomechanically. However, the clinical result is that a bodily tooth movement is achieved. The tooth movement itself is a tipping of the crown, combined with subsequent root uprighting (**Fig. 16**). This is additionally complicated by the fact that precise determination of the force and moment is clinically problematic as a result of variation of root geometry and individual attachment. Only slight changes in the root geometry of an upper molar will cause significant changes in the location of the CRo (**Fig. 18**). However, this also changes the tipping of the tooth or—in the case of a bodily tooth movement—the coordination of force and moment to be applied. A further complicating biomechanical factor for a clinical bodily tooth movement is the influence of material parameters. When analyzed, friction measurements display jagged rather than straight curves (**Fig. 17**). If this is transmitted to the teeth as impulses on account of the material, the clinical realization of a purely bodily tooth movement is doubtful. Due to varying parameters such as attachment, root geometry, and bone and PDL response, we refer to a biomechanically optimized tooth movement.

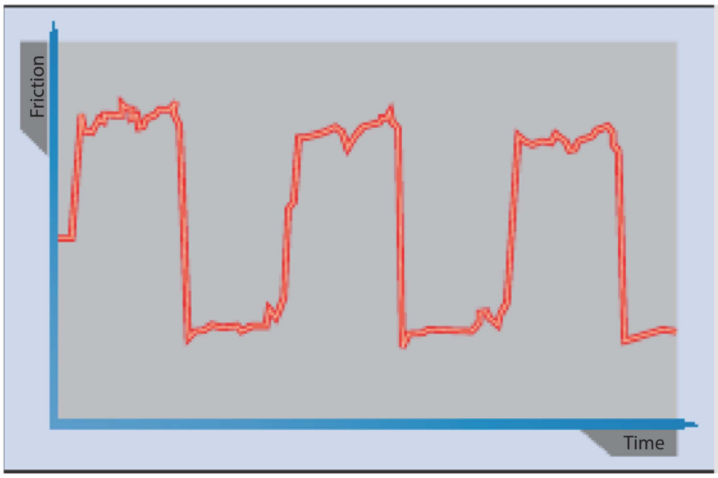


16 Clinical bodily tooth movement

Bodily movement in the sagittal plane is achieved by bracket angulation in straight wire therapy (left).

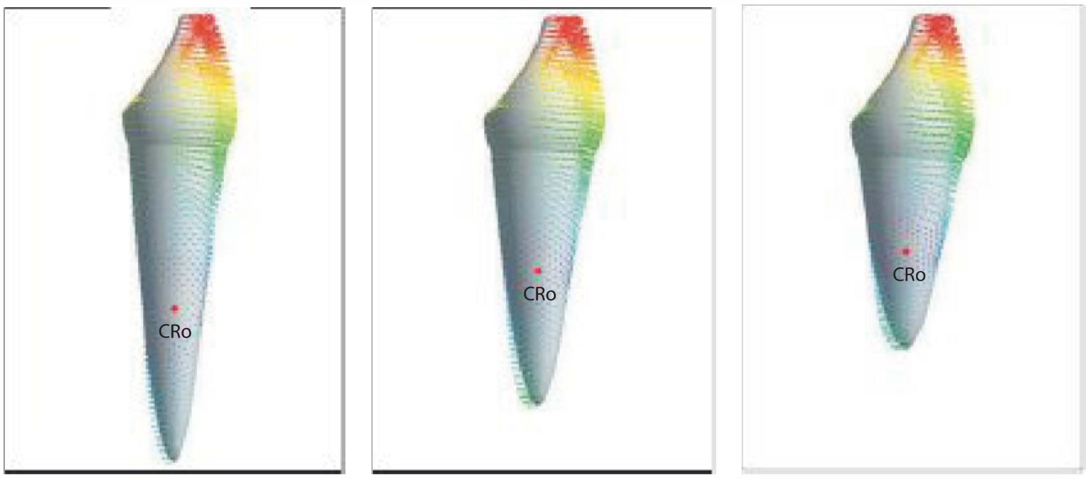
Center: The application of force primarily results in tipping of the crown as there is play between the archwire and bracket slot. The crown tips until the friction in the slot is great enough to halt further tipping.

Right: After tipping of the crown, the root is uprighted and this results in a bodily tooth movement.



17 Influence of friction on bodily tooth movement

In the case of archwire-guided tooth movement, the influence of friction via guidance of the tooth movement along the archwire is an important influencing factor. A precise look at the measurements shows that a uniform curve is not produced, but smaller or stronger impulses can equally have an influence on tooth movement. The influence of material parameters on tooth movement is not inconsiderable.



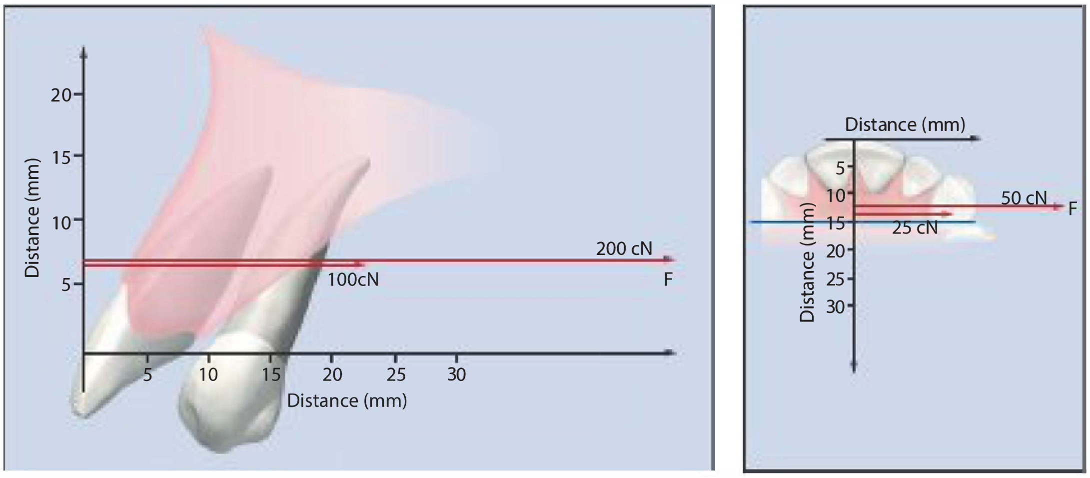
18 Influence of root geometry on the center of rotation and tooth movement

In the FE simulation of the root geometry of an anterior tooth, it is clear that realization and control via a bodily tooth movement is still clinically problematic nowadays. Variations in root geometry alter the CRo substantially and hence also alter the stress peaks on the tooth, PDL, and bone.

1.1.3 Centers of Resistance for Groups of Teeth

In the case of tipping and bodily tooth movement, not only individual teeth, but also groups of teeth can be moved. Clinically, this occurs with intrusion and extrusion as well as retraction and gap closure. It therefore makes sense to define the CRe not only for individual teeth, but also for two teeth (**Fig. 19**), four teeth (**Fig. 20**), and six teeth (**Fig. 21**) (Pedersen et al 1991). However, the determination of centers of resistance on macerated skulls is only an approximation of the actual clinical reality. In individual cases, radiological checks of the axial position are necessary before finishing, so as to correct any deviations, especially of the axial position of the anterior teeth.

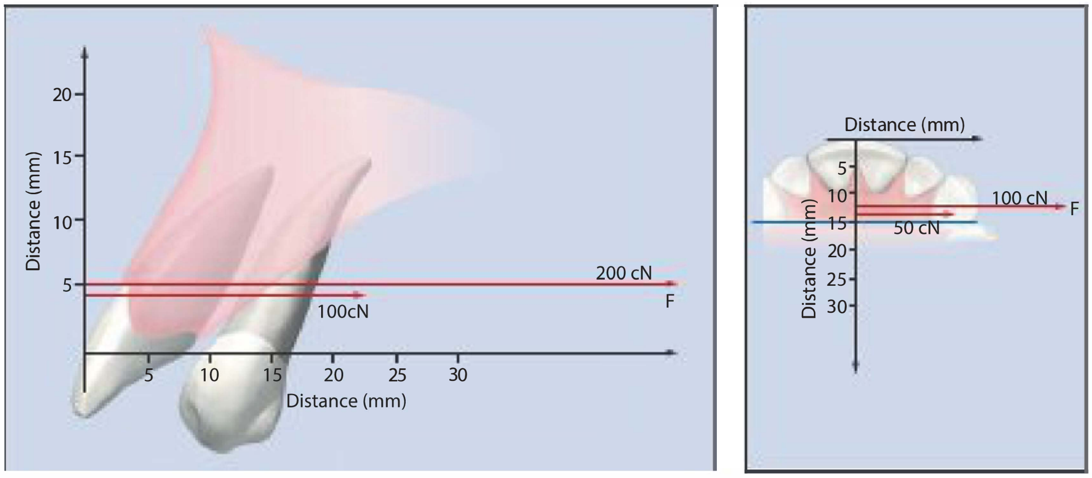
Clinical Indication–Movement of Groups of Teeth
- Class II/2 and intrusion of two central incisors
- Overbite and segmented intrusion of the four mandibular incisors
- Overbite and segmented intrusion of six mandibular incisors
- Retraction of the four maxillary and mandibular incisors
- En masse retraction of the six anterior teeth



19 Center of resistance for two incisors with sagittal and vertical forces

Center: Sagittal forces: the CRe for two incisors, with applied sagittal forces of 1 to 2 N, is approximately 6.5 mm apically from the vertical bracket position.

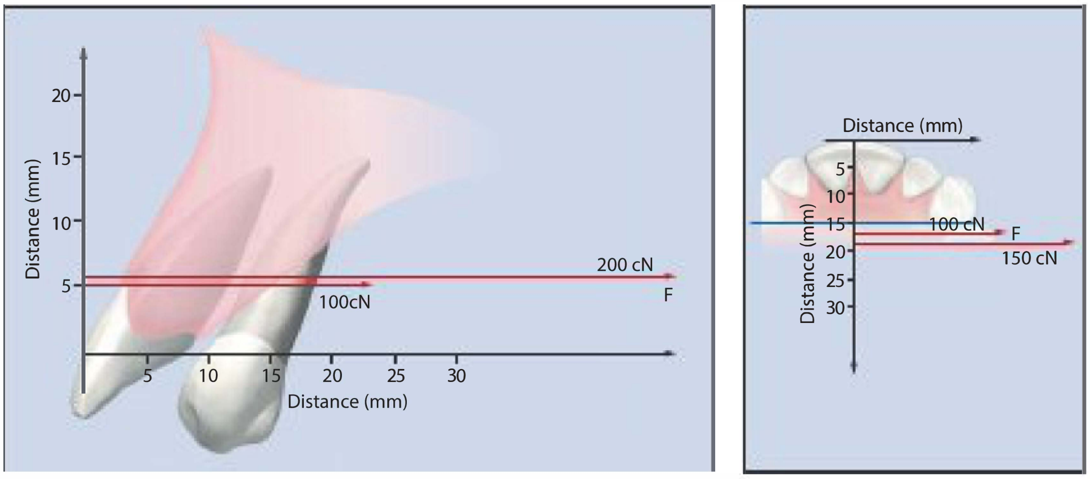
Right: Vertical forces: the CRe for two incisors, with applied vertical forces of 0.25 to 0.5 N, is approximately 13 mm distally from the bracket position or 3 mm anterior to the distal area of the canines. (Adapted from Pedersen et al 1991.)



20 Center of resistance for four incisors with sagittal and vertical forces

Center: Sagittal forces: The CRe for four incisors, with applied sagittal forces of 1 to 2 N, is approximately 5 mm apically from the vertical bracket position.

Right: Vertical forces: The CRe for four incisors, with applied vertical forces of 0.5 to 1 N, is approximately 13 mm distally from the bracket position or 3 mm anterior to the distal area of the canines. (Adapted from Pedersen et al 1991.)



21 Center of resistance for six incisors with sagittal and vertical forces

Center: Sagittal forces: The CRe for six incisors, with applied sagittal forces of 3 to 4 N, is approximately 5 mm apically from the vertical bracket position.

Right: Vertical forces: The CRe for six incisors, with applied vertical forces of 1 to 1.5 N, is approximately 19 mm distally from the bracket position or 3 mm posterior to the distal area of the canines. (Adapted from Pedersen et al 1991.)

The intrusion of two teeth occurs clinically in Class II/2 therapy. However, the location of the CRe is less significant because transmission of the force mesially to the CRe is indicated in almost 90% of cases. However, the CRe does need to be ascertained when treating adult patients (**Fig. 22**, **Fig. 23**). Incisors can thus be specifically intruded and retracted.

Knowledge of the location of the centers of resistance can also be used specifically for intrusion of the mandibular incisors with segmented archwires or micro-screws (**Fig. 20**, **Fig. 23**). The segmented intrusion mechanism shows this efficiently for intrusion of four incisors in the maxilla and mandible (Burstone 1977, Sander et al 1996). In our experience, the segmented archwire technique alone is not efficient enough for the intrusion of six anterior teeth. Either the canine must be intruded beforehand or the anterior teeth and the canines are intruded together using micro-screws.

The ideal force application point can be selected (**Fig. 20**, **Fig. 24**) for the intramaxillary retraction of incisors. For reciprocal anchorage, 5-mm-long power hooks are used. For maximum anchorage, a micro-screw is inserted at the corresponding vertical position. Torque loss is then greatly reduced.

22 Clinical: center of resistance for two incisors

Biomechanics are helpful in the retraction of two incisors in adult patients. Controlled retraction and intrusion thus result in a vertical attachment gain. Simple leveling with full archwires or sliding mechanics is not indicated in this patient. Controlled tipping, slight intrusion, and retraction with the application of force through the CRe are to be used in this clinical situation.

23 Clinical: center of resistance for four incisors

The intrusion of four incisors in the mandible is most effective if the force can be transmitted through the CRe. This does not produce any unwanted protrusion. In our patients, the protrusion of the mandibular incisors is only indicated in a few cases, with a segmented compound intrusion mechanism being used for clinical applications involving larger intrusion distances (see Chapter 3).

24 Clinical: center of resistance for four incisors

In the case of maximum anchorage, retraction of the incisors is achieved with the aid of micro-screws. The direction of pull can be selected by means of the height of the micro-screws such that the force runs through the presumed CRe of four or six incisors. At the same time, this results in good control of the axial position of the incisors. Given initial retroclination, however, torque and intrusion cannot be dispensed with.

1.1.4 Segmented Archwire Technique

The segmented archwire technique for specific treatment goals and individual patients is indispensable, despite using self-ligating or friction-reduced mechanics and materials. In the treatment of adults, it enables better control of biomechanics. When correcting crowding, it allows better control of the axial position of the incisors. In the case of intrusion, it permits transmission of force through the CRe and hence there are no side effects on the axial position of the incisors. In the case of larger sagittal movements, more effective and more efficient tooth movements are achieved with segmented archwires (**Fig. 25**, **Fig. 26**, **Fig. 27**).

Indication for segmented archwire technique

- Adult patient:
  - Better control of biomechanics
- Correction of crowding through slicing:
  - Control of the axial position of the incisors
- Intrusion of individual teeth or groups of teeth:
  - Force transmission through the CRe
- Distance of sagittal movements ≥ 4 mm:
  - No friction

25 Segmented archwire mechanism: adult patient

For better control of the biomechanics of complex movement patterns, a segmented archwire mechanism is often useful in the treatment of adult patients. In the patient shown here, the canine must be moved not only distally, but also palatally (left). With the segmented archwire, the individual force and moment components can be adjusted and then produce the clinical result (right).

26 Segmented archwire mechanism: modified sliding mechanics

If there is crowding of the anterior teeth with correct axial position, or if leveling of the curve of Spee is indicated, segmented archwires must be clinically employed. Due to the properties of the material, however, today's NiTi archwires no longer require a loop. At the same time, interproximal reduction of enamel or extraction is necessary with leveling.

27 Segmented archwire mechanism: moving distance ≥ 4 mm

For a moving distance of more than 4 mm, a simple tensile mechanism with chains, Class II traction appliances, or NiTi tension springs is insufficient. In spite of the 0.018 × 0.025 steel archwires simultaneously used, the tipping movement itself and the side effects of the tensile mechanism give rise to extrusive forces that make complete gap closure impossible and result in lingual or palatal tipping of the anterior teeth or a sagittally unfavorable position of the molars.

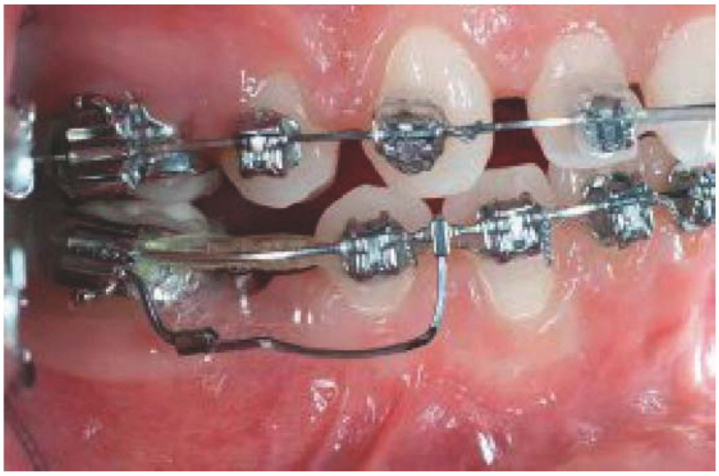
1.1.5 Sliding Mechanics

Sliding mechanics are user-friendly (**Fig. 28**), though they involve risks that result from biomechanical side effects on the full archwire. Clinically, however, sliding mechanics can be activated with greater ease and control, and consequently we employ modified sliding mechanics in our treatment concepts for young patients (**Fig. 29**, **Fig. 30**). These differ according to the various anomalies. Thus, for an Angle Class II/2 anomaly, intrusion is performed before leveling with a NiTi intrusion mechanism.

Indication for sliding mechanics
- Young patients
- Nonextraction patients
- Extraction patients with intermaxillary and reciprocal gap closure
- Extraction patients with intramaxillary gap closure (reciprocal or in a sagittal direction of movement)

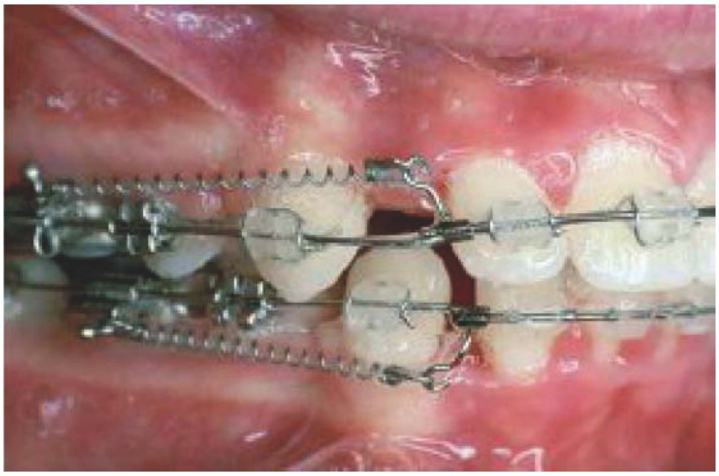
28 Modified sliding mechanics: nonextraction

Sliding mechanics can be employed in most cases where no extraction has been performed. In this patient group only slight sagittal movements are necessary. The influence of friction is therefore slight. Frequently, leveling of teeth and bite raising are paramount. The axial position in the mandible needs to be checked.



29 Modified sliding mechanics: extraction with intermaxillary gap closure

For many young patients, closure of the gap after extraction of four premolars may take place reciprocally via Class II traction mechanisms. The biomechanical side effects of traction appliances must be taken into consideration in the process. A prerequisite for the use of sliding mechanics in extraction cases is therefore a neutral or horizontally deep skeletal configuration.

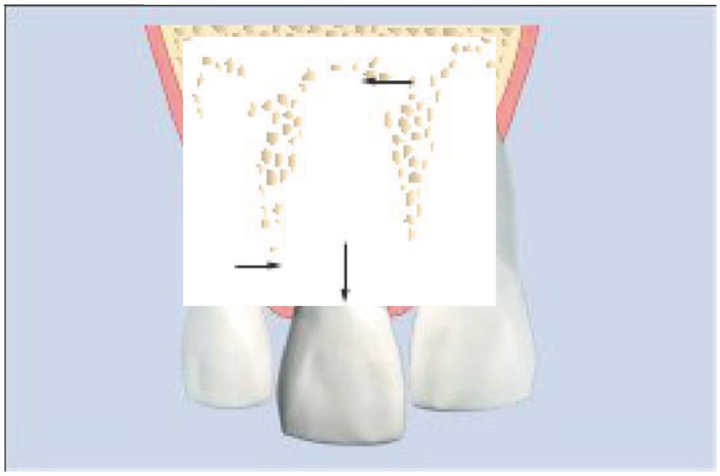


30 Modified sliding mechanics: extraction with intramaxillary gap closure

Sliding technology can also be used for intramaxillary or intramandibular gap closure. In particular, this is indicated for patients with a vertical skull structure. Anchorage in the jawbones must be properly taken into account. Compared with a segmented archwire, a full archwire requires more anchorage.

1.2 Extrusion

The extrusion of teeth is performed clinically in the region of the posterior teeth and the anterior teeth. Extrusion movements do not cause any compression of the PDL but cause tensile stresses, which are transmitted via the PDLs to the bone (**Fig. 31**). Although no compression of the PDL occurs, slight forces should be applied to ensure that the tooth is not moved out of the alveolus during orthodontic treatment. In young patients, the PDL fibres are stretched to a varying extent. According to Thilander (2012), the supra-alveolar fiber bundles are more affected than the central and apical PDLs by stretching (**Fig. 31**). The majority of the fibers stretched during extrusion adapt after a short retention phase. However, the supra-alveolar fiber bundles remain stretched for longer and are seen as a factor in the greater instability of the extrusion versus the intrusion movement (Thilander 2012). Regeneration of the PDLs takes place at different speeds in young people and adults. This must be taken into account with respect to retention.



31 Extrusion and response of the PDL and bone

The extrusion movement with small forces produces a tensile stress in the PDL that results in bone apposition apically and coronally of the alveolar bone (A, B). In this way, the tooth is extruded with the bone, with the PDLs being subject to different levels of stress in the process. Most of the stretching occurs in the supra-alveolar ligaments. (Adapted from Thilander 2012.)

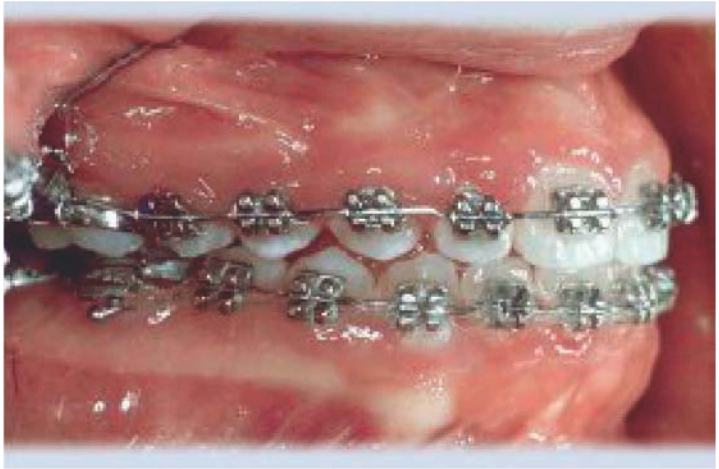
32 Extrusion of the posterior teeth: removable appliances

During the eruption of the teeth, extrusion of the posterior teeth can be controlled. Ideally, bimaxillary devices are employed shortly before changing of the supporting zones in the posterior region. Guide strips on the acrylic material ensure a targeted extrusion movement. As the appliances are not worn 24 hours a day, the influence of masticatory forces is a factor which must not be underestimated with regard to relapse.

33 Extrusion of the posterior teeth: fixed orthodontic

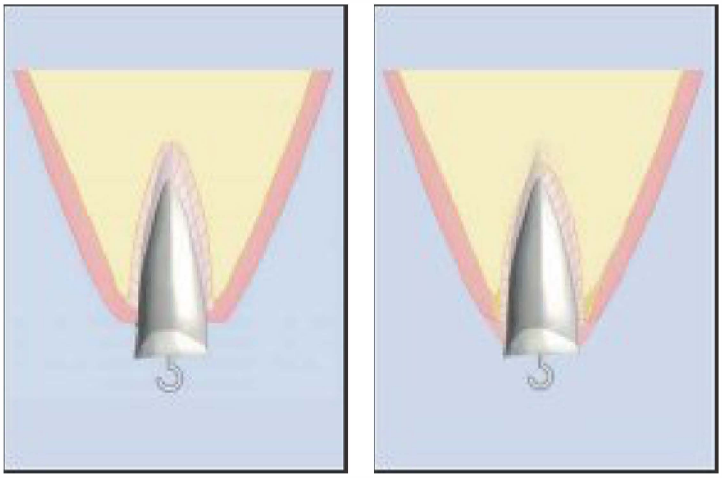
The posterior segment can be specifically extruded with orthodontic appliances. One of the most frequent bends in the archwire is the sweep for leveling the curve of Spee. Vertical traction appliances can also be employed in combination with bite plates. Retention in the posterior region is difficult because masticatory forces operate after the bite planes have been removed. Adequate retention must be planned during treatment.

Extrusion can be performed on groups of teeth or individual teeth. Extrusion in the posterior area results clinically in raising of the bite and/or leveling of the curve of Spee. Extrusion can be performed during eruption of the posterior teeth using functional orthodontic devices in the late mixed dentition or orthodontic appliances in the permanent dentition (**Fig. 32**, **Fig. 33**). The extrusion of the anterior teeth must be metrically restricted and is not indicated in many cases for aesthetic reasons (**Fig. 34**). Extrusion of individual teeth is performed for impacted, displaced teeth (**Fig. 36**), and forced eruption (**Fig. 35**). During the extrusion movement, the tooth with adjacent bone is moved using slight force (Kajiyama et al 1993, Thilander 2012). By this means, attachment can be obtained (Melsen et al 1988). Strong or great force may move the tooth out of the alveolus (Mantzikos et al 1997, 1999). Clinically, advantage can be taken of these effects. As the tooth with bone is moved, the alveolar process can be redeveloped. Apart from the attachment gain in periodontal diseases, this can be used as a preimplantation therapy for vertical bone development before removal of the tooth or a retained root after a dental trauma (**Fig. 35**).



34 Extrusion of the anterior teeth

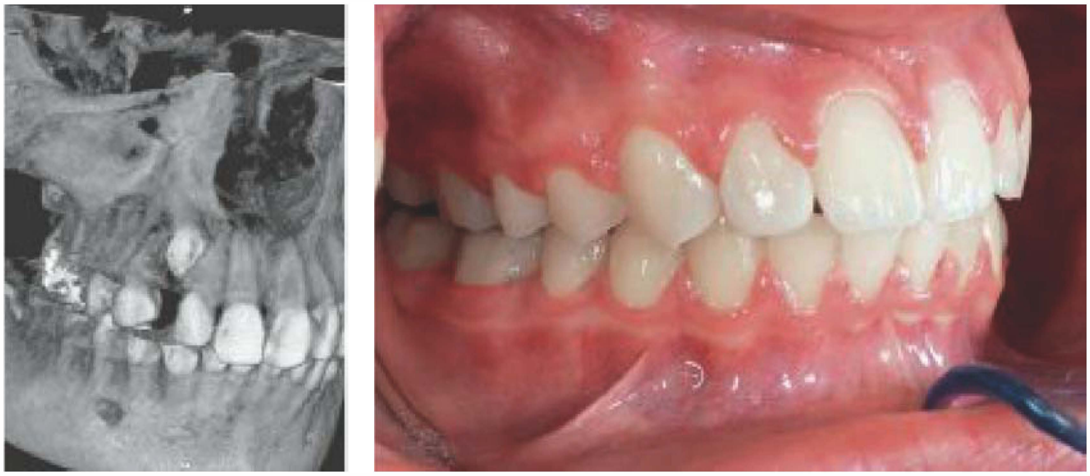
Extrusion of the anterior teeth is rarely indicated for patients. In our treatment concept, we restrict ourselves to an extrusion movement of 1 to 2 mm. In our patients with open bite and a vertical skeletal configuration, there is usually also a gummy smile in the maxilla or the upper lip is too short. An extrusion of the anterior teeth is not indicated for aesthetic reasons, but may be useful for overcorrection (see Chapter 4).



35 Forced eruption of individual teeth

Left: Orthodontically forced eruption may move the tooth out of the alveolus if great force is applied. This may be indicated in the treatment of adult patients for tooth fractures and subsequent prosthetic restoration.

Right: Forced eruption with light force moves the tooth and bone in an occlusal direction. This is indicated for the adjustment of displaced teeth and before implantation.

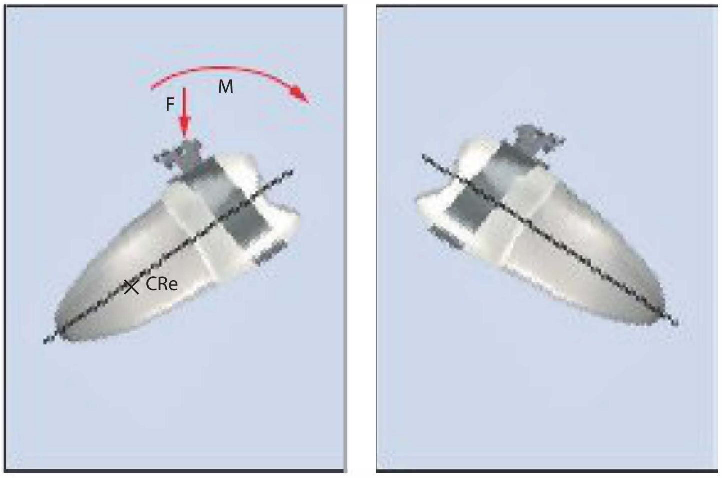


36 Extrusion of the canines

The extrusion of individual teeth is performed orthodontically for impacted or displaced teeth. The maxillary canine is one of the teeth most frequently involved. This tooth can be specifically extruded employing forces of 0.2 to 0.3 N. After adjustment in the dental arch, it has a normal attachment with a corresponding proportion of bone because the bone is included in the movement.

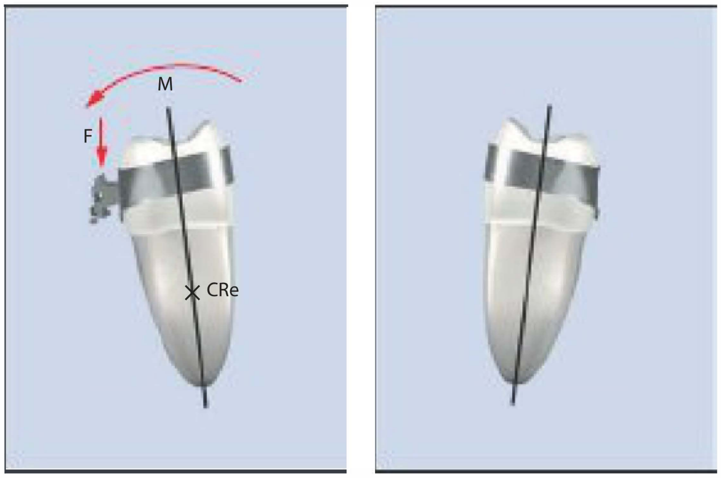
1.3 Intrusion

Intrusion is a biomechanically demanding movement as bodily intrusion can clinically only be performed with difficulty. The predictability of the response always depends on the axial position of the tooth to be intruded. Thus, the intrusion of a mandibular molar depends on the oro-vestibular axial position (**Fig. 37**, **Fig. 38**). If the mandibular molar is tipped in a lingual direction, intrusion may exaggerate the lingual tipping (**Fig. 37**). In the mandible, in particular, the straight wire appliance intensifies this effect as a result of torque incorporated into the attachment. This clinical situation may arise with Class III anomalies. Where there is a skeletal cause, the posterior teeth compensate for the transversely oversized mandible and are often tipped in a lingual direction. Conversely, where there is a small apical base, the molar may also be tipped too far in a vestibular direction. This is frequently due to crowding in the molar region. In this case, intrusion would result in vestibular tipping (**Fig. 38**). Oro-vestibular uprighting therefore always precedes the intrusion or mesialization of individual teeth. Intrusion occurs clinically with deep bite and open bite. It may be present in the anterior and posterior region, and affects individual teeth or tooth segments (**Fig. 41**, **Fig. 42**).



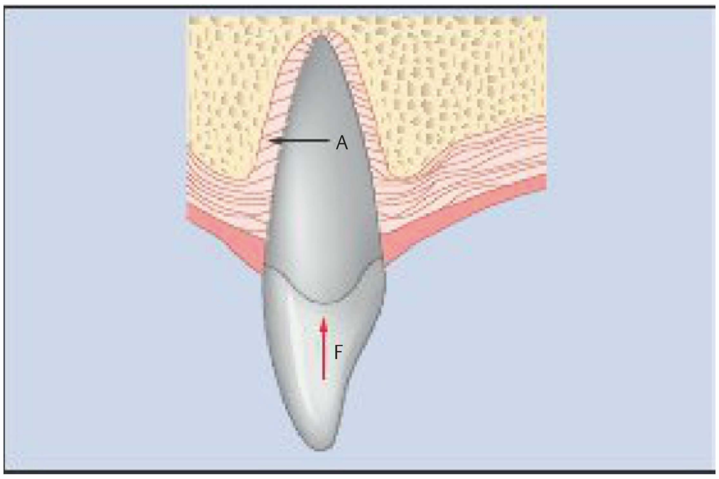
37 Individual tooth intrusion as a function of the buccal vestibular axial position

The intrusion of individual teeth (F) depends on the axial position. The predictability of the oro-vestibular response of the tooth depends on the initial oro-vestibular position. In Class III patients, the posterior teeth of the mandible are often tipped in a lingual direction in a compensatory fashion. Here intrusion results in intensified lingual tipping. The initiated buccal eccentric force (F) results in a tipping moment (M) in a lingual direction.



38 Individual tooth intrusion as a function of the buccal vestibular axial position

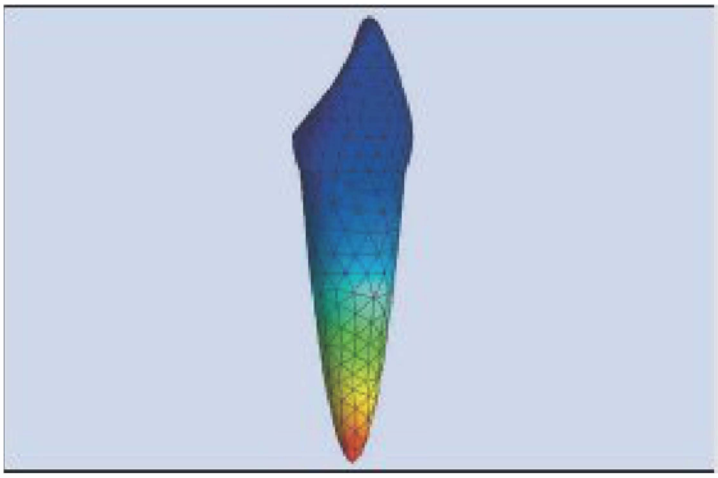
In patients with crowding in the molar region, the molars are often tipped in a vestibular direction. Here intrusion (F) results in intensification of the vestibular position. The buccal eccentric force (F) results in a tipping moment (M) in a buccal direction. In pronounced oro-vestibular axial positions, oro-vestibular uprighting is always necessary before intrusion and sagittal movement for biomechanical reasons.



39 Intrusion and response of the PDL and adjacent bone

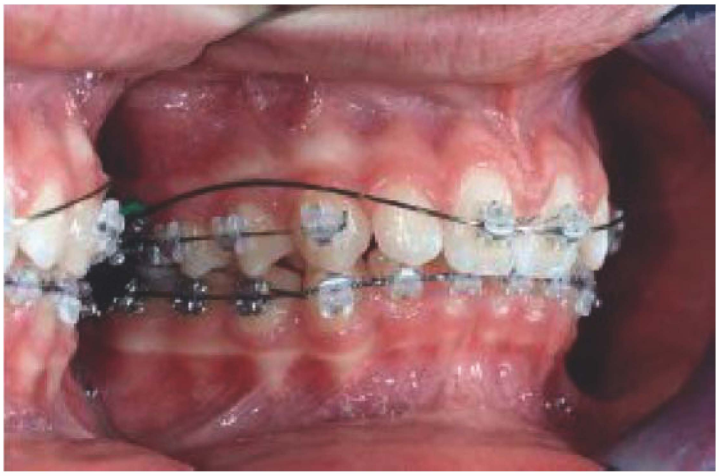
The intrusion of teeth (F) results in relaxation of the gingival ligaments of the periodontium. Primarily, the ligaments in the central third are stretched (A). At the same time, the periodontal gap is compressed in the apical region. For an effective biological response, controlled minor forces must be applied. (Adapted from Thilander 2012.)

Unlike the extrusion movement, the gingival ligaments of the periodontium are relaxed during intrusion (Thilander 2012). The resulting stresses mainly occur in the central third of the PDL (**Fig. 39**). According to Thilander (2012), this results in reorganization of the stretched ligaments over a period of 2 to 3 months. These biological parameters must be allowed during the retention phase of the intrusion movement. Retention in adults must be prolonged accordingly. The relaxation of the gingival ligaments means that intrusion is more stable than extrusion. This has been confirmed experimentally and clinically (Thilander 2012). In our treatment concept, controlled intrusion is an important part of the therapy. While continuous minor forces can be used for young patients, intermittent minor forces are recommended for adult patients because their apical bone may be more compact and more time is required for the appropriate biological response (**Fig. 40**) (Thilander 2012).



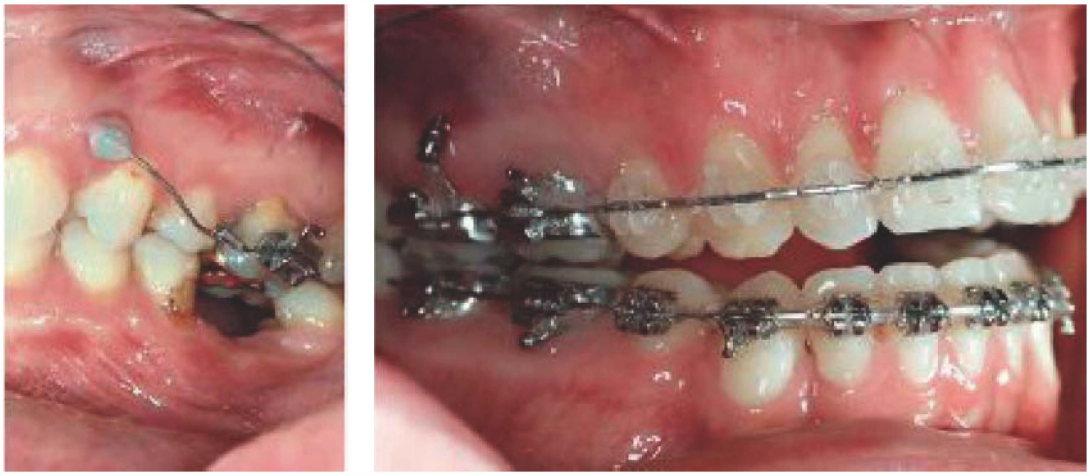
40 Finite element simulation: intrusion of a single-rooted tooth

The intrusion of teeth leads to compression in the apical region. As compression is focused on a small area, minor forces of 0.1 to 0.5 N must be applied depending on the particular tooth. The apical stresses in the PDL and adjacent alveolar bone then lead to the desired clinical response.



41 Intrusion of the anterior teeth

Intrusion of the anterior teeth in the maxilla and mandible is a frequent measure used in our treatment concept for the efficient correction of a deep bite or a Class II/2 anomaly. In young patients, continuous minor forces can be employed. In our modified sliding mechanics, we accordingly use specific NiTi materials for intrusion before leveling.



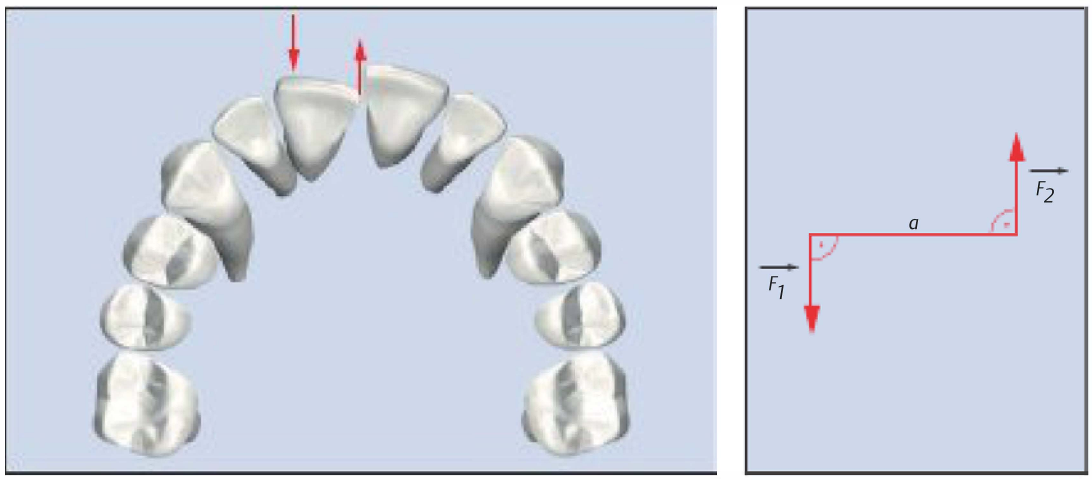
42 Intrusion of the posterior teeth

We use intrusion of the posterior teeth in the maxilla and mandible in our treatment concept for an open bite. As a rule, tooth segments are intruded and the occlusal plane is altered. Clinically, vertical tooth migration is also indicated in adult patients due to a lack of vertical support. In this situation, individual teeth have to be appropriately intruded (left).

1.4 Rotation

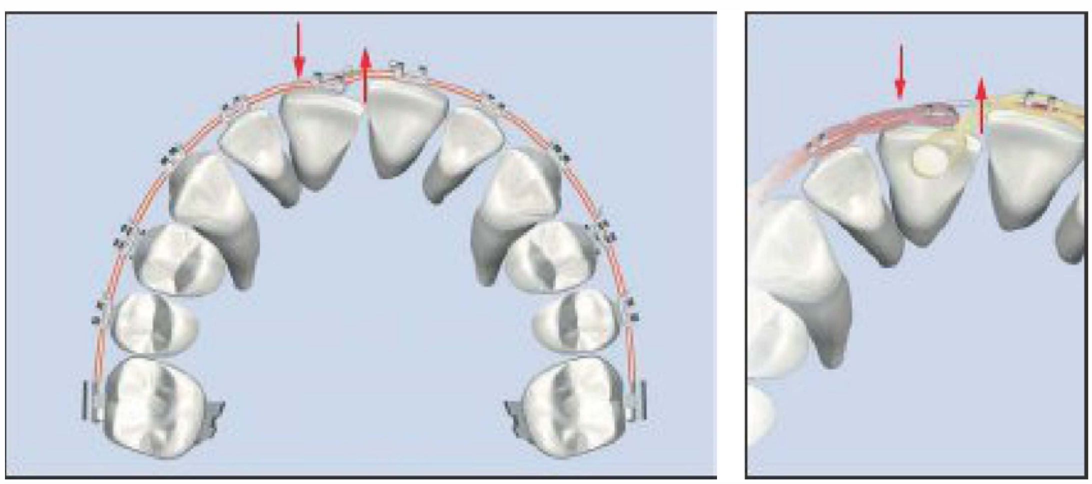
Rotation is a movement along the longitudinal axis of the tooth. Biomechanically, it can be initiated by a force couple (**Fig. 43**). The force couple then generates the moment for the clinical derotation of teeth. Clinically, the moment or force couple can be achieved via the slot and the archwire itself or by opposing tensions (**Fig. 44**, **Fig. 45**). In the orthodontic derotation of teeth, the stress is distributed over the entire PDL, enabling greater forces to be applied (Thilander 2012).

While the fibers of the apical and central third of the tooth adapt after a brief retention period (Reitan 1960), a minimum retention period of 232 days is specified for the free gingival fibers (Thilander 2012). Discussion of the stability of derotations is clinically controversial. While Thilander (2012) recommends a fiberotomy, Heimisdottir et al (2008) did not reveal any improved stability as a result of surgical severance of the supragingival fibers of the PDL. Overcorrection as well as long-term stabilization of severely rotated teeth is therefore a clinical requirement.



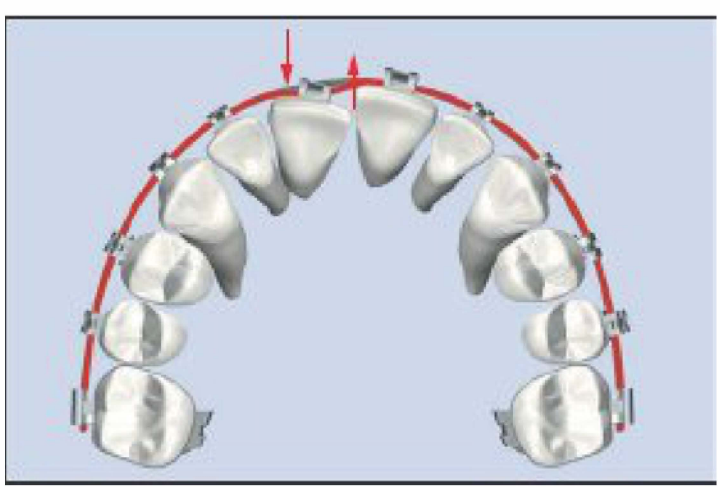
43 Biomechanics: rotation

If a force acts on a rotatable rigid body, it generates a moment. This corresponds to the effect of a force couple (right). The force couple can be clinically achieved by means of opposing tensions or corresponding wire rests in the slot. Derotation by a force couple is only possible to a limited extent with slight mesiodistal dimension of the slot.



44 Derotation of teeth with a steel ligature and chains

In the twin bracket technique, the derotation of individual teeth is achieved by the introduction of a steel ligature. The steel ligature is twisted at the greatest distance from the archwire and the archwire is introduced into the slot in the best possible way. This ensures maximum derotation of the tooth. Elastics are not clinically efficient. For more severe rotations, opposing chains can also be used as an alternative to the steel ligature (right).



45 Derotation of teeth with NiTi archwires and SL brackets

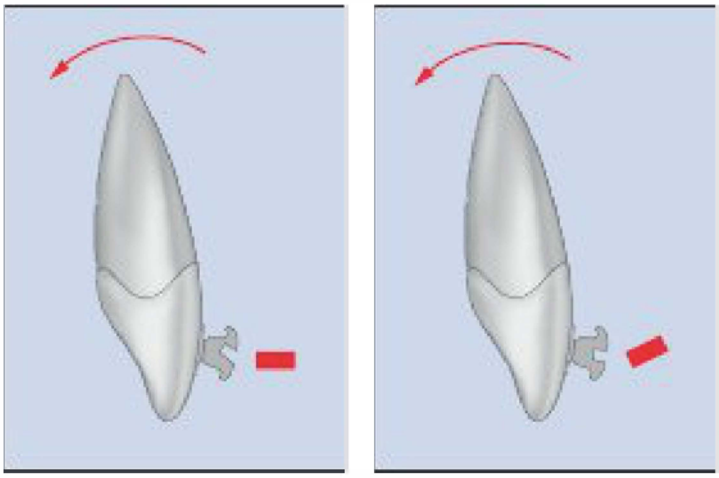
When using self-ligating brackets, derotations of teeth are performed using right-angled NiTi archwires with dimensions of 0.014 × 0.025 and 0.018 × 0.025. As the force or applied moment may be greater for the rotation movement, NiTi archwires with a force range of 1 N can be used. With round archwires, only a slight derotation effect can usually be expected in the clinical situation.

■ 1.5 Torque

Applied torque results in movement of the root or crown. In the straight wire technique, torque is introduced in the archwire by means of programmed values in the bracket base and third-order bends. Bending of torque is indispensable in the straight wire technique as slot-filling archwires are not used in the majority of patients. There is a clinical indication for palatal root torque, reverse torque, and buccal root torque (**Fig. 46**, **Fig. 47**, **Fig. 48**).

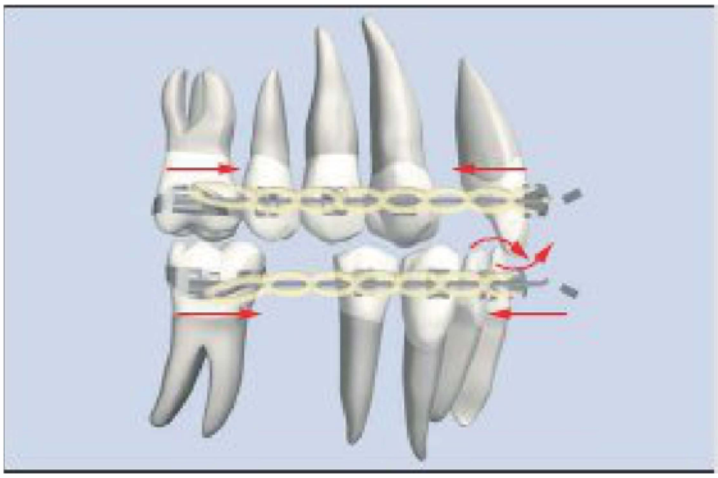
Indication for torque

- Palatal/lingual root torque:
  - Axial position of the maxillary incisors
  - Controlled tipping
  - Retraction of the maxillary and mandibular incisors
  - Crossbite correction: dental Class III
- Reverse torque:
  - Labial coronal torque for mesialization of the molars in the maxilla and mandible
- Buccal root torque:
  - Buccal movement of the roots in the maxilla



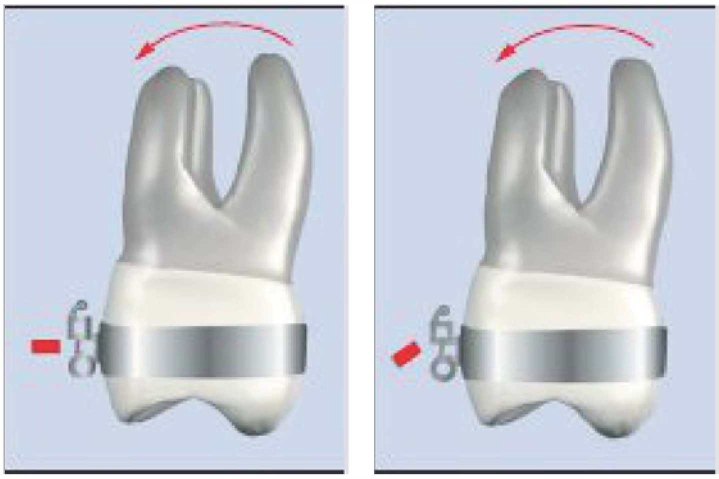
46 Palatal root torque

There is a clinical indication for palatal root torque with a 0.022 slot technique in our treatment concept for Class II/2 anomaly, Class II/1 anomaly, and in many extraction cases. Movement of the root in the maxilla in a palatal direction can be partially offset by the use of brackets with higher torque values (left). Even today, additional torque in the archwire is required in many patients.



47 Labial torque of the crown or reverse torque

Reverse or labial torque of the crown (T) can be used for anchorage in the area of the anterior teeth. This may be necessary in both the maxilla and mandible, particularly if closure of a gap in a distal to mesial direction is indicated. Labial torque of the crown in the anterior teeth therefore does not move the crown in a labial direction. It only acts as an anchor for the tensile force (F) used.

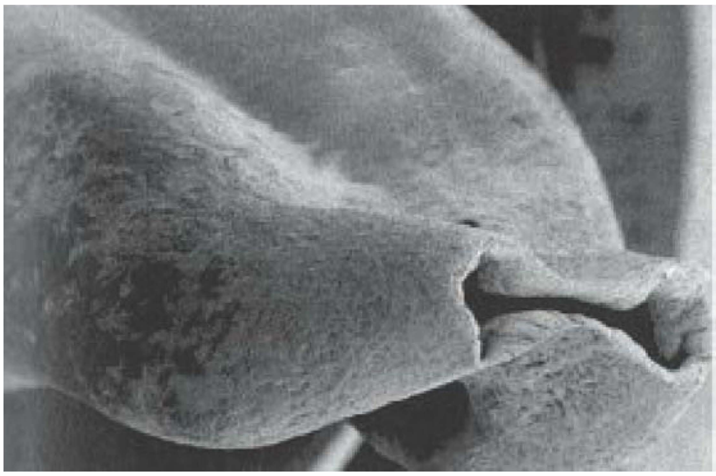


48 Buccal root torque

Comparable to anterior tooth torque in the maxilla, buccal root torque only features in the straight wire system to a limited extent. As a result of this fundamental problem, in many instances the finishing torque in the maxillary anterior teeth and the buccal root torque in the maxilla have to be bent inwards (right) as the torque in the bracket is insufficient for many patients (left).

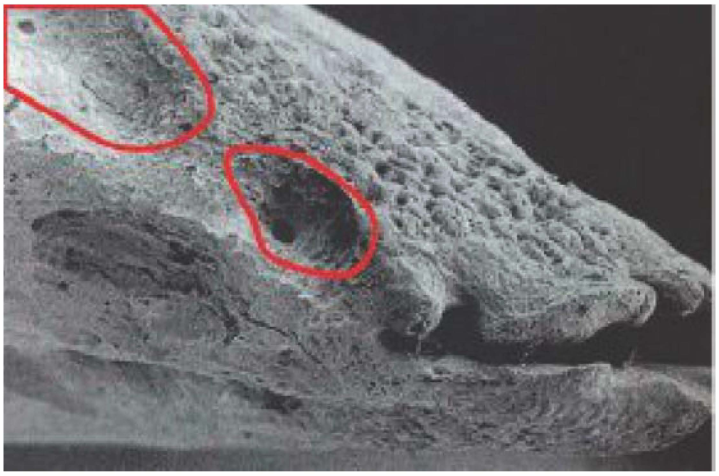
In most patients, the torque movement in orthodontic treatment is a movement of the root rather than a movement of the crown. The latter movement occurs in correction of the anterior crossbite or compensation of a Class III anomaly. In orthodontically induced root movement in the maxillary anterior teeth, the root is moved in a palatal direction. This is a critical movement as, compared to intrusion, the roots in the apical region are subject to a high stress load. In our experience, clinical effects are only visible after a period of 8 weeks, even with the application of small moments.

According to our treatment concept, a light wire system is also recommended when applying moments. It was shown with human premolars that both the magnitude of the moment and the duration of application of torque influenced the amount of resorption (Casa et al 2001). Torque application should therefore be used in a targeted manner and for a defined period of time. The application of a small moment of 3 N mm produced significantly fewer resorptive areas on the tooth surface (**Fig. 49**, **Fig. 50**). By contrast, the surfaces of teeth to which moments of 6 N mm were applied showed significantly more resorptive areas (**Fig. 50**, **Fig. 51**).



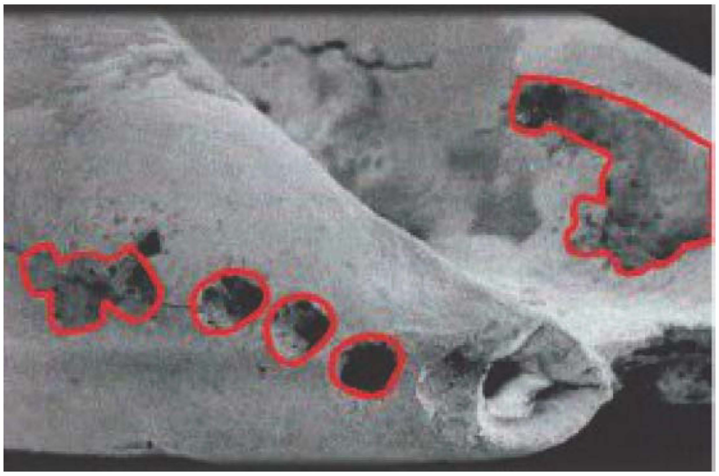
49 SEM image of a premolar that has not been moved

SEM image of a human premolar root of a maxillary first premolar. The root surfaces of premolars, which had not been moved, served as a comparison with premolar roots stressed with different moments. The root surface of the premolar which has not been moved appears homogeneous. No resorptive areas are discernible (Casa et al 2001).



50 Torque application with moment of 3 N mm for 4 weeks

A NiTi wire was used for torque. We were able to apply a defined moment biomechanically by means of a compound connection with steel. The applied moment of 3 N mm for 4 weeks shows slight surface resorptions in the SEM image on the root surface of the premolar which has been moved (Casa et al 2001).

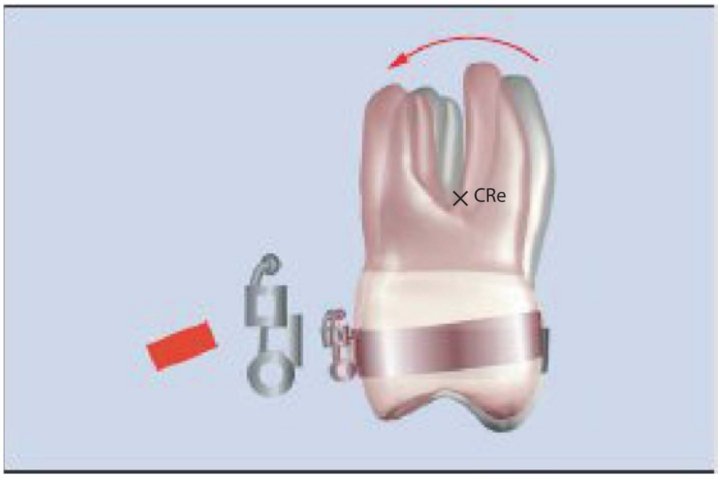


51 Torque application with moment of 6 N mm for 4 weeks

The applied moment of 6 N mm for 4 weeks shows clear resorptions in the SEM image on the root surface of the premolar which has been moved. Both, deep craters and extended resorptive areas are shown. The resorptive areas are significantly deeper and more pronounced when a moment of 6 N mm is applied, compared with 3 N mm (Casa et al 2001).

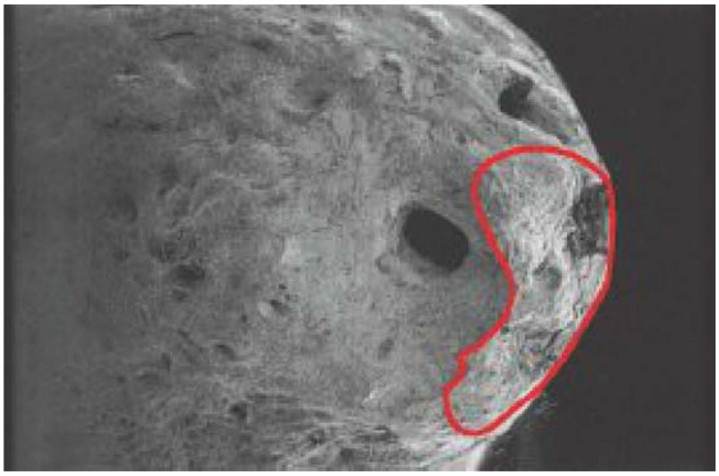
A NiTi element was used for torque application. Application of a small, defined moment was possible on account of the compound element (NiTi/steel). Apart from the amount of moment, we were also able to show that the duration of the torque effect influences the extent of resorption on the tooth surface (**Fig. 53**, **Fig. 54**). Torque application of 6 N mm for 4 weeks revealed significant differences in the extent and degree of resorption compared with torque of 6 N mm for 1 week. From the study, it is possible to conclude that the use of wire materials with a small Young's modulus is particularly appropriate for the application of torque—regardless of whether palatal anterior tooth torque or buccal root torque is applied. This is in accordance with studies by Reitan and Kvam (1971), who found hyalinization zones in the central and apical third on lateral incisors in response to greater forces. However, an additional conclusion is that resorptive areas can also be found with slight torque, although they are not clinically relevant in most cases.

In the case of buccal root torque (**Fig. 52**), it must also be noted that the bone coverage of the teeth is very thin. This restricts the extent of the movement clinically.



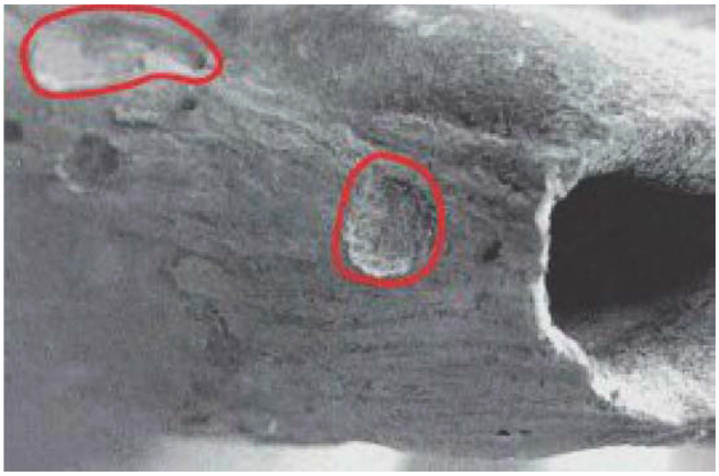
52 Buccal root torque

In the case of buccal root torque, there is a correction of the transverse axial position of the teeth. This functionally enables correct articulation. When small forces are applied, the movement primarily gives rise to compression in the central third of the root (Reitan and Kvam 1971). The apical portion is moved only afterward. Small moments must be applied with buccal root torque to induce a movement with fewer biological side effects.



53 Torque application with moment of 6 N mm for 1 week

Scanning electron microscopic image of the root surface of a premolar loaded by a constant moment of 6 N mm after 1 week. After only 1 week, significant resorptions are visible on the tooth surface of the premolar. As a result, the magnitude of moment applied has an effect on the degree of resorption (Casa et al 2001).



54 Torque application with moment of 6 N mm for 3 weeks

Scanning electron microscopic image of the root surface of a premolar loaded by a constant moment of 6 N mm after 3 weeks. After 3 weeks of application, significantly more areas on the tooth surface display resorptive areas which, compared with 1 week's application, extend into the dentine. The time factor is therefore crucially important for the effect of moment (Casa et al 2001).

1.6 Relationship between Force and Resorption

In the clinical use of removable and fixed appliances, apart from biomechanical parameters of force transmission and direction of movement, the force and magnitude of moment are important factors. An orthodontically induced force leads to desirable resorption in the region of the bone and thus to a change in the position of the tooth. While areas of resorption on the bone, induced via the PDL, are a desirable effect, areas of resorption on the tooth itself are usually therapeutically undesirable. The location and extent of the resorptions are crucial to their clinical relevance.

1.6.1 Force

Technique

The application of force is closely related to the technique used. With a full archwire technique involving the whole arch in tooth movement, frictional forces arise that have to be overcome. On the other hand, with a segmented archwire, these frictional forces do not arise. Different forces must therefore be applied for the two different techniques.

55 Forces used in orthodontic treatment

The magnitudes of force used in the literature vary between authors. More recent literature shows that small forces should be used in orthodontic treatment (10–60 cN). This corresponds to the results of histological studies by Reitan (1957, 1960), who recommends forces of 50 to 60 cN for tipping movements. Small forces of 10 to 50 cN produce more effective tooth movement and fewer resorptions compared with 100 cN (Gonzales et al 2008). For specific movements such as intrusion and extrusion, forces significantly lower than the specified values may be recommended (0.1–0.3 N). Compared with the segmented archwire technique (with no additional frictional forces), greater forces have to be applied in the sliding archwire or full archwire technique because additional frictional forces that arise make it necessary to apply a greater clinical force.

Author	Year	Pressure (kPa)	Force (cN)	Object	Force duration	Species
Storey and Smith	1952	10–17	150–250	Cmax	21 d	Human
Reitan	1960	2–10	40–140	P1max	27 d	Human
Reitan	1957	5–6	50–60	Cmax	18 d	Human
Lee	1964	10–17	150–260	Cmax	7 d	Human
Hixon et al	1969	30–100	300–1000	Cmax	56 d	Human
Jarabak and Fizzell	1972	7–11	105–170	Cmax	60 d	Human
Boester and Johnston	1975	9–21	140–310	Cmax	70 d	Human
King et al	1991	65–180	20–60	M_1max	1–14 d	Rat
Lee	1995	17–18	255–275	Cmax	50 d	Human
Pilon et al	1996	10–40	50–200	P_2max	120 d	Dog
Gibson et al	1992	133	40	M_1max	1–24 h	Rat
Owman-Moll et al	1996	5–20	50–200	P_1max	49 d	Human
Faltin et al	1998		50–100	P_1max	30–44 d	Human
Verna et al	2000	83	25	M_1max	21 d	Rat
Iwaski et al	2000	4–13	18–60	Cmax	84 d	Human
Kohno et al	2002	4–11	1.2–10	M_1max	2–14 d	Rat
Gonzales et al	2008	33–330	10–50	M_1max	3–28 d	Rat

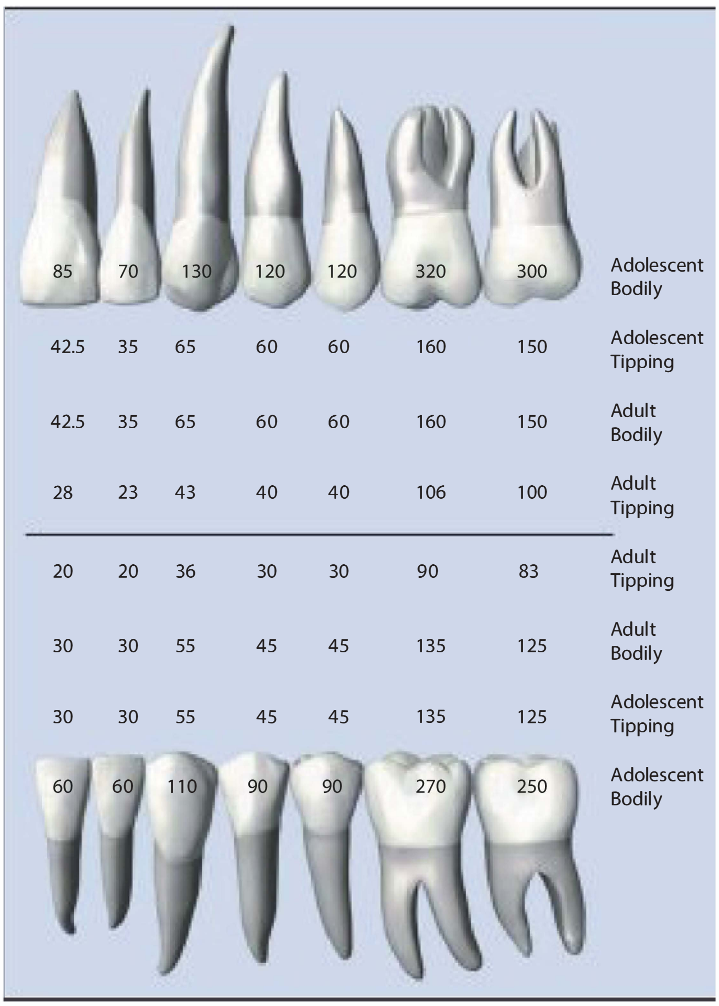
Magnitude of Force

The magnitude of force to be applied in therapy is variously reported in the literature (**Table 55**). A distinction must be drawn between clinical, experimental, and histological studies. The teeth being moved also vary. However, the trend discernible in more recent literature suggests that application of small forces is indicated in orthodontic treatment. When considering the magnitude of force, a distinction must be made between the magnitude of physical force and the pressure (force per root surface in the PDL) (**Table 55**). It is still difficult at present to draw a conclusion regarding the optimal magnitude of force. A. M. Schwarz (1961) provided initial indications of the ideal force in the form of 4 degrees of biological efficiency:

- The first degree of biological efficiency comprises forces that are so small that they do not result in any orthodontically effective tooth movement.
- The second degree of biological efficiency comprises forces which generate pressure of 0.15 and 0.2 N/cm² on the root surface. At this degree of efficiency, the pressure generated by the force is lower than the blood pressure in the PDL, thus ensuring continuous circulation in the PDL. This is a favorable condition for bone remodeling (direct resorption).

- The forces of the third and fourth degrees of biological efficiency exceed the capillary blood pressure in the region of the PDL, as a result of which circulation is no longer possible in some areas of the PDL (0.2–0.5 N/cm^2, > 0.5 N/cm^2). If there is a lengthy interruption of the circulation of the blood, periodontal damage may occur as a result of the circulatory disturbance.

From a clinical perspective, it is difficult to achieve the desirable second degree of biological efficiency in accordance with A.M. Schwarz (1961). This is closely related to the variation in size and shape of root surfaces. At present, such variation morphologically limits the extent to which an exact force can be specified for a particular tooth (Ren et al 2003). The inclusion of the root surfaces in the magnitude of force nevertheless makes sense (**Fig. 56**). On the basis of comparative tables and known direction of movement, an ideal force to be applied can be ascertained via the root surfaces. Different magnitudes of force for the various teeth can be derived from these considerations (**Fig. 56**).



56 Magnitude of force as a function of the root surface of the teeth

Average magnitude of force in cN in our treatment concept for the individual teeth for a bodily and tipping tooth movement as a function of the patient's age. As tipping movements signify a greater load on the tooth and adjacent PDL and bone, the force must be reduced by half or a third of the physical force. In addition, a distinction must be drawn between young and adult patients. The magnitude of force is smaller for adults as the root surface is decreased due to reduced attachment. (Adapted from Reitan 1957, 1960, Lee 1965, Ricketts et al 1988, Sander et al 2011.)

Differently sized areas out of the total root surface are utilized, depending on the direction of movement. Ideally, this would be half for a bodily sagittal movement. If the total root surface is additionally considered, it may realistically be assumed that approximately one-third of the root surface is used for the movement in a transverse direction. In the worst-case scenario, only approximately 1/10th of the total surface will be used for an intrusive movement (Ricketts et al 1988, Sander et al 2011). This information may be used to draw up recommendations on the magnitudes of force for individual tooth movements.

Bodily and Tipping Tooth Movement

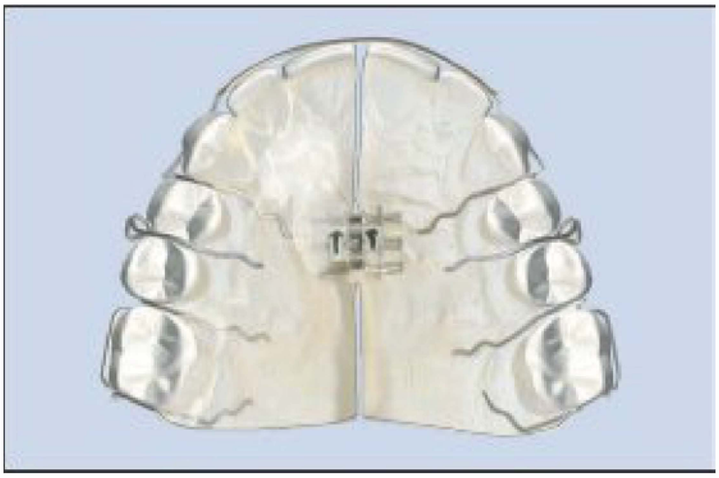
The magnitude of force for a bodily tooth movement may be significantly greater due to better distribution of stresses on the tooth and bone surface. For tipping tooth movements, the force should only be half or one-third of the bodily force (Ricketts et al 1988, Sander et al 2011).

Duration of Force Effect

Intermittent and noncontinuous forces must be distinguished from continuous forces. Intermittent forces may be greater than continuous forces (Thilander 2012). In clinical terms, this means that a headgear worn only at night can exert a greater force than an intraoral compression spring with a continuous effect (**Fig. 59**). When applying continuous forces with NiTi, it is also true that smaller forces maintain the circulation of the blood (Noda et al 2009). The force applied with a compression spring in an orthodontic appliance also depends on the frictional forces. With removable appliances (**Fig. 57**), such as active plates, comparatively high forces are applied via screws. Clinically, however, this is not a problem as regeneration of the periodontal tissue can take place due to the intermittent application of force.

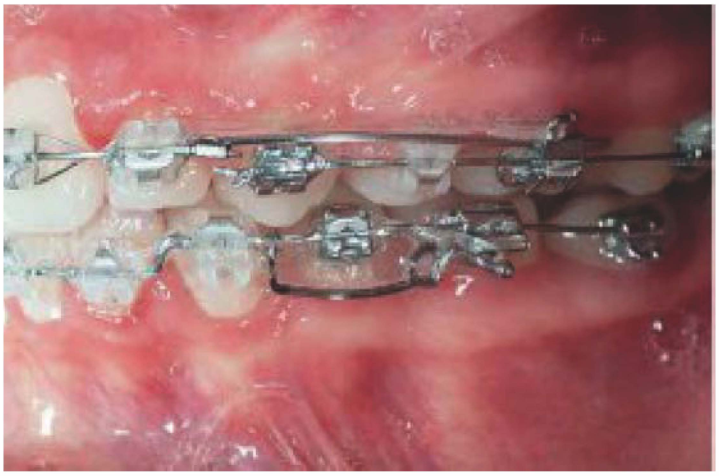
Stroke

Apart from the actual physical magnitude of force, a distinction should also be drawn in terms of stroke. The force is a vectorial quantity. It has a strength (magnitude) and a direction. It may be active over a short or long distance or activation length. This is called the stroke. Accordingly, reference is made to a short or long stroke.



57 Application of short-stroke forces

Screws in removable devices apply short-stroke forces. When a screw is activated in a rigid orthodontic plate, a movement of 0.1 mm is induced for activation of 90 degrees per side. As the system is relatively rigid, high forces can be applied. This is because virtually no force has any more effect after the movement takes place.



58 Application of long-stroke forces

Spring elements apply long-stroke forces. The uprighting spring is an element that applies more or less continuous forces and moments to the tooth over a greater range of tooth movement. Slight changes in the position of the tooth do not result in a significant reduction in force or moment. Clinically, therefore, the forces and moment employed must be significantly lower than for short-stroke forces.

Application of Short-Stroke Forces

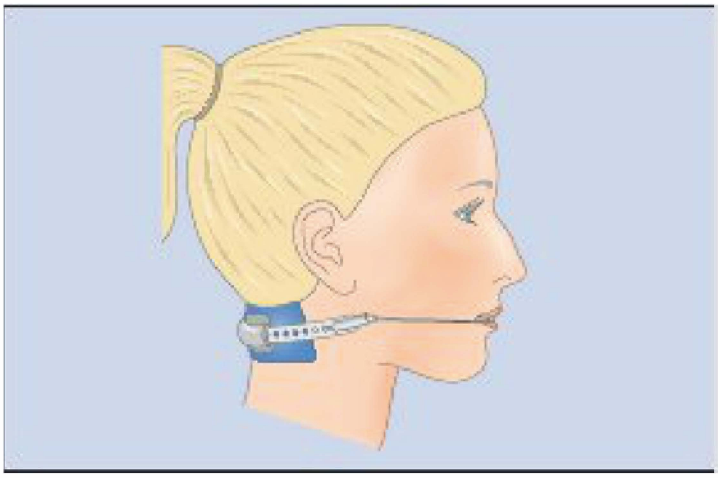
Short-stroke forces arise in removable appliances. An example of a short-stroke force in orthodontics is a removable plate with a single-spindle screw (**Fig. 57**). If the patient activates the screw on a removable plate to distalize a molar unilaterally, for example, this usually involves a quarter turn. This is equivalent to 0.1 mm. Once the patient uses the appliance, it becomes 0.1 mm more rigid than before. When using the appliance, relatively high forces may be produced as the system itself barely yields. Balancing of the forces is only possible by distortion or movement of the teeth in the periodontal gap. If the teeth have moved by 0.1 mm, no force has any further effect. Due to this short-stroke (short-way) approach, it is generally assumed that high forces produced in the process will also not cause any damage to the teeth.

Application of Long-Stroke Forces

Long-stroke forces arise in spring elements in orthodontic therapy. A spring element for the uprighting of molars can be seen as an example of a long-stroke (long-way) force (**Fig. 58**). With an uprighting spring, the forces and torque act on the tooth more or less continuously. Even slight changes to the position of the tooth do not result in a significant alteration of the level of force.

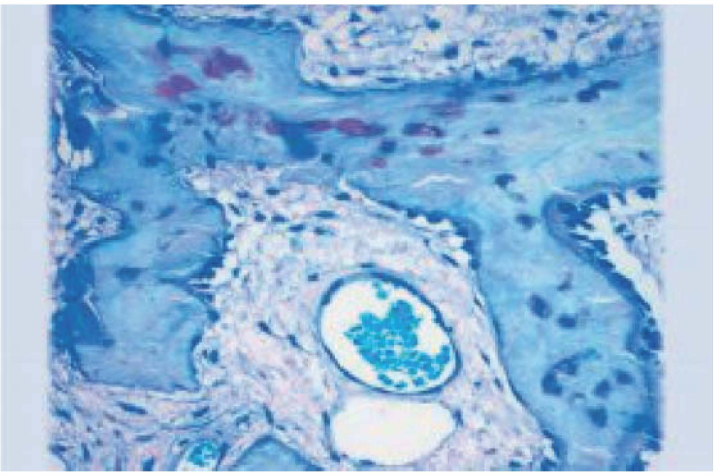
Potential Adaptation of the Tissue

A factor to be taken into account which influences tooth movement and resorption is the adaptive potential of the tissue. This also influences the magnitude of force. The adaptation potential of tissue decreases with age. Perfusion of hard and soft tissue is reduced by comparison with a young person and, as a result, the speed and possible extent of tooth movement are limited (**Fig. 60**). In older patients, not only is there less available bone overall, but it is also more poorly perfused. The bone has fewer medullary cavities and more trabecular structures (Roberts 2012). Bone density increases, while its elasticity decreases with age. As a result of these circumstances, hyalinization is much more likely to occur in orthodontically induced tooth movement (Kita et al 1987, Göz 1990). Even slight forces are enough to overload the local damping system, resulting in excessively high PDL pressure.



59 Application of intermittent forces

Intermittent forces are applied when using headgear. The headgear is not worn 24 hours per day—the wearing time is 10 hours. An intermittent force is an interrupted application of force. It results in stress phases and rest phases. These forces are produced in therapy with removable devices (plates, functional orthodontics) and orthodontic appliances such as headgear.



60 Tissue adaptation in juvenile and adult patients

As well as macroscopic differences in bone formation, there are histological differences between juvenile and adult patients. The juvenile patient has significantly more medullary cavities and blood vessels which supply the bone (center). In adult patients, smaller forces and longer refractory phases must therefore be allowed for during orthodontic therapy.

Courtesy of Dr. Miehe, Institute of Anatomy and Cell Biology, Greifswald, Germany.

As a therapeutic consequence, orthodontically applied force should therefore be significantly reduced in adults. Likewise, additional support for tissue activity is advisable. First, calcium supplementation is recommended. According to a study by Krishnan and Davidovitch (2009b), total tissue turnover can be significantly increased by the additional intake of 500 mg of calcium per day. Second, daily vitamin C supplement is recommended. Like age, general illnesses are also a determining factor in the adaptation potential of tissues. From an orthodontic perspective, diabetes mellitus stands out among general illnesses on account of its frequency. The microvascular and macrovascular angiopathies resulting from diabetes and the diabetic metabolic state significantly impair the bone turnover rate (bone loss and regeneration) (Davidovitch and Krishnan 2009, Reichert et al 2009). While orthodontic tooth movement is basically possible, the retention phase must be significantly extended because bone formation (ossification) is particularly delayed.

1.6.2 Resorption

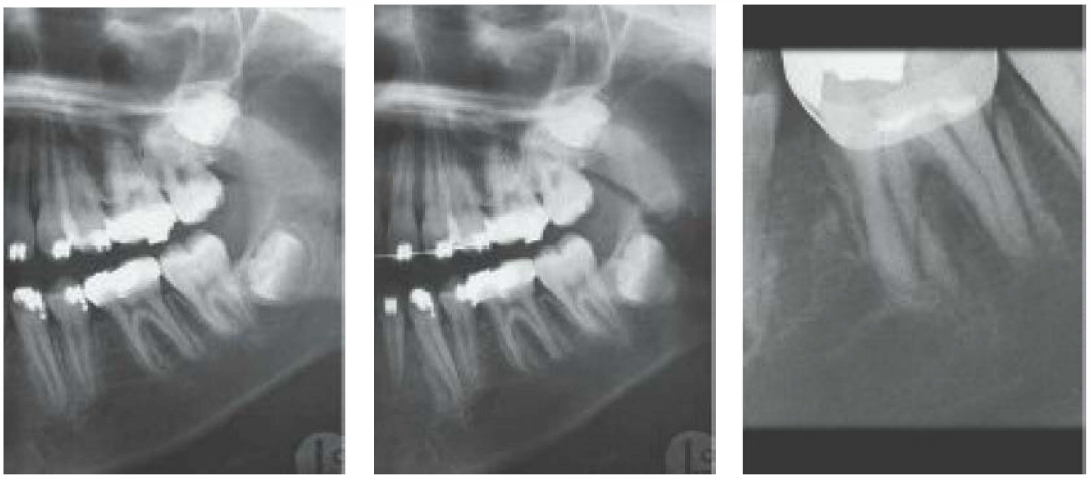
During orthodontic therapy, a distinction must be drawn between resorption affecting the bone and the tooth (**Fig. 61**, **Fig. 62**, **Fig. 63**). Resorptive processes are a prerequisite for enabling tooth movement to be induced by orthodontic appliances. It is the cells in the PDL that initiate the tooth movement. A stable change in the position of the tooth can be achieved by means of bone formation and loss (**Fig. 61**). In general, physiological and pathological resorption must be differentiated. Among the group of pathological resorptions, resorption of the tooth and particularly resorption of the root must be mentioned above all. However, not all root resorptions are clinically relevant and thus pathological.

Physiological Resorption of the Tooth

In principle, root resorption is a physiological process. During the change from primary to secondary dentition, there is a process of resorption of the deciduous teeth by the permanent teeth (**Fig. 62**). Changes in the direction of eruption may disrupt this process. Orthodontic monitoring of regular tooth eruption is therefore necessary.

Physiological Resorption of the Bone

Orthodontically induced tooth movement produces bone resorption by osteoclasts on the pressure side and bone apposition by osteoblasts on the tensile side of the adjacent bone of the PDL (Sandstedt 1904, Oppenheim 1911, Schwarz 1932, Reitan 1960, Heller and Nanda 1979, Masella and Meister 2006, Thilander 2012). Minor orthodontic forces, taking into account appropriate biomechanical principles, move the tooth without major biological side effects. Major forces in orthodontic therapy, on the contrary, display longer-lasting hyalinization with corresponding risks (Reitan 1985). Biomechanically, even when small forces are clinically applied, there is the problem of orthodontic forces never being evenly distributed in the PDL (Burstone 1962). For clinical orthodontic therapy, small forces are advisable as they induce direct resorption. Reitan (1957, 1969) therefore recommends 0.2 to 0.3 N for the tipping movement of small teeth and 0.5 to 0.75 N for the tipping movement of large teeth. Bodily movements are to be applied with forces of 0.4 to 0.5 N for small teeth and 1.5 N for large teeth. Extrusion is specified as 0.3 to 0.5 N and intrusion as 0.25 N.



61 Physiological resorption of the bone

During orthodontic tooth movement, a stable change in the position of the tooth is achieved by means of physiological bone resorption and bone apposition. In the patient shown here, after extraction therapy the molar with crown and root was moved in a mesial direction (left before and center after root movement). Bone regeneration on the distal surface of the root is discernible (right).

62 Physiological resorption of the tooth

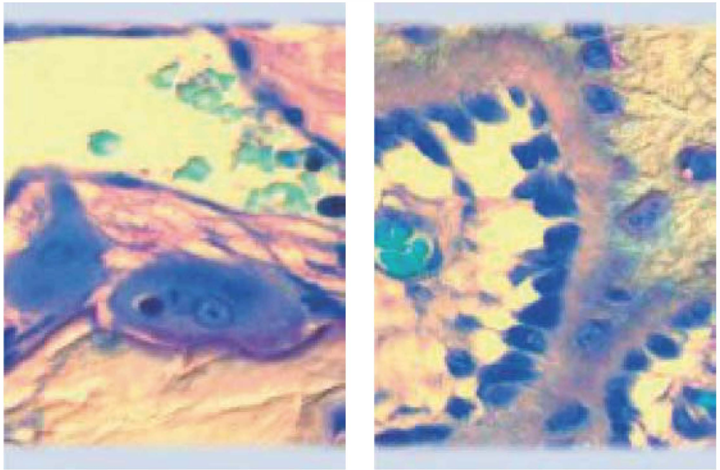
During the natural eruption of teeth, the deciduous tooth is resorbed by the permanent tooth. Physiological resorption thus takes place in the coronal region of the remaining tooth germ. This enables regular tooth eruption. If eruption is disrupted, regular resorption cannot take place as a result of an atypical position of tooth bud and direction of eruption. Extraction of the deciduous tooth may then be necessary (right).

Direct/Anterior Resorption

Direct resorption occurs in response to application of minor forces and biomechanically optimized tooth movement (**Fig. 64**). Tipping tooth movements lead to hyalinization even with small forces. Hyalinization can also occur with bodily tooth movement in the first stage of the movement, but it is significantly less pronounced (Reitan 1957, 1960, 1985, Thilander 2012). The application of minor forces and bodily tooth movement result in direct or anterior resorption. The circulation of the blood is not interrupted when the PDL is compressed and the cell activity of the PDL is maintained.

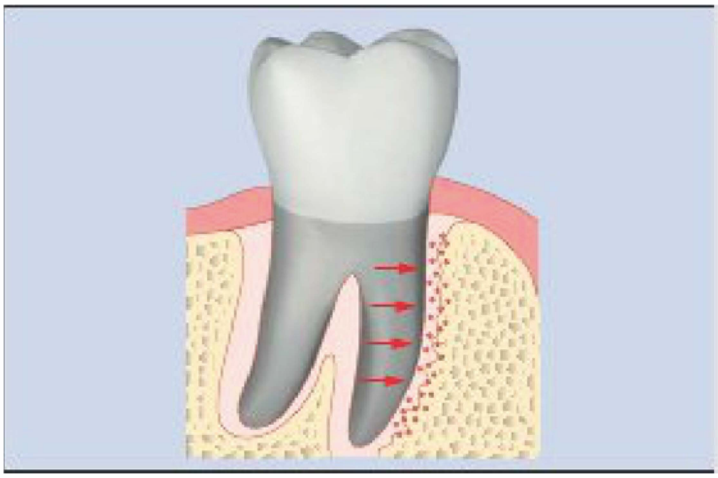
Indirect/Undermining Resorption

In the case of indirect or undermining resorption (**Fig. 65**), the periodontal gap is compressed in sizeable areas of the PDL to such an extent that the blood is prevented from circulating and distinct hyalinized zones are produced. The cells of the PDL can no longer bring about resorption of the bone. Only adjacent cells and cells from medullary cavities of the adjacent cancellous bone induce undermining resorption (Reitan 1960, Krishnan et al 2009). Indirect resorption occurs when major forces are applied.



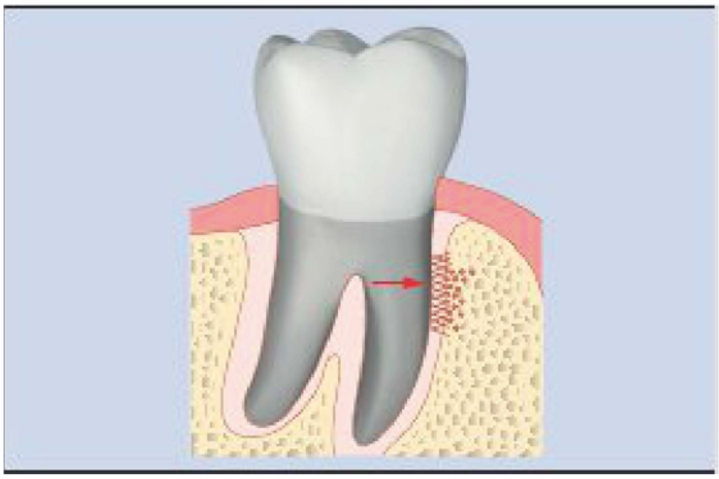
63 Physiological bone resorption

Orthodontically induced force results in pressure and tension on the root surface and a corresponding distribution of tension in the PDL and bone. Bone loss in the area of the compression zone is achieved by osteoclast activity (left). Bone formation is led by osteoblasts (right). (Courtesy of Dr. Miehe, Institute for Anatomy and Cell Biology, Greifswald, Germany.)



64 Direct/anterior resorption

In the case of direct resorption, resorption of the adjacent bone in the compressed area takes place from the PDL. A prerequisite is that perfusion of the PDL remains intact. Small forces and distribution of the pressure as consistently as possible, as in bodily tooth movement, are essential for physiological cell activity. (Adapted from Reitan 1957, 1960.)



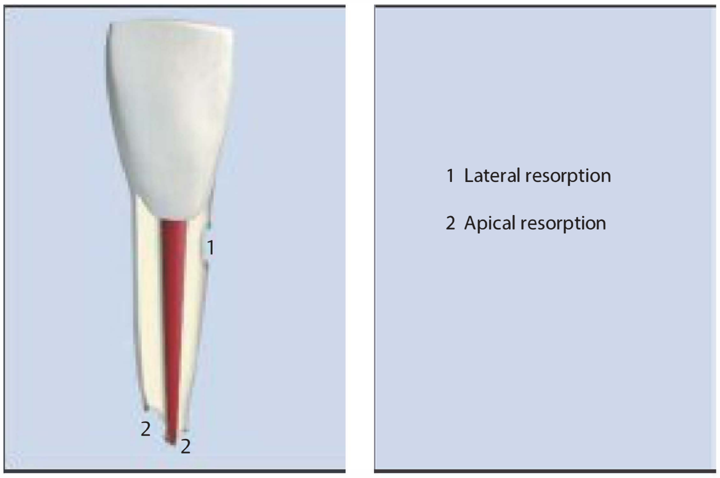
65 Indirect/undermining resorption

Indirect resorption of the bone adjacent to the PDL emanates from the bone itself and occurs when major forces are applied and pressure is distributed unevenly in the PDL. As a result of intense compression of the PDL, the periodontal gap is compressed to such an extent that perfusion is no longer intact and pronounced areas of hyalinization arise. (Adapted from Reitan 1957, 1960.)

1.6.3 Root Resorption

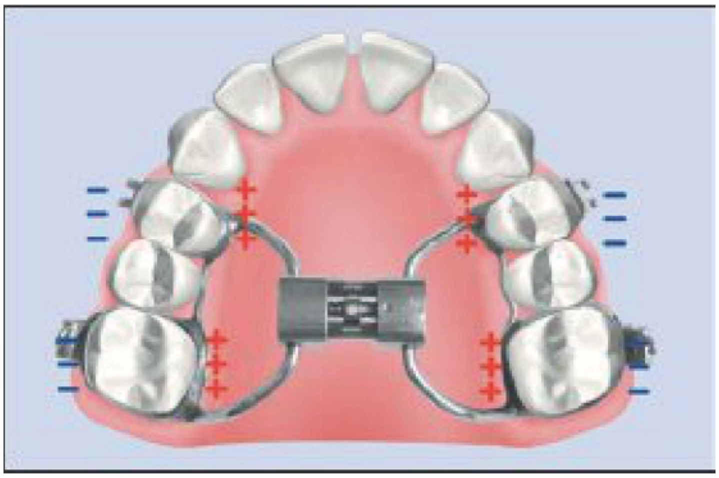
Root resorptions may occur in permanent teeth. According to Ngan et al (2004), resorption in permanent teeth involves a disturbance of the protective mechanism of the cementum in areas where cementoclasts and osteoclasts are active. It is assumed that the balance between resorption and apposition is shifted unfavorably in phases of tooth movement (Brezniak and Wasserstein 1993). However, root resorptions (**Fig. 74**, **Fig. 75**) are also described in patients who have not undergone any orthodontic treatment (Harris and Butler 1992).

In patients with resorptions without orthodontic treatment, dysfunctions above all have an influence on root resorption. Tongue dysfunction, onychophagia, and incisal premature contact can result in a jiggling effect (**Fig. 71**, **Fig. 72**). According to Horn et al (1995), these forces may be 3 to 6 N. In addition, premature contacts in the area of the incisors can easily be in the region of 10 N or more at nighttime (Wichelhaus et al 2003). Resorptions are already known to occur as a result of inflammatory processes (Tronstad 1988) and as a reparative process in ankylosed teeth. Resorptions can occur anywhere on the dental root.



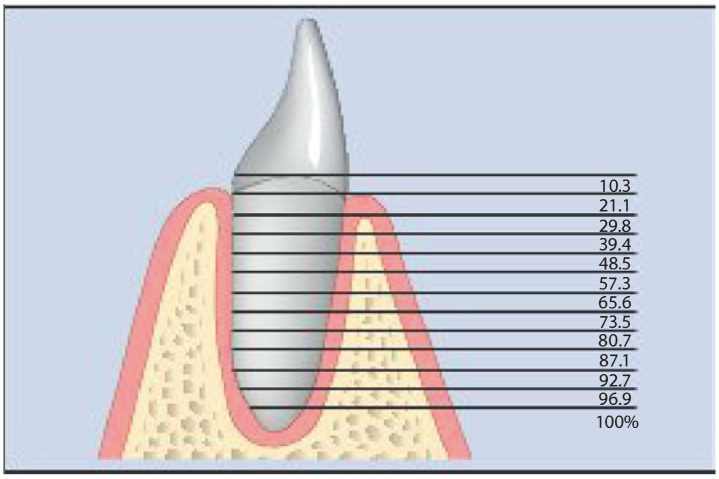
66 Classification of root resorptions according to location

Orthodontically, lateral resorptions can be distinguished from apical resorptions. As a rule, repair mechanisms in the form of replacement cementum compensate for lateral resorptions. Trauma-related lateral resorptions, which can occur after replantation, are an exception. In most cases, resorptions resulting from trauma lead to loss of the tooth. Unlike lateral resorptions, apical resorptions caused by orthodontics are not compensated for by replacement cementum.



67 Orthodontically induced lateral root resorptions

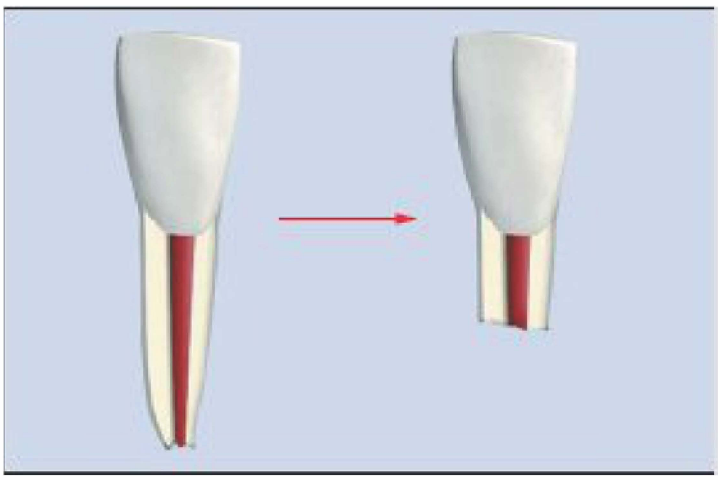
If an RPE appliance is used, it produces a pressure zone in a vestibular direction and a tensile area in a palatal direction on the teeth to which the appliance is attached. Resulting resorptions cannot be detected using conventional dental films or a panoramic tomogram.



68 Classification of the attachment loss according to marginal and apical resorption processes

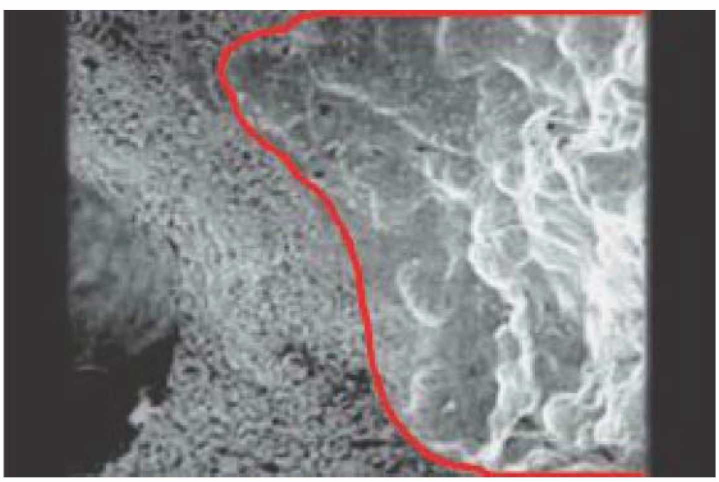
Marginal attachment loss has a greater influence on the overall attachment compared with apical root resorptions. A marginal attachment loss signifies almost 30% reduction of the overall attachment. Compared with this, root resorption of 3 mm leads to an attachment loss of 7%. (Adapted from Kalkwarf et al 1986, Göz 2000.)

The magnitude of force (Reitan 1960, Harry and Sims 1982, Owman-Moll 1995, Faltin et al 1998), the duration of the force (Zachrisson and Alnaes 1973, Malmgren et al 1982, Lilja et al 1983, Dermaut and De Munck 1986, Vardimon et al 1991, Owman-Moll 1995, Kurol et al 1996), the adaptation potential of the associated tissue (Stöckli 1973, Burstone and Koenig 1976, Reid and Boyde 1987, Rakosi and Jonas 1989), and genetic predisposition (Hartsfield 2009, 2012) (**Fig. 74**, **Fig. 75**) are determining factors in orthodontic root resorptions. Lateral or buccal root resorptions such as those produced by an RPE appliance have not been discussed much in the literature as they are very difficult to diagnose and the lateral resorptions have repair mechanisms (**Fig. 66**, **Fig. 67**). Ottolengui (1914) first referred to root resorptions in extracted teeth. Ketcham (1927) and Rudolph (1936) described resorptions visible on X-rays. These are not small resorption lacunae, but apical resorptions with different levels of severity (**Fig. 68**, **Fig.69**, **Fig. 70**). Clearly visible root shortening (EARR: external apical root resorption) must be taken into consideration before and during orthodontic therapy. The resorptions to be expected in more than 90% of orthodontically treated patients are on average 1.5 to 2 mm (Remington et al 1989, Linge and Linge 1991) and are not clinically relevant with regard to attachment (**Fig. 68**).



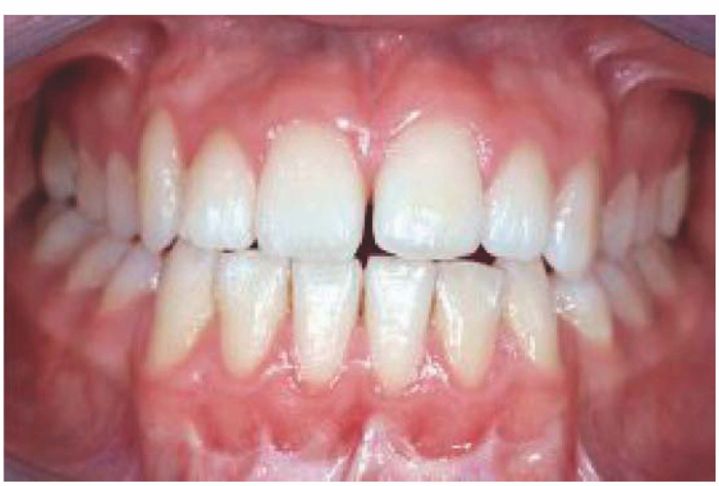
69 External apical root resorption (EARR)

Nonphysiological resorptions may be idiopathic or iatrogenic in origin. They are accompanied by shortening of the root. No repair mechanism is anticipated with apical root resorptions. This type of resorption is clearly discernible on the X-rays customarily used by dentists.



70 Orthodontically induced apical root resorptions

Apical root resorptions can be induced by orthodontic treatment. Critical movements in this respect are intrusion, extrusion and torque. The duration and magnitude of force are orthodontic parameters for orthodontically induced resorptions. SEM image of a dental root with apical resorption lacunae after orthodontic treatment (Casa et al 2001).



71 Dysfunctions and root resorptions: premature contacts

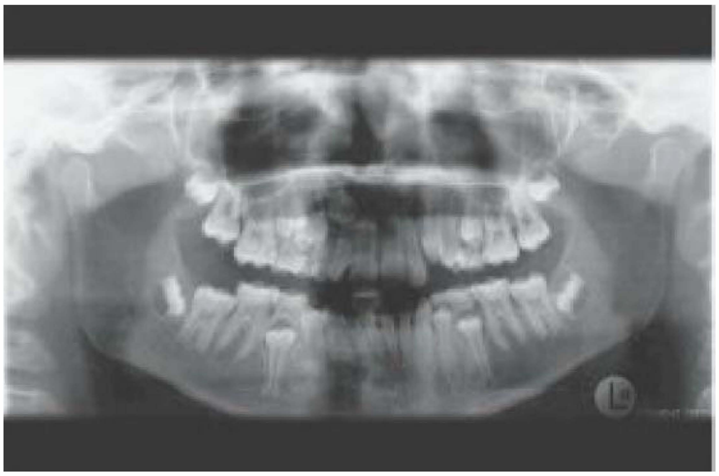
Dysfunctions can lead to resorptions. This applies, in particular, to premature contacts in the incisal area. The risk of premature contacts may arise in the presence of faulty contacts, induced by differing growth of the jaw in Class III anomalies. During the growth phase of patients undergoing orthognathic surgery, we therefore use long-term bite plates in our treatment concept.

72 Dysfunctions and root resorptions: tongue dysfunction

An anterior open bite, caused by tongue dysfunction, root resorptions may also occur without orthodontic intervention. If permanent dentition is already present, the likelihood of permanently eliminating tongue dysfunction is low. Orthodontic treatment of the teeth already resorbed must be avoided at all costs.

73 Dysfunctions and root resorptions: disrupted eruption

When teeth erupt in the wrong direction, this can lead to resorptions affecting the root of adjacent teeth. This can affect the upper canines in particular. Eruption in the wrong direction results in resorption of the roots of the lateral incisor. Monitoring the eruption of the teeth and timely extraction of the Class III anomaly is a clinical necessity in these cases.



74 Root resorptions: agenesis

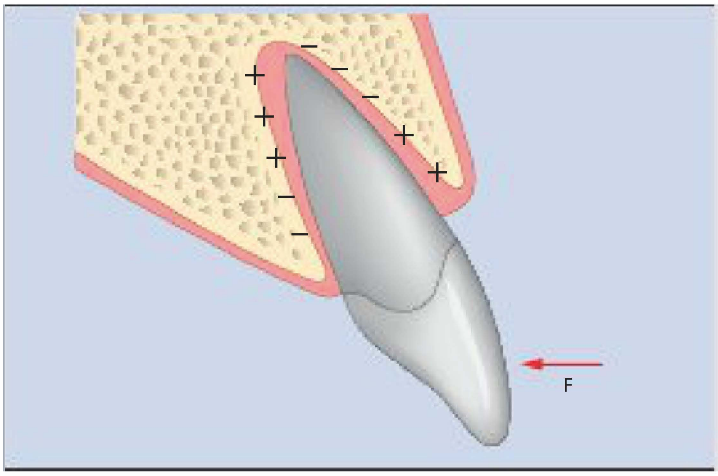
Patient with familial multiple agenesis. Tooth 35 and 34 have not developed. Patients with agenesis have a higher incidence of idiopathic root resorptions in our patient population. Only limited orthodontic treatment is possible. Extraction therapy to offset agenesis should only be performed with small moving distances, if at all.

75 Root resorptions: agenesis

Same patient as in **Fig. 74** at a later date. The orthopantogram (OPG) shows the resorption of the deciduous dental roots of 74 and 75, although the permanent teeth have not developed. In addition, the patient is an allergy sufferer. Extensive orthodontic measures should be avoided in this case as there is a high risk of root resorption during orthodontic treatment.

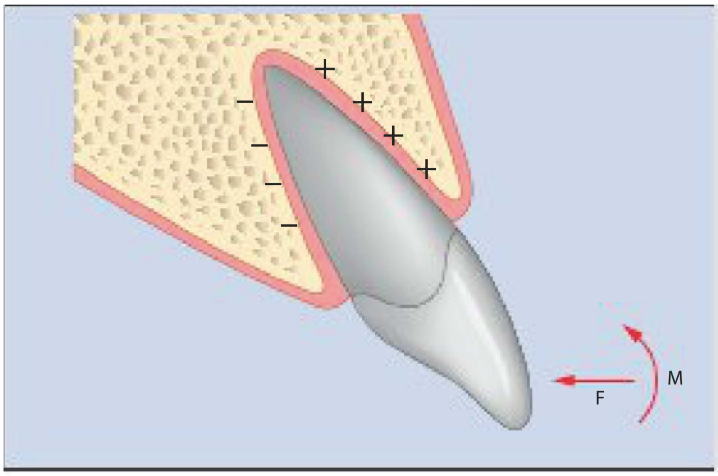
1.7 Orthodontic Tooth Movement

The aim of orthodontic treatment is to move teeth as efficiently and carefully as possible and with minimal side effects for tooth, tissue, and bone (von Böhl and Kuijpers-Jagtman 2009). It is essential to ensure an optimal force system for the biological response of the periodontium and tissue. Unwanted tissue responses, necroses, and root resorptions may occur as attendant symptoms, depending on the application of force and duration of the force effect. The significance of mechanical stimuli on the bone, tissue, and teeth has already been studied since the mid-19th century (von Meyer 1867, Wolff 1892). Reconstruction of the bone is a remodeling process. Osteoclasts resorb bony material and osteoblasts form new bone. The remodeling processes are the result of complex interactions between cells or between cells and the matrix. Hormones, cytokines, and growth factors act as messengers and intermediaries (Krishnan and Davidovitch 2009a, 2009b). The alveolar bone is also stressed during daily mastication, but it only changes by apposition and resorption, subject to a certain amount, direction, and duration (Meikle 2006).



76 Tooth movement: tipping, tensile (+), and pressure zones (−)

In an orthodontically induced tipping tooth movement, given palatal movement of an anterior tooth, a pressure zone is produced palatally in the cervical third and vestibularly direction in the apical third of the alveolar bone with a compressed periodontal gap. Accordingly, tensile zones with a widened periodontal gap are produced on opposite sides.



77 Orthodontic tooth movement: bodily movement, tensile (+), and pressure zones (−)

In the case of an orthodontically induced bodily movement of an anterior tooth in a palatal direction, a pressure zone is produced over the entire palatal surface of the root and of the adjacent alveolar bone with compression of the periodontal gap. Accordingly, a tensile zone with an enlarged periodontal gap is produced on the vestibular surface.

One of the first studies concerning force and tooth movement was undertaken by Sandstedt (1904, 1905): osteoblasts bring about bone apposition on the tensile side and osteoclasts cause bone resorption on the pressure side. However, the distribution of pressure and tensile zones differs depending on the type of movement: tipping (**Fig. 76**) or bodily (**Fig. 77**).

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1.7.1 Tissues Supporting the Teeth

The most important structures of the tissues supporting the teeth that are actively involved in tooth movement are the periodontium and the alveolar bone.

Periodontal Fiber

The diagonal structure of the fiber bundles of the periodontium dampens the masticatory forces that arise (**Fig. 78**). A distinction is drawn between dentogingival, dentoperiosteal, transseptal, alveologingival, and circular ligaments in the fiber bundles (Reitan 1989). The direction and location of the fibers are not uniform in the individual periodontal fibers.