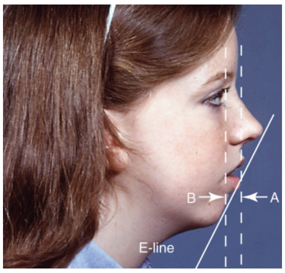
(Proclined incisors align themselves in an arc of a larger circle: → if retrusive incisors are present, less space is available.)

- Evaluation of lip prominence:
  - Observe the distance that each lip projects forward from a true vertical line through the depth of the concavity at its base = soft tissue points A & B.
    → a different line of reference is used for each lip.
  - Lip prominence of > 2-3 mm in the presence of lip incompetence indicates dentoalveolar protrusion.

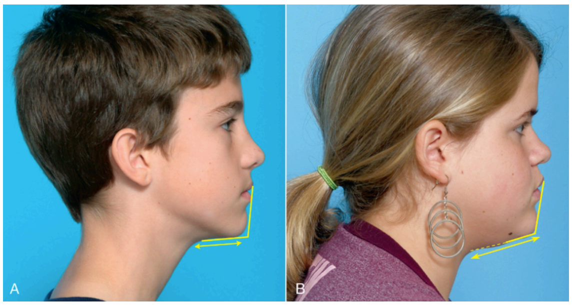


- Excessive incisor protrusion exists if:
  - Lips are prominent and everted.
  - Lips are separated at rest > 3/4 mm.
    (Some lip separation is normal in children, but breathing through the nose is also possible while the lips are apart.)

- **E-line** (*Ricketts, 1960*): Line from the nose tip to the chin:
  Lips should be on or slightly before the line.
  The position is influenced by vertical facial and dental relationships:
  E.g. short lower face height → lips can be protrusive.
- Patients with short lower face height can have everted and protrusive lips, because they are overclosed and the upper lip presses against the lower lip.
  → Evaluate the mentolabial fold angulation (angle between the labial surface of the lower lip and the labial surface of the chin). Normally this angle is somewhat obtuse. A greatly decreased angle indicates overclosure.

- **Check the mn plane angle**

- **Throatform:**
  - **Contour of the submental tissues** (straight is better).
    → Submental fat deposition and a low tongue posture contribute to a stepped throat contour.
  - **Chin-throat angle** (closer to 90° is better).
  - **Throat length** (long is better up to a certain point).



Mini-esthetics: Tooth-lip relationship

- Smile variables:

Variable	Ideal	Maximum	Minimum
Variables Best Viewed in Full Face			
Smile arc	Tracks the lower lip	0.6mm higher at canines	Greater than flat
Buccal corridor (as % black space of intercommissure width)	16%	88%	8%
Gingival display	2.3mm tooth coverage	0.8mm tooth coverage	4.5mm tooth coverage
Occlusal cant	0	2.8 degrees	
Upper to lower dental midlines	0	3.6mm	
Variables Viewed Either in Full Face or as Close-up of Lower Face			
Upper dental midline to face	0mm	2.9 to 3.2mm	
Upper central to central incisor gingival height discrepancy	0mm	2.0 to 2.1mm	
Upper lateral to central incisor gingival height discrepancy	−0.4mm	0.4 to 1.2mm	−1.9 to −2.9mm
Overbite	2 to 2.3mm	5.4 to 5.7mm	0.4 to 0.9mm
Upper central to lateral incisal edge step	1.2 to 1.4mm	2.0 to 2.9mm	

- Symmetry of the **dental midline** of each arch to the skeletal midline of that jaw.

- **Up-downward transverse rotation** of the dentition.

- **Vertical relationship** of the teeth to the lips at rest and on smile.

- Overbite: 2-2.3 mm best

- **Smile analysis:**
  Two smiles:
  1. **Posed or social smile:**
     - Reproducible, presented to the world usually.
     - = Focus of orthodontic tx.
  2. **Enjoyment smile**:
     - Varies with the emotion being displayed.
- **Smile arc**:
  = Relationship of the curvature of the lower lip to the curvature of the maxillary incisors.
  Best appearance if the two lines match each other.

- Upper central to lateral incisal edge step 1.2 - 1.4 mm.

- **Gingiva:**
  - Ideal elevation of the lip on smile for adolescents:
    Slightly below the gingival margin with 2 mm tooth coverage.
  - 1-4 mm tooth coverage is still considered attractive.

  Influencing factors for gingiva display:
  - Usual cause for excessive display of mx gingiva is a long-face due to excessive downward growth of the mx which moves the mx down below the upper lip and results in a disproportionately long lower third of the face.
  - DD Incomplete gingival recessions that accompanies eruption in childhood.
  - DD Incomplete eruption and short upper lip.
- **Buccal corridor**:
  = Distance between the maxillary posterior teeth (especially premolars) and the inside of the cheek.

- Minimal buccal corridors of 16% are favored.
- Transversal arch width should be related to the face.

- Some “smile-features” are viewed differently by patients when the full face is the context and they are not focused only onto the mouth:
  - Upper incisal edges and canines should parallel the curvature of the lower lip.
  - Transverse cant of the occlusal plane is less tolerated by patients.
    Notification dentist: ≥1 mm.
    Notification layperson: ≥ 2-3 mm = 3-4°.
  - More upper to lower midline discrepancy is acceptable.
  - Small buccal corridors are preferred.
  - Facial attractiveness and gender make a difference for some of the mini-esthetic-features.
  - Mesial or distal tip of an upper incisor > 2 mm is judged unaesthetic.

TABLE 6.7 Esthetic Variables: Maximum and Minimum for Esthetic Acceptability Considering Facial Attractiveness and Gender

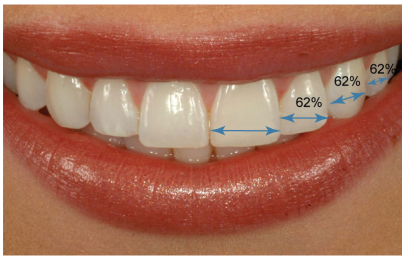
From Chang C, Springer NC, Fields HW, etal. *Am J Orthod Dentofac Orthop.* 2011;140:e171–e180.

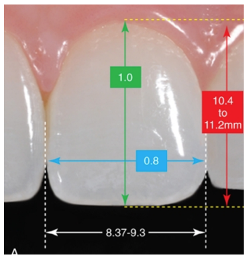
Some smile variables are influenced by facial attractiveness and gender. This can be difficult to manage given the need to determine the patient’s facial attractiveness. To simplify application of the information, the range of acceptability or “common ground” for all levels of facial attractiveness is noted below for each gender.

Smile Variable	**Gender**	**Maximum**	**Minimum**
Buccal corridor (percentage dark space of intercommissure distance)	M	24	15
	F	17	10
Gingival display (mm of tooth coverage)	M	0.5	1
	F	0.5	0.5
Smile arc (mm canine above incisal edge + or below −)	M	3.8	1.8
	F	3.8	1.8
Upper midline to face	M	2.3	0
	F	2	0

Micro-esthetics: Dental appearance

- Unaffected by the size of view (full face background).
- **Ideal tooth proportions to each other:** = golden proportion of **0.62%.**
  From anterior → posterior: **1.0:0.62:0.38:0.24**

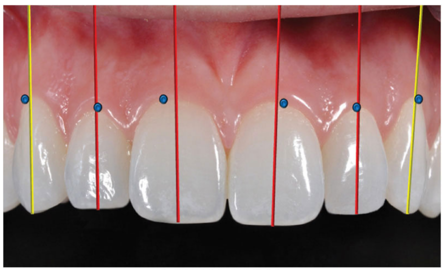


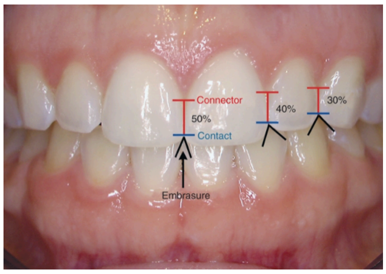


- **Height-width proportion** of the individual teeth: Ideal relation incisors to premolars = **0.8.**
  (1+1: height 10.4-11.2 mm, width 8.37-9.3 mm)
  Check with tables if the width or the length is not correct in case of a disproportion.

  Mirabella D.: Ideal relation width - length:
    - 1+1: **85%**
    - 2+2: **77%**
    - 3+3: **80%**

- **Gingiva height:**
    - 1+1 highest level.
    - 2+2 1.5 mm lower.
    - 3+3 same level as 1+1.
- **Gingiva shape:** Refers to the curvature of the gingiva at the margin of the tooth.
    - 2+2: Symmetric half oval.
      Gingival zenith (most apical point of the tissue) in the longitudinal axis.
    - 1+1,3+3: Elliptical and oriented distally to the long axis of the tooth.
      Gingival zenith located distal to the longitudinal axis.
    - Laypeople and dentist recognize differences of more than 2 mm.





- **Connectors:** = Region where adjacent teeth appear to touch in an unmagnified photograph.
  (may extends apical or occlusally from the actual contact point).
    - Greatest height between 1+1.
    - Height diminishes from the anterior to the posterior teeth while moving apically.
- **Embrasures:** = Triangular spaces incisal and gingival to the contact area.
    - Ideally larger in size than the connectors and filled by the interdental papillae.
    - **Black triangles**: = Open gingival embrasure apical to the connectors due to short interdental papillae. Possible causes are periodontal disease or orthodontic corrections of severely crowded and rotated maxillary incisors.
    - *Tarnov 1992:*
      Presence of a papilla depends on the distance of the contact point ot the alveolar bone.
        - Distance ≦ 5mm : Papilla 100% of the patients
        - Distance ≧ 7 mm : Papilla 27% of the patients
- **Tooth shade and color:**
    - Lighter and brighter teeth at younger age.
    - Older age: Formation of secondary dentin & thinning of facial enamel.
      → Decrease in translucency and greater contribution of the darker underlying dentin.
    - Normal progression of shade change from the midline to the posterior regions is important for a nice and natural smile.
    - Brightness 1+1 > 2+2 > 3+3. 54+45 more closely matched to 2+2.
    - Bleaching is possible to optimize the tooth shade.

<table>
<tr><td colspan="2">Which diagnostic records are needed?</td></tr>
<tr><td>Health of teeth and oral structures</td><td>- IO photographs with maximum retraction of the cheeks and lips.
- OPT:
• Discover pathologic lesions.
• Condyles.
• Screening image if CBCT or MRI is necessary.
- Periapical and BW only if greater detail is required.
(suspicion of root resorption, periodontal diseases)
→ ABO: Individual IO radiographs are required for adults to supplement the panoramic radiograph. Exception: If only a partial fixed appliance is planned.
- CBCT for impacted canines.</td></tr>
<tr><td>Dental alignment and occlusion

<u>Indications:</u>
→ for adults only:
- Restorations
- TMJ diseases
- Orthognathic surgery
- CR/IK slide</td><td>- Impressions for dental casts (plaster or digital).
- Dental casts should have symmetric bases oriented to the midline of the palate:
→ Easier to analyze arch form and detect asymmetry within the dental arches.
- Neatly trimmed and polished casts are more acceptable for presentation to the patient.
- Bite registration in IK. Additionally in CR, if a lateral shift or great anterior shift exists.

- <u>Articular mounting</u>: Matter of debate if necessary:
• Document discrepancy between the occlusal relation at the initial contact of the teeth and the relation at the patient’s full or habitual occlusion.
• Record the lateral and excursive paths of the mandible.
• Important for restorative dentistry:
→ Restored teeth must accommodate the path of movement.
• No point for preadolescent patients:
o Contours of the TMJ are not fully developed:
→ Condylar guidance is much less prominent than in adults.
o Shape of the temporal fossa reflects function during growth in adults. Completion of the articular eminence and the medial contours of the joint do not develop until mature canine function is reached and the chewing pattern matures from the one of a child to the one of an adult.
o Relationship between the dentition and the joint which is recorded in articulator mounting changes rapidly while skeletal growth is continuing and tends to be only of historic interest after orthodontic tx.
• Indicated in adults with TMJ problems to document significant discrepancies between habitual and relaxed mandibular position.
• Indicated for orthognathic surgery planning.
• Virtual articulators are available and are accurate (cave: high costs).</td></tr>
<tr><td>Facial and dental appearance</td><td>- No growth modification in children without a pre tx ceph.
- No ceph is required if minor problems in children or adjunctive procedures in adults are treated without significant changes of jaw relationship or incisor position.
- Frontal, profile and oblique eo pictures.
- Optional a video sequence showing the patient in function.</td></tr>
<tr><td colspan="2">Analysis and diagnostic records</td></tr>
<tr><td>Cast analysis:
symmetry
space
tooth size</td><td>- <u>Symmetry:</u>
• Asymmetric arches are also possible in a symmetric face.
• Place a transparent ruled grid over the dental arch to make detection of distortions easier.
• Asymmetry in arch form.
• Asymmetry within the dental arch, but with symmetric arch form due to lateral drifts of teeth.

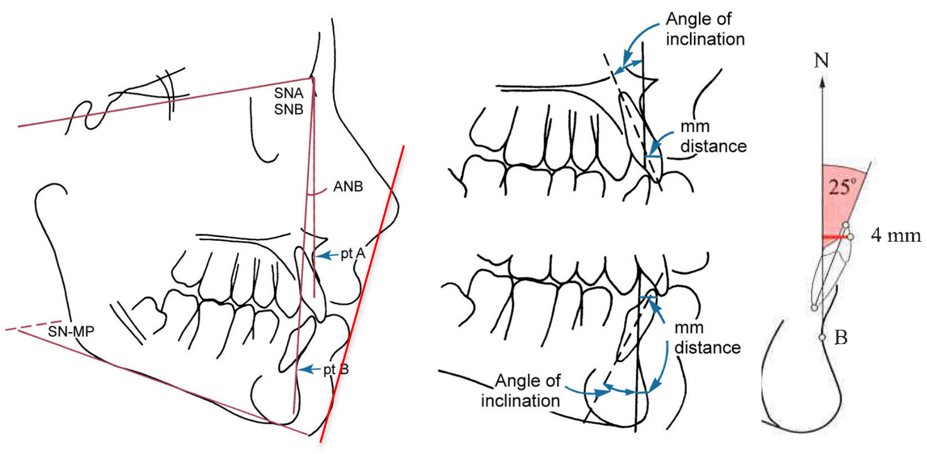
- <u>Alignment (Crowding): Space Analysis.</u>
Measure the size of the teeth vs. the space available for them.

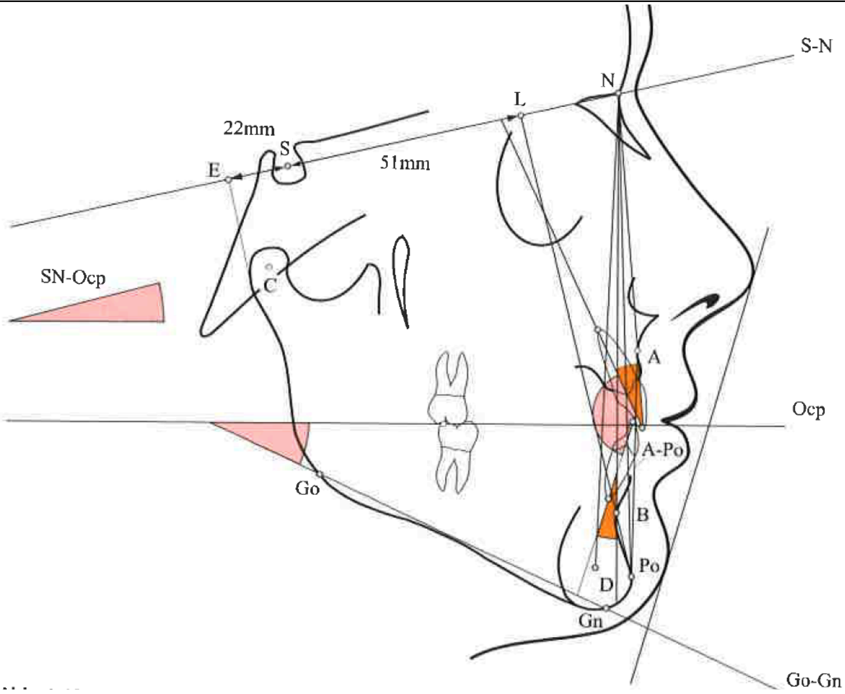
- <u>Tooth size analysis:</u>
• 5% of population have some degree of disproportion among the sizes of individual teeth = tooth size discrepancy.
• Bolton analysis, 1957:
Measure the md width of each permanent tooth. Compare the summed widths from the upper teeth (6 or 12) with the total width of the lower teeth.
Proportions:
- Bolton 6: 77.2%</td></tr>
</table>

	- Bolton 12: **91.3%** *Cave: Bolton measured 55 models with ideal OJ, OB and alignment.* *Bolton analysis neglects arch shape, tip, torque & bucco-lingual width of the teeth which contribute to the alignment.* • Indices for discrepancy: - 2+2 not wider than 2-2. - 5+5 should have the same width as 5-5. - Discrepancy <1.5 mm is rarely significant for tx. *Othmann, 2007*: Discrepancy < 2 mm is not clinically significant. - If the discrepancy is larger: →Achieving an ideal occlusion can be difficult.
Cephalometric analysis → s. Block course Geneva for different analysis & pictures	- First introduced 1934 by Hofrath in Germany and Broadbeck in the US. - A lateral ceph is necessary to distinguish and clarify the differing dental and skeletal contributions to malocclusions which present identical dental relationships. - Detect pathologic processes and anomalies in the cervical spine. (degenerative processes) - Any malocclusion is created by interaction of: 1 Cranium and cranial base 2 Skeletal maxilla and nasomaxillary complex 3 Skeletal mandible 4 Maxilla teeth and alveolar process 5 Mandibular teeth and alveolar process (1-3 exist independent from the teeth, 4 & 5 can be displaced independent from the supporting bone) - Superimposition: o Recognize and evaluate changes from tx and growth. o Distinction of the two of them is not possible. - Construct 50-100 landmarks: o Compare the lines and angle measurements or express the data graphically to compare it with a graphic reference. o Landmarks can be intersections or extreme points. (e.g. the most anterior point of the chin) Cave: Extreme point's location changes with the head position. - Sources for errors: o Head position o Magnification o System error o Distortions o Localization of the landmark - Compare the patient with a reference group: - **Down's analysis:** o First done after WW II (~1948). o Developed at the university of **Illinois**. o Reference group = 25 untreated adolescent whites with ideal dental occlusion. - **Steiner**: Measurements originally based on one **Hollywood starlet**. - **Michigan growth study**: o Developed in **Ann Arbor**. o Typical group of children including those with mild and moderate malocclusion (better than to take only individual with ideal occlusion). o Reference group mostly used nowadays. - **Burlington:** o Developed in **Ontario.** - **Bolton study:** o Developed in **Cleveland.**
Choice of horizontal reference lines	- **Frankfurt plane**: = Horizontal reference line for the orientation. o Originally developed for the orientation of dried skulls 1882 at a conference in Frankfurt. o Upper rim of the external auditory meatus (porion) to the inferior border of the orbital rim (orbitale). Machine porion from the earplugs is sometimes used to replace the porion. o Cave: Porion is difficult to localize on the lateral cephalogram.

	- **SN line:**
	  ○ 6-7° upward anteriorly to the Frankfurt plane.
	  ○ If the difference is sign. > 6°, any measurement based on SN should be corrected by this difference.
	
	- **Physiological head position:**
	  ○ Established physiologically not anatomically.
	  ○ Individuals should look at a distant object or with the eyes in a mirror and move the head slightly up and down in increasingly smaller movements.
	  ○ Precisely reproducible within 1-2°.
	  ○ Up to 10° difference to the anatomically Frankfurt plane.
	  ○ The established line is perpendicular to the true vertical line.
	  ○ Preferred reference line in modern cephalometrics.

Downs analysis 1948	- First done after WW II. Developed at the university of Illinois.
	- Reference group = 25 untreated adolescent whites selected due to their ideal dental occlusion.
	
	- **4 facial types:**
	  ○ Mesognathic with straight profile and normal chin.
	  ○ Retrognathic with recessive chin.
	  ○ Prognathic where chin is prominent.
	  ○ Prognathism when mandibula is large.
	
	- **Facial angle**.
	- Chin prominence: **N-Po / FH**.
	- Mn plane angle: **ML / FH**.
	- Y axis: **S-Gn / FH**. Forward or backward position of chin in relation to the face (60°).

Steiner analysis 1950	- Reference values originally based on one Hollywood starlet.
	
	- **SNA, SNB.**
	- **ANB** (main interest of Steiner) magnitude of skeletal discrepancy.
	  ○ Influenced by the vertical height of the face (vertical height ↑ → ANB ↑)
	  ○ Influenced by the anterior / posterior position of N (jaw protrusion ↑ = ANB ↑)
	  ○ Influenced by the AP difference in jaw position.
	- **Angular** inclination (DD tipping vs. bodily movement) and **Distance** (establish the relative protrusion of the dentition) in mm:
	  ○ **Upper incisors to NA**
	  ○ **Lower incisor to NB**
	- Chin prominence: **Pogonion to NB**
	- **Holdaway ratio** *(Holdaway 1983)* **:** LI-NB / Po-NB
	  ○ Ideal: 1:1.
	  ○ If > 4:1 → extractions are indicated
	  ○ → The more prominent the chin, the more prominent the incisors can be.
	- Inclination of the **mn plane to SN** = vertical indicator.
	- **S-Line**: Po – Pronasion (Pronasion = midpoint line subnasale & tip of the nose)
	
	



Cave:
- More posterior position of N or more protrusive jaws → ANB ↑ even if the horizontal relationship is not changed.
- Relies only on tooth movement to correct skeletal malocclusion.
  → This is represented by the **Steiner compromises**: Ideal values for upper and lower incisor inclination adapted to the sagittal malocclusion (ANB)

Tabelle 4-14 Individualisierte Sollwerte der Schneidezahnstellung in Abhängigkeit vom ANB-Winkel nach *Steiner*

ANB	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8	9
1-NA [mm]	11	10	9	8	7	6	5	4	3	2	1	0	−1	−2	−3
1-NB [mm]	2,25	2,5	2,75	3	3,25	3,5	3,75	4	4,25	4,5	4,75	5	5,25	5,5	5,75

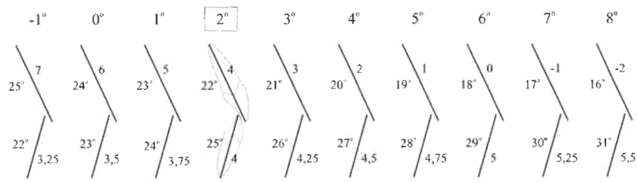


Abb. 4-42
Schematische Darstellung der individuellen Schneidezahnstellung von Inklination und Position

Sassouni analysis 1955

- Mediterranean sample, 100 individuals.

- First analysis to emphasize vertical AND horizontal relationships and the interaction between vertical and horizontal proportions:
  - Point out several horizontal anatomic planes → tend to converge toward a single point (called X here):
    - **Anterior cranial base**
    - **FHP**
    - **Palatal plane**
    - **Occlusal plane**
    - **Mandibular plane**
  - Inclination of the planes to each other reflect the vertical proportionality of the face:
    - Intersection close to the face and quick divergence when passing anteriorly → proportion long anteriorly, short posteriorly.
      = **Skeletal open bite**. (term introduced by Sassouni)
    - Lines nearly parallel, converge far behind the face
      = **Skeletal deep bite**. (term introduced by Sassouni)

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- Unusual inclination of one plane needs further examination.
- Sagittal component:
- Anterior arc with center in X through: **Spa - Is -Pg**.
- Posterior arc with center in X through: **Sp** (posterior wall of sella turcica**) - Go.**
→ Evaluation of the relationship of various points to this arc.
Cave: Difficult if the face becomes more disproportionate.

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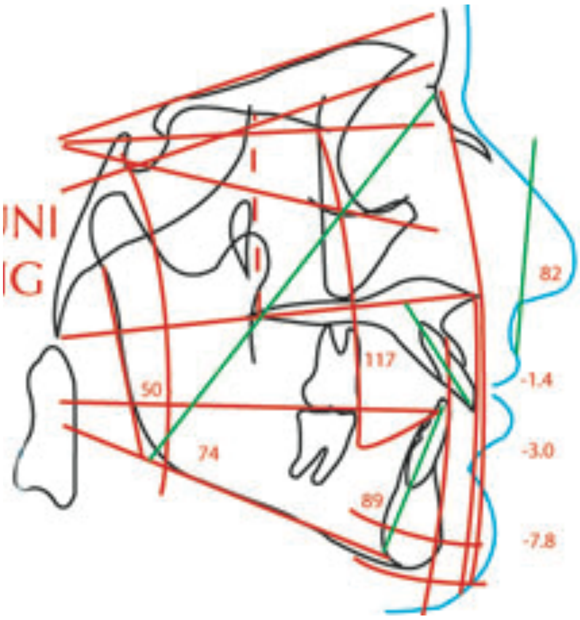

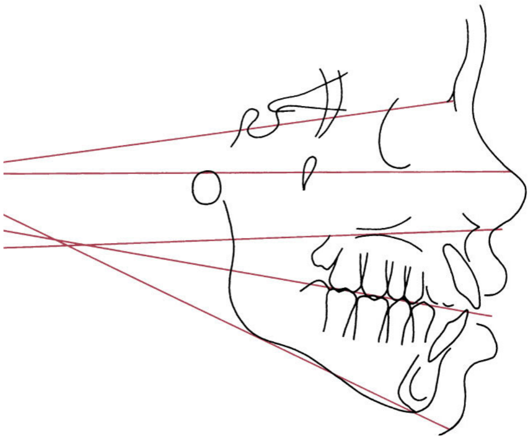

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Ricketts analysis 1960

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<td>

- <u>Measurements to locate the chin space:</u>

- **Facial axis of angle**: Ba-N – Pt-Gn:
Describes the direction of growth of the mandible at the chin.
Remains stable in a normally growing child or reduces a little.
- **Facial depth angle** FH to N-Pog.
- **Mandibular plane angle**: ML to FH.
- **Lower face height**: ANS-Xi and Xi-Pm
- **Mandibular arc**: DC-Xi to the distal extrapolation of the corpus axis.

- <u>Measurements to determine convexity:</u>

- **Convexity of point A**: A to facial plane measured perpendicular in mm.

- <u>Measurements to locate the denture in the face:</u>

- **Lower incisors protrusion: Iii to A-Pg.** (A-Pg defined by Downs)
- **Lower incisor inclination to A-Pg**.
- **Upper molar position**: = Distance between the most distal point of the maxillary first permanent molar and PTV (= Hinterwand fossa pterygoidalis).
Norm = patient's age + 3 mm.
At least **21 ± 3 mm** need in later years for the eruption of the 2nd & 3th molar.

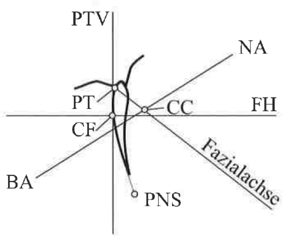

Abb. 4-53
Bestimmung der Punkte PT, CF und CC in der *Ricketts*-Analyse: Der Punkt CF beschreibt den

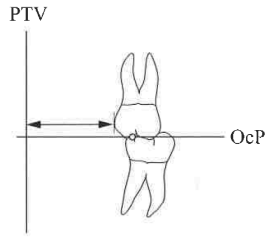

Abb. 4-54
Stand des oberen ersten Molaren zur Pterygoidsenkrechten (PTV)

- **Interincisal angle.**

- <u>Measurements to determine the profile:</u>

- **Lower lip to E-plane** (tip of the nose - tip of the chin).
Lips should be behind this line
- **Maxillary depth**: N-A to FH

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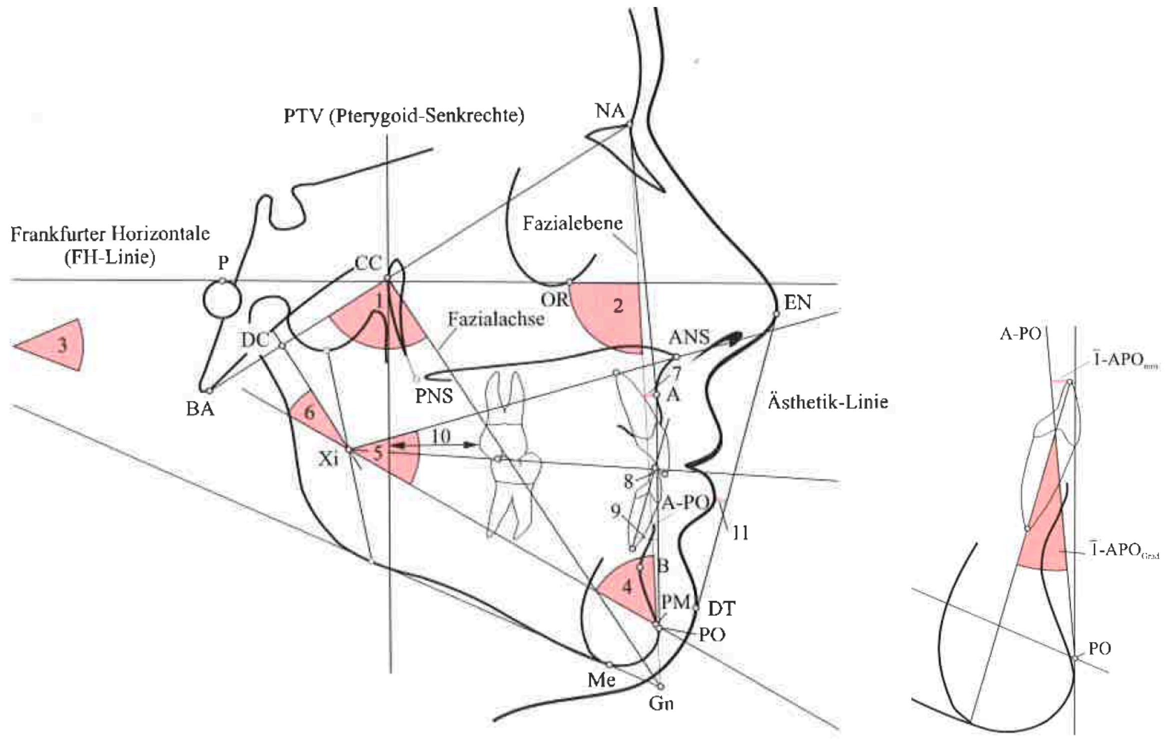
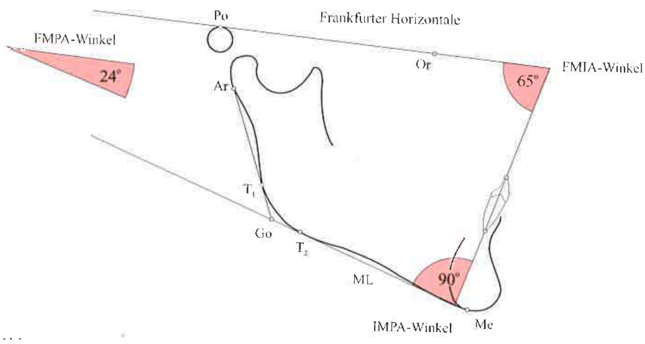
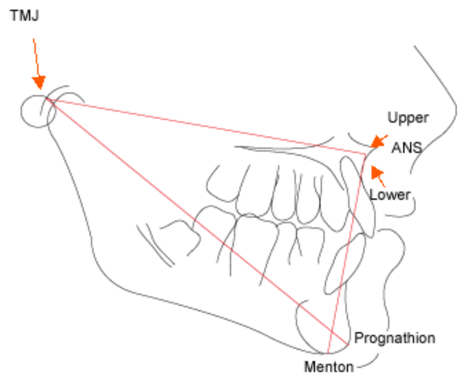
<tr><td colspan="2">
</td></tr>
<tr><td>Tweed 1969</td><td>- Sum of the angles = ~180°.

</td></tr>
<tr><td>Harvold analysis 1974</td><td>- Aimed to describe the severity or degree of jaw disharmony.
- Development of “unit lengths” for mn & mx.
- Teeth have no influence on the measurements.
- Data from the Burlington growth study (Ontario).
- Cave: Vertical distance between mx and mn ↓ → anterior position of the chin ↑ for any given unit difference.


- Mx length: TMJ (posterior wall of the glenoid fossa) - to ANS (defined where the spine is 3 mm thick)
- Mn length: TMJ - gnathion
- Lower face height: Upper ANS (where the spine is 3 mm thick) - menton.</td></tr>
</table>

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<tr>
<td>Björk & Jarabak 1972

(Jarabak analysis = based on the analysis of Broadbent, Björk, Downs, Steiner, Ricketts, Sassouni und Wylie)</td>
<td>
- Useful to predict growth.
- Sample: 300 subjects of 12 y, 300 soldiers 21-23 y.

- 5 angles:

Saddle angle: S - N - Ar.
Dolicho-/ Meso-/ Brachiofacial cannot be modified.
Articulare angle: S - Ar - Go.
Retro-/Prognathism.
Gonial angle: Ar - Go - Me.
Shape of the mandible
Upper ½ Gonial angle: Horizontal indicator.
Lower ½ Gonial angle: Vertical indicator.
Summenwinkel = saddle angle + articulare angle + gonial angle = 396° ± 4°

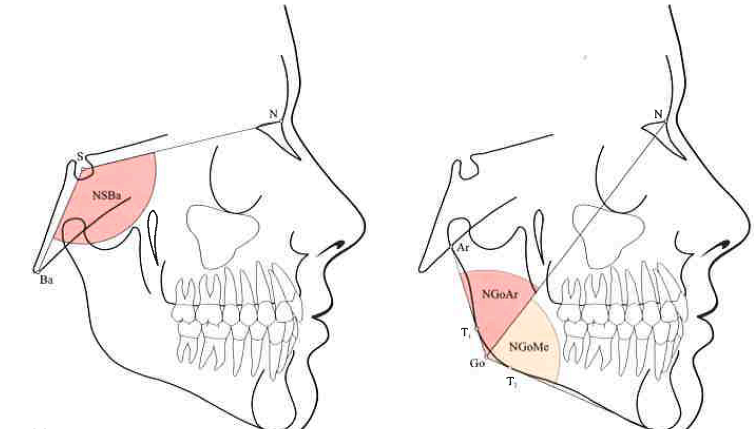


Abb. 4-24
NSBa-Winkel

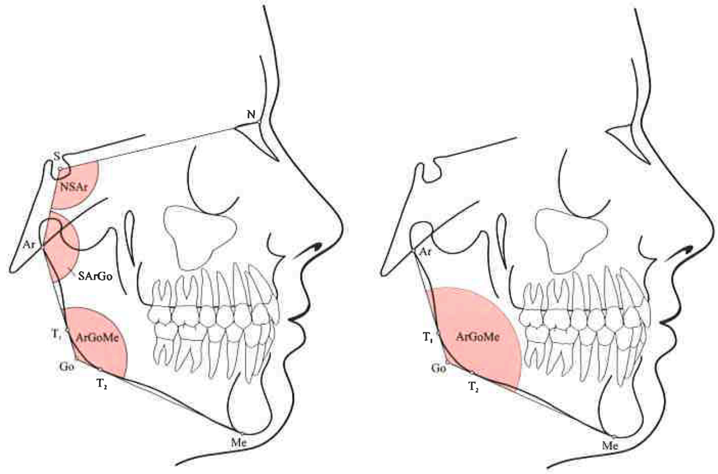


Abb. 4-27
Summenwinkel nach Björk: Summation der Winkel NSAr, SArGo und ArGoMe

Abb. 4-28
ArGoMe-Winkel

- Direction of growth:

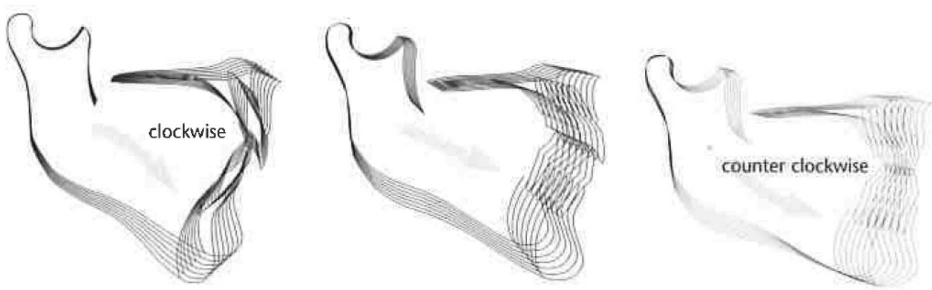


Abb. 4-57
Wachstumstypen nach Jarabak: clockwise, neutrales und counter clockwise Wachstum
</td>
</tr>
</table>

<table>
<tr><td>Wits analysis

(Jacobson, 1975)

University of Witwatersrand South Africa</td><td>- Wits: = Projection of A & B to the occlusal plane.
→ Measure the linear difference between the points:
Nearly 0 in females / -1 in males with a normal anterior-posterior jaw relationship.

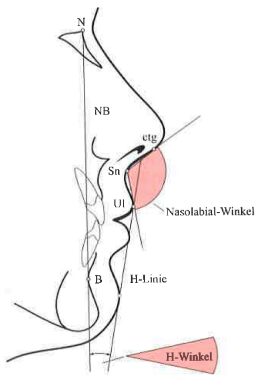
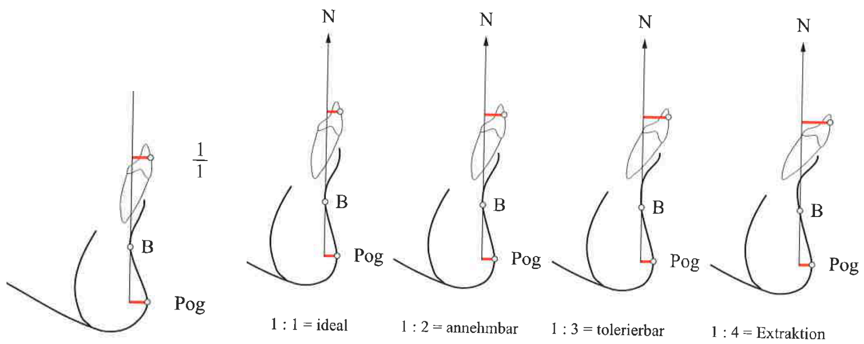
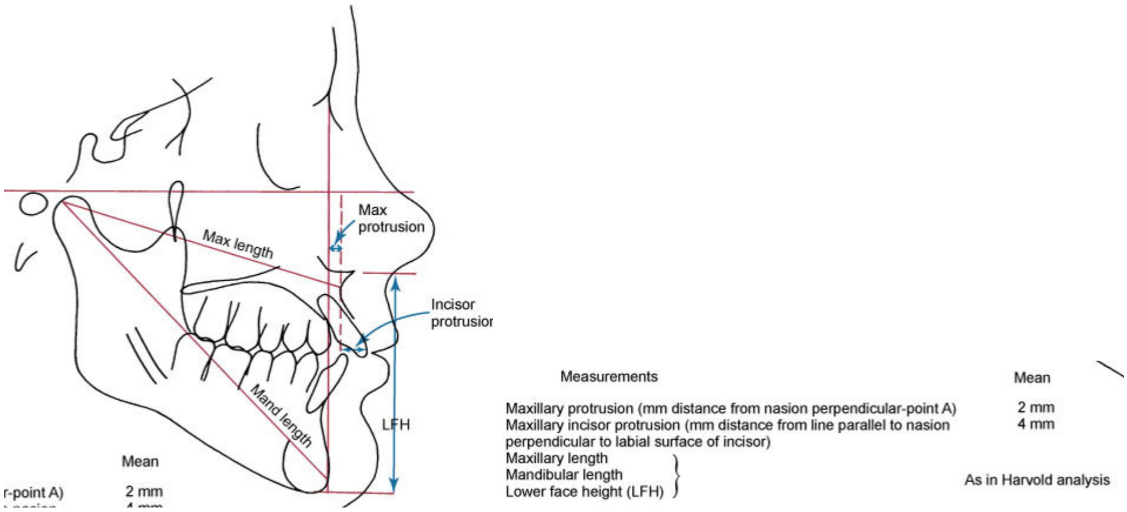
- Aimed to describe the severity or degree of jaw disharmony.
- Influenced by the teeth (horizontally and vertically) and the curvature of the lower occlusion (Spee curve).
○ Posterior rotation of the occlusion = Wits ↓.
○ Anterior rotation of the occlusion = Wits ↑.
- Indication: To be used when the ANB is not reliable.
- Fails to distinguish skeletal and dental discrepancies.
- Does not specify which jaw is wrong if there is a skeletal problem.</td></tr>
<tr><td>Holdaway analysis 1983</td><td>- Holdaway ratio : LI-NB / Po-NB.
→ The more prominent the chin, the more prominent the incisors can be.
- H-Line: Pg - upper lip point.
- H-angle: Angle H-Line / NB</td></tr>
<tr><td colspan="2">

Abb. 4-48
Nasolabialwinkel und Weichteilwinkel nach Holdaway

</td></tr>
<tr><td>McNamara analysis 1984</td><td>- Anatomic Frankfort plane & basion-nasion line used as reference lines.
- McNamara line = Line through point N, perpendicular to FH = Nasion perpendicular.
- Anterior-posterior position of maxilla / mandibula evaluated to their position in relation to the nasion perpendicular.
- Comparison of maxillary and mandibular length.
(linear relation between both of them = Harvold approach)
- I/ related to the maxilla with line through A perpendicular to FH.
(similar to Steiner)
- /I related to A-Pg line. (Rickets)

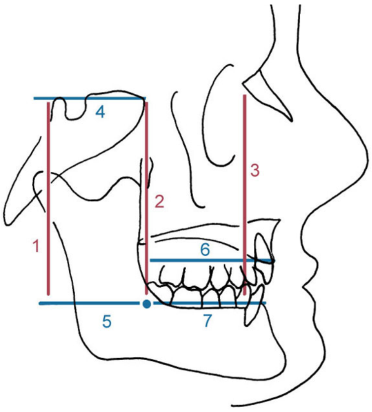
- <u>Analysis of the airways:</u>
○ Upper pharynx diameter:
= Shortest distance from posterior pharyngeal wall to the anterior half of the soft palate.
Breathing is impairment if the distance is decreased.
○ Lower pharynx diameter:
= Shortest distance from posterior of the tongue to the posterior pharyngeal wall.
If >15 mm: Prognathism, enlarged tonsils, mouth breather, dolichofacial pattern.
- <u>Vertical values:</u>
○ Lower anterior facial height: ANS to Me
○ Mandibular plane angle
○ Facial axis angle (PTM, Ba, N, Gn) → anticlockwise/clockwise
- <u>Soft tissue evaluation:</u>
○ Nasolabial angle.
○ Cant of the upper lip in relation to a vertical line through N.

- <u>Pros:</u>
○ Normative data are based on the well-defined Bolton sample.
○ Anterior-posterior difference of the maxilla and mandibula is projected to an approximation of the true vertical line.
→ The difference is measured how it is visualized by the patient (nearly true horizontal line).</td></tr>
</table>



Counterpart analysis by Enlow 1972

- Changes in proportions in one part of the head and face (skeletal or dental) can either add to increase a jaw discrepancy or compensate so that the jaws fit correctly even though there are skeletal discrepancies.
- Adaption in clinical practice:
    - The judgment should be based on how the values are related to each other (face type) rather than judge “normality” based on individual values (cephalometric values).
    - Examination of the patient’s proportions.



If anterior face height is long, facial balance and proper proportion are preserved if posterior face height and mandibular ramus height also are relatively large. On the other hand, short posterior face height can lead to a skeletal open bite tendency even if anterior face height is normal because the proportionality is disturbed. The same is true for AP dimensions. If both maxillary and mandibular lengths are normal but the cranial base is long, the maxilla will be carried forward relative to the mandible, and maxillary protrusion will result. By the same token, a short maxilla could compensate perfectly for a long cranial base.

Template analysis

- = Direct comparison of the lateral ceph of a patient with a template.
  → Compensatory skeletal and dental deviations within an individual can be observed directly.
  → Overall impression how the patient’s dentofacial structures are related.

- Templates:
    - **Schematic templates**: (Michigan (Ann Arbor), Burlington (Ontario))
      Show the changing position of selected landmarks within age on a single template.
    - **Anatomically complete templates** (Broadbent-Bolton (Cleveland, Alabama)):
        - More used.
        - Different templates for each age.
        - Convenient for direct visual comparison with the patient’s ceph. Cranial base & maxillary / mandibular superimposition.
        - Most often, the Bolton templates are used.

- Chose a template according to the patient’s physical size and the developmental age. Length of the anterior cranial base should be approximately the same for the patient and the template.

- <u>Superimpositions:</u>
    - Cranial base (SN-line): Relationship maxilla / mandibula to the cranium.
    - Maxillary superimposition on the palatal contour of the maxilla: Relationship of the maxillary dentition to the maxilla.

<table>
<tr><td></td><td>• Mandibular superimposition on the mandibular symphysis along the lower border / mandibular canal if it’s present:
Relationship of the mandibular dentition to the mandible.</td></tr>
<tr><td>Cephalometric analysis summary</td><td>1. Pathologic issues present?
1:1000 ceph shows severe pathologic processes.
2. Check for head positioning errors in case of an asymmetry.
3. Check landmark points.
4. Look for consistency of similar types (sagittal or vertical) of measurements.
5. Look for facial proportions or lack of it.</td></tr>
<tr><td>Analysis of 3D images from CBCT</td><td>- <u>Indications to use CBCT:</u>
• Ectopically erupting or impacted teeth (esp. 3+3) requiring surgical exposure:
- Extend of damage to adjacent permanent teeth.
- Define the path along which the tooth should be moved to bring it efficient into the mouth without further damage.
(studies show, that CBCT influences the way of tx planning regarding how to align the retained tooth)
- If a small field of view FOV is chosen, radiation is equal to ± 2 periapical x-ray.
• Severe facial asymmetry, especially asymmetries involving roll and yaw:
- Distances between any points can be measured.
- If a severe asymmetry exists, may chose CT to produce a precisely dimensioned stereolithographic model of the skeleton from the data.
Cave: CT = higher radiation doses.
• Syndromes and sequel of facial trauma.
• Hard tissue problems in the TMJ.

- Contrast resolution:
= Ability to distinguish between tissues of different densities.
(somewhat limited in CBCT because images have low soft tissues contrast).
- Spatial resolution =
Ability to distinguish between separate structures that are positioned very close together.
Voxel size ↓ → spatial resolution ↑.
- Noise:
= Unevenness of the distribution of the x-ray radiation on the radiographic field.
(There are always some voxels which get more or less radiation and they pretend that they are thicker or erosive structures.)
Exposure ↑ = Noise ↓ (= evenness ↑)

- Determinants of radiation doses:
○ Greater resolution needed → Radiation doses ↑
○ Voxel size ↓ → Radiation dose ↑
○ Field of view
○ Exposure ↑ = Noise ↓

- Pathologic changes on CBCT should be detected either by a trained orthodontist or a maxillofacial radiologist.
- Synthetic cephs created from the CBCT images are comparable enough to conventional cephalograms for clinical use.
- Superimposition is possible on landmarks (some success at defining them at the moment) or more accurate voxel-based at the cranial base.
- Changes between two timepoints can be displayed as color maps.</td></tr>
<tr><td>Notes seminar Karl Dulla:
OPG</td><td>- Aufhellung im Proc. condylaris = Fossa pterygoidea

- Speichelsteine:
• Parotissteine im Stenongang. OPT ~ Mitte R. ascendens.
• Submandibularissteine im Watsongang. OPT regio 8-8 nach cranial-mesial.
• ø Therapie von Speichelsteinen, solange ø Beschwerden.

- Verkalkungen des Lymphgewebes:
• Lymphknoten:
Im Angulus mn Bereich. Weiter posterior als Submandibularissteine.
• Tonsillolythen: In Tonsillenkrypten. Oft bei jungen Patienten. Sichtbar IO.

- Verkalkungen der Gefässwänden:
• Artheromatosen: Karotisverkalkungen. Regio C3, C4.
→ Risiko für Hirninfarkt, wenn sie sich lösen.</td></tr>
</table>

	• Arteriolosklerosen: Verkalkungen in kleinen Gefässen. • Phleboloith: Verkalkungen von kleinen Thromen z.B. in Venenklappen. - Verkalkung von Ligamenten: • Lig. stylomandibulare / Lig. stylohoideum → Eagle Syndrom. - Odontom: • Komplex = strukturlos. • Zusammengesetzt = viele kleine Zahngebilde.

Notes

- Peg shaped teeth:
    - = m-d width at the contact point < m-d width cervical.
    - Prevalence:
        - Whites: 1.3%
        - Blacks: 1.5%
        - Mongolese: 3.1%
    - RR female vs. males = 1.35

- Squeezed premolars:
    - = diameter m-d > diameter b-l.
    - Prevalence ~0.6%.
- Dens invaginatus:
    - = Invagination of the enamel organ into the dental papilla before the mineralization took place.
    - Prevalence:
        - 6.8%
        - Mostly permanent teeth.
        - 90% 2+2.
        - 6.5% posterior teeth.
    - Types:
        - 1. 79%. Within the crown.
        - 2. 15%. Extension into the pulp within the root channel.
        - 3a. Extension beyond the root channel. Ø communication with the pulp. PDL contact through lateral pseudo foramina.
        - 3b. Extension beyond the root channel. Ø communication with the pulp. PDL contact through the foramen apicale.
- Taurodontism:
    - = Failure of the diaphragma of ther Hertwig Epithelscheide to invaginate at the correct vertical level. → ø invagination at the cemento-enamel junction.
    - Prevalence:
        - 2.5-3.2% US
        - Mostly molars.
        - Primary and permanent teeth concerned.
        - Uni- or bilateral.
        - Frequently in patients with Down's syndrome.
    - *Kjar, 2008*: Risk for apical root resorptions.

- Transposition:
    - Prevalence: 0.33%
    - M=F.
    - Mx > Mn → Hypothesis: Mx = less dense bone.
    - May associated with delayed exfoliation of primary teeth.

Orthodontic classification

- Reduce the database to a patient's problemlist:

    - Angle classification

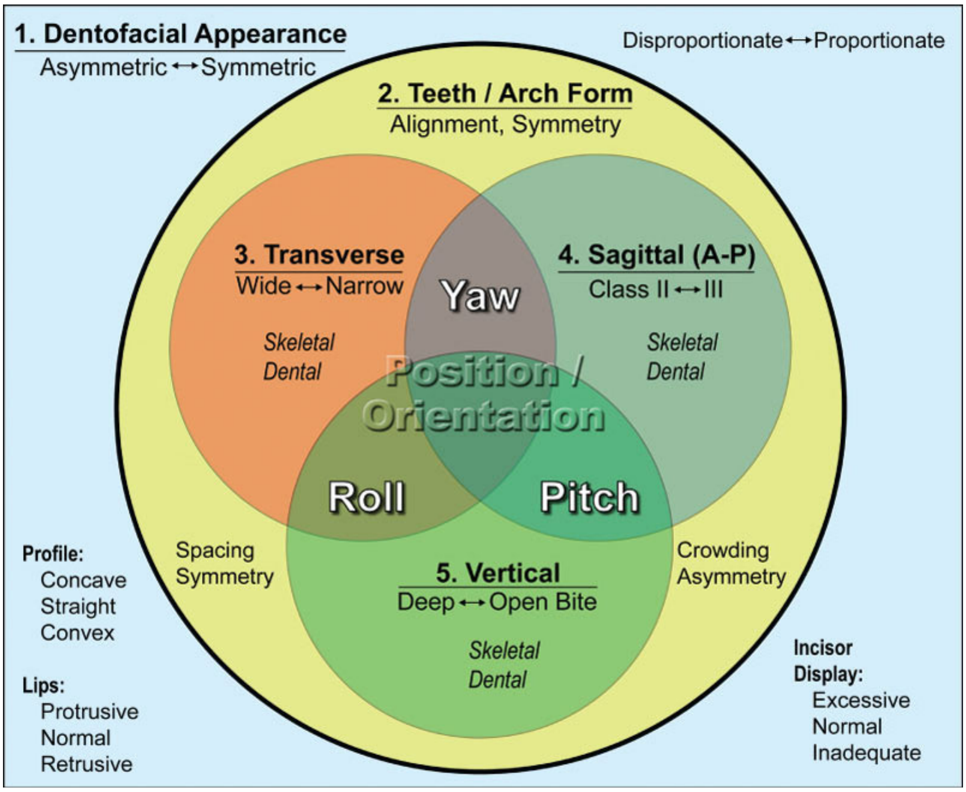
Normal occlusion	Normal (Class I) molar relationship, teeth on line of occlusion
Class I malocclusion	Normal (Class I) molar relationship, teeth crowded, rotated, and so on
Class II malocclusion	Lower molar distal to upper molar, relationship of other teeth to line of occlusion not specified
Class III malocclusion	Lower molar mesial to upper molar, relationship of other teeth to line of occlusion not specified

    - *Martin Dewey*: Proposed subdivisions for Angle cl.I.
    - Cl.II subdivision = Occlusion is cl.II on one side and cl.I at the other.

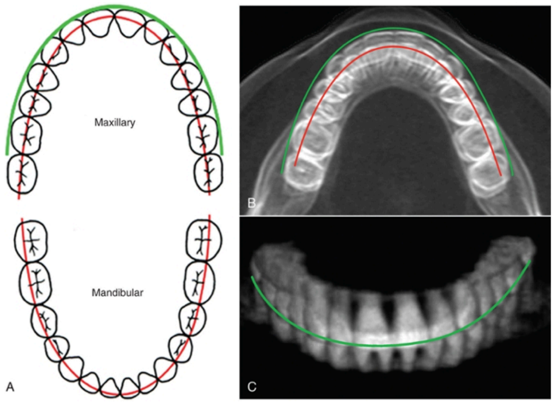
    - Extension of the Angle classification:
        - Type of malocclusion
        - Molar relationship
        - Jaw relationship
        - Pattern of growth

    → Although the 4 factors correlate with each other, correlations are far from perfect.

    - *1960 Ackermann & Proffit:*
    5 Characteristics Classification System
    Interaction of the tooth and jaw relationship with the facial appearance



- Additions to the 5 characteristics classification system:
    - **Esthetic line of dention:**
    Follows the facial edges of the maxillary anterior and posterior teeth which are seen when the anterior tooth display is evaluated.

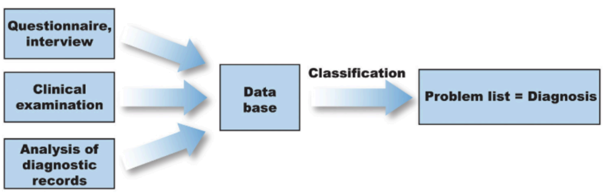


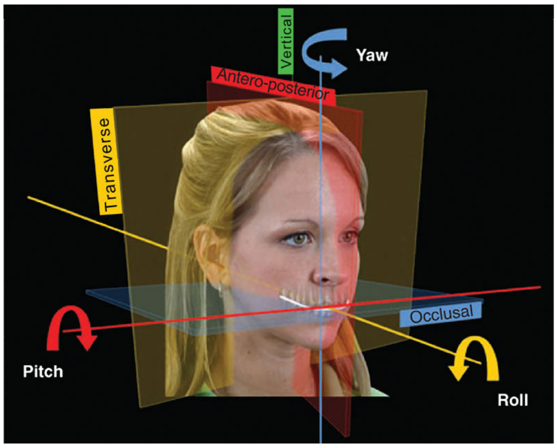
Red = Angles line of occlusion

- Mx: Central fossa of the molars, cingulum of the canines & incisors.
- Mn: Buccal cusps of the molars, incisal edges of the canines & incisors.

Green = Esthetic line

- 3 rotational axes pitch perpendicular to a plane:
  - **Pitch axis**: (dt. Querachse) Up-down deviations around the anteroposterior axis. (vertical relation of the teeth to the lips and cheeks)
  - **Roll-axis**: (dt. Längsachse) Up-down deviations around the transverse axis. vertical position of the teeth when there is a difference between the left and right side)
  - **Yaw-axis**: (dt. Hochachse) Left-right deviations around the vertical axis. (midlines deviations /chin asymmetry)
    Rare in the maxilla, present in 40% patients with deficient or excessive mn growth.





Classification by the characteristics of malocclusion	1. Evaluation of facial proportions and esthetics. 2. Evaluation of the alignment and symmetry within the arches. 3. Evaluation of the transverse plane of space: o Dental or skeletal malocclusion? → Width of the skeletal base can be seen by the width of the palatal vault on casts. o Maxillary lingual crossbite / mandibular buccal crossbite (rare)? o Transverse displacements of the lower molars in the mandible are rare → it means, in most cases the maxilla is not correct. o Specify which jaw is not correct. 4. Evaluation of the anteroposterior plane of space. 5. Evaluation of the vertical plane of space: Why? → Cause? What anatomic location is the discrepancy?

Development of a problem list

2 types of problems:

1. Those relating to disease or pathologic processes.
2. Those relating to disturbance of development which have created the patient's malocclusion.
   → = Orthodontic problem list.

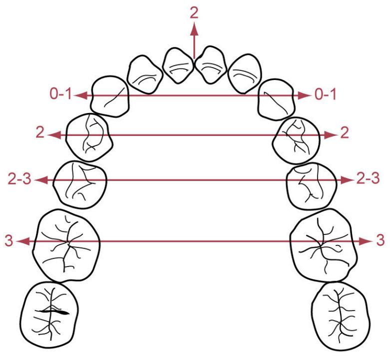
- If possible, problems should be indicated quantitatively or at least classified as mild, moderate or severe.
- All problems must be identified and characterized, omitting nothing of significance.

Proffit Chapter 7:

Orthodontic Treatment Planning: From the Problem List to a Specific Plan

Treatment planning concepts and goals	
Treatment plan	- = Strategy that comes from a wise clinician using his best judgment to address the problem and maximizing benefit to the patient while minimizing costs and risks. - Should always be developed with the patient. - Cost-benefit / risk-benefit analysis. - Avoid missed opportunities (false negative tx) or excessive tx (false positive).
Major issues in planning tx	
Patient input	Patient must be involved in tx planning: • Ethically: Patient has a right to control what happens. • Practically: Better compliance for a tx that the patient supports.
Predictability and complexity of tx	- Tx choice must be evidence based. - Complexity of tx defines who should to it → generalist vs. specialist.

Dental crowding: To expand or extract

	Extraction	Expansion
Esthetic considerations		
Lips - The relative prominence is affected by the nose and the chin. - Lower lips should be at least as prominent as the chin. - Follow $^2/_3$ the extent of the incisor movement	- Flat lips. - Risk of retrusive upper lip in case of excessive incisor retraction.	- Full lips - Teeth more prominent: → Cave insufficient lip closure at rest. - Thin lips follow the tooth movement more than thick lips.
Stability Considerations		
Maximum expansion mandible  	- More stable	**Mandibula** = Limitation for a stable expansion. - Maximum 2 mm forward movement limited by lip pressure. (pressure increases sharply after this point) - Lingually tipped incisors can be further moved forward. - Severely crowded incisors are maybe already protruded and no additional extra protrusion is allowed. Cave: Risk of fenestration of the alveolar bone or gingival recessions. - Expansion around the canines is not stable. (intercanine width diminishes with age even in untreated individual) - Expansion regio premolars and molars ca be stable if not overdone. - Increased risk of fenestration beyond 3 mm of transverse tooth movement. - **Maxilla**: Expansion posterior 3+3 possible by opening the midpalatal suture

- The more you can expand without moving the incisors forward, the more patients you can treat without extractions.
- The more you can close extraction spaces without overretracting the incisors, the more you can treat with extractions.
- The lower arch is more constrained than the upper:
  → Limitations for stable expansion are tighter than in the upper arch.
- Excessive expansion increases the risk of mucogingival problems.
- Extraction or expansion make no difference for masticatory function.
- Lip moves usually $^2/_3$ of the distance that the incisors are retracted.
  Lip retraction stops when the protruding lips come into contact at rest.
  → Maximum 2-3 mm lip retraction in cl.I extraction cases
- Lip pressure is one of the limiting factors in forward movement of the incisors:
  Lip pressure increases sharply 2 mm out into space usually occupied by the lips.
- Patients with similar malocclusions treated either with or without extractions show little or no difference in profile and frontal appearance.

< 4 mm arch length discrepancy	- Extractions are rarely indicated. - May just slightly reduce the width of selected teeth without expansion.
5-9 mm arch length discrepancy	- Extraction and non-extraction tx possible depending on hard- and soft tissue characteristics. - Several different teeth can be chosen if extractions are planned. - Without extractions, there's normally expansion necessary.
≥ 10 mm arch length discrepancy	- Extractions are almost always indicated. - Little or no effect on lip support and facial appearance, if the crowding is so severe. - Choice 4±4 or 4+4 & 2-2 for extraction.

Spaces in mm from various extractions: (note clear in Proffit if the values are for the mn or the mx)
(with typical anchorage management, not skeletal anchorage)

Extraction	Relief of incisors crowding	Incisor retraction		Posterior forward	
		Maximum	Minimum	Maximum	Minimum
Central incisor	5	3	2	1	0
Lateral	5	3	2	1	0
Canine	6	5	3	2	0
First premolar	5	5	2	5	2
Second premolar	3	3	0	6	4
First molar	3	2	0	8	6
Second molar	2	1	0	-	-

Planning treatment for maximal esthetic improvement	
Macro-esthetics: Facial disproportions	**Camouflage:** - Camouflage = Correct facial disproportions without changing the jaws position. - Success lies in the eye of the beholder. → For borderline cases, the dentist cannot judge if camouflage tx is successful, but only the patient / family / friends. - Depends on the patient, if facial appearance is satisfactory enough with camouflage or if a greater change with surgery is needed. - More possibilities to treat cl.II cases than cl.III cases. **Surgery:** - Pictures with simulation of different tx options are appreciated by patients. → Aesthetic awareness↑, but not creation of unrealistic expectations. - Mx or mx advancement increases the volume and makes patients look younger / The contrary is also true for mx or mn posterior reposition. - Genioplasty: o Improves lower incisors stability and decreases the chance of gingival recession by adding bone in the front of protruding incisors. o Enhances facial appearance - Sometimes cosmetic plastic surgery is indicated: o Rhinoplasty: Indicated for nose deviations, dorsal humps… o Correction of paranasal deficiencies with grafts / alloplastic implants. **Growth modification:** - Greater growth modification possible for cl.III than cl.II cases. (Reverse than for camouflage tx) - Computer predictions of growing patients are often inaccurate, because of the difficulty of predicting growth.
Mini-esthetics: Improving the smile framework	- **Vertical tooth-lip relation:** o Minimum 75% of the crown visible. o Tooth display female > male. o Elongation of upper incisors makes the patient look younger. o Extrusive / intrusive mechanics with archwires. o **Absolut intrusion** o **Relative intrusion**: ▪ Incisor eruption is prevented while growth provides vertical space into which the posterior teeth erupt. o **Extrusion**: ▪ Elongation of posterior teeth which causes the jaws to rotate. ▪ Increase of anterior face height. o Use of class II elastics → Tendency to rotate the occlusal plan down anteriorly. o Orthognathic surgery. o Recontouring the gingiva to gain normal crown height. - **Buccal corridors:** o Small corridors are preferred (16%). o Transversal mx expansion decreases buccal corridor width and improves the appearance of the smile. o Too much expansion of the natural dentition can have an unnatural appearance of the teeth. - **Smile arc:** o Most important determinant of the attractiveness of the smile. o Should follow the contour of the lower lip. o Is determined by placing the brackets / step bends. - **Smile symmetry** • Greater elevation of the lip on one side, which pretends teeth asymmetry is not possible to correct with tx.
Micro-esthetics: Enhance the appearance of the teeth	- **Reshape teeth:** • Reshape incisal edges of anterior teeth, remove mamelons, smooth out irregular edges from minor traumas. • Maybe easier to be done before brackets are placed. • Needed primarily when one tooth is used as a substitute for another (3→2).

	- **Correcting black triangles:** • Remove enamel at the contact points so that the teeth can be moved closer together. → Moving the contact area apically eliminates most of the space. • Do not distort the proportional relationship of the teeth to each other. • Progression of connector heights should be maintained. → May also correct 32+23 if 1+1 are corrected (i.e. narrowed). - **Interact with a restorative dentist: composite build-ups, ceramic laminates** • Laminates are indicated if the tooth's color and shade should be changed in addition to the size of the crown. • Timing: o At the end of tx: Vacuum formed retainer to hold the teeth, new retainer after the restorations are done. *or* o Short before the end of tx: Leave some extra space, remove brackets, replace brackets immediate after the restorations are done and close the remaining space. - **Reshape gingival contours:** Application of soft laser: • Does not cut hard tissues → no risk of damage to the teeth or alveolar bone. • Biologic dressing: Coagulates, sterilizes and seals the soft tissues. • No bleeding. • No waiting period for healing.

Planning comprehensive orthodontic tx

1. **Pathologic processes** must be under control:
   They are not more important than orthodontic development problems, but could become accentuated by orthodontic tx.
2. Setting **priorities** to the orthodontic problems in a problem list:
   Tx plan must focus on what's most important for the patient.
   Informed consent is necessary if the dentist and a patient do not agree on what's the most important issue.
3. Find a **solution for each problem** as if it was the only one:
   Broad possibilities, no details of tx procedure are required.
4. **Interactions** between possible solutions.
5. **Compromise**: Sometimes one tx plan will not solve all the problems for the patient.
   → Emphasize one of the goals (should be the patient's most important) at the expense of the others.
6. **Analysis of benefit vs. costs:**
   "Is it worth?"
   Costs = Burden of tx: money, discomfort, aggravation, time, cooperation…
7. **Other considerations**: Uncertainty of growth pattern…

- Periodontal disease:
  - Orthodontic tx in the presence of active periodontal disease is likely to accelerate the disease process. (*Thilander, 1996*)
  - In the absence of active disease orthodontic tx will not lead to further bone loss, even if significant bone loss has occurred previously. (*Ogihara, 2010*)

Patient-parent consultation: Obtaining informed consent	- No paternalistic approach (doctor knows what's best and takes the decisions). - Oral information required. Handouts, videos… are not enough): • Existing problems. • Tx and tx alternatives. • Interactions, unavoidable compromises, practical considerations. • Possible outcomes. - Inform about side effects: • Pain and discomfort. • Root resorptions. • Possible damage to the teeth caused by inadequate hygiene: White spots, caries, gingivitis. • Issues unique to the patient: Missing / impacted teeth, TMJ… - Patients remember information best when it is given in layman's terminology and by using visual presentation. - Interactions, unavoidable compromises and practical considerations must be shared with the patient. - Involve the patient in the final decision: → Putting the problem on him and giving him responsibility makes him more cooperative.
Detailed plan: Specifying the tx procedures	- Any tx procedure must fulfill two criteria: • **Effectiveness** in producing the desired result. • **Efficiency** in doing so without wasting either doctor's or patient's time. → Must be considered for the various tx possibilities.

Treatment planning in special circumstances	

Dental disease problems	- Root filled teeth:
	  o Move like normal teeth as long as the periodontal ligament is normal.
	  o No greater risk for root resorption.
	- Trauma teeth:
	Higher risk of root resorption in case of a severe trauma.
	- Periodontics:
	  o Prior periodontal tx is no contraindication for orthodontic tx.
	  → Exception: Osseous surgery.
	  o Consider a graft prior to orthodontics in case of a small attached gingiva in the mandibular anterior region.
	  → There is mixed evidence regarding the usefulness of pre-tx and post-tx gingival grafting.

Systemic disease problems	- Patient with other diseases present a greater risk for compliance.
	- Avoid prolonged comprehensive orthodontic tx, accept compromises.
	
	- <u>Diabetes:</u>
	  o Risk of accelerated periodontal breakdown if not under control.
	  o No problems if under control.
	
	- <u>Arthritic degeneration:</u>
	• Juvenile rheumatoid arthritis can produce severe mn deficiency.
	• Adult rheumatoid arthritis can destroy the condylar process and create deformity.
	• Long term steroid medicaments can increase periodontal problems.
	• Bisphosphonates can make orthodontic tx almost impossible.
	
	- <u>Pregnancy:</u>
	• Orthodontic tx is possible but don't start during pregnancy.
	• No x-rays.
	• Gingival hyperplasia due to hormonal variations.
	• Bone turnover makes patients susceptible for alveolar bone loss and root resorptions.
	• Apply a holding pattern in the last trimester.
	• Little jaw growth is possible during pregnancy.

Anomalies and jaw injuries	- <u>Fractures of the maxilla:</u>
	• Rare.
	• Immediate reposition is indicated.
	If not possible, apply protraction force from a face mask before the fractures heal completely for repositioning.
	
	- <u>Asymmetric mandibular deficiency:</u>
	• If the translation of the condyle is restricted due to scarring, don't use a functional appliance before surgical correction.
	• Indicated appliance:
	  o Bite block between the teeth on the normal side while providing space for eruption on the deficient side.
	  o More advancement on the deficient side in the construction bite.
	
	- <u>Hemimandibular hypertrophy</u>: 2 surgical tx possibilities:
	• Ramus osteotomy to correct the asymmetry after the excessive growth has ceased. (preferred if possible)
	• Condylectomy to remove the excessively growing condyle + joint reconstruction.
	Cave: Try to avoid TMJ surgery → risk for scar tissue formation.
	
	- <u>Sleep apnoe:</u>
	• Origin: Blockage or severe narrowing of the airways at any point between the nostrils and lung, but usually in the upper pharynx to midpharynx (blocked by the tongue when muscles relax during sleep and the mn drops backward).
	• Airway width cannot be evaluated in lateral cephs and only limited in 3D imaging. (instant changes all the time)
	• Risk factors:
	  o Mn deficiency.
	  o Obesity.

- Increasing Age.
- Alcohol.

- Tx:
  - An IO appliance to hold the mn forward can be effective for patients with low to moderate sleep apnoe severity.
  - Surgical mn advancement.
    (SKG Bern: only effective if minimum 6-7 mm advancement)
  - Widening of the mx:
    → Effective only if the obstruction is within the nasal part.
  - Surgical mx upward reposition can decrease resistance to nasal airflow. (nostrils are widened)

Cleft lip and palate

2-4 weeks	Lip closure (infant orthopedics?)
12-18 months	Palate closure
7-8 years	Alignment of maxillary incisors
7-9 years	Alveolar bone graft *(before eruption of lateral incisor, if present, or canine)*
Adolescence	Comprehensive orthodontics Lip/nose revision?
Late adolescence	Orthognathic surgery?

- <u>Infant orthopedics:</u>
- 2-4 weeks: Lip closure.
- Early grafting of the alveolar process is contraindicated.
  → Tends to interfere with later growth.
- In case of bilateral clefts, the premaxillary segment is often displaced anteriorly and the posterior maxillary segments are lingually collapsed.
  - Expand the posterior segments.
  - Light elastic strap across the anterior segment /
    Orthodontic appliance pinned to the segments which applies a contraction force /
    Pressure from the lips to reposition the anterior part.
  - Short-term benefit is more impressive than the long-term benefit.
    → Only indicated in bilateral clefts.
  - Alternative: Lip closure in two stages.

- <u>Late primary and early mixed dentition:</u>
- Many orthodontic problems arise from effects of the surgical repair and not because of the cleft itself.
  → E.g. anterior & lateral crossbite caused by strain of the repaired lip and repair of the palatal vault is not found in untreated cleft individuals.
- Correct the incisor position: Often they erupt rotated and in a crossbite.
- Prepare the patient for the alveolar bone graft:
  About age 7y, if 2+2 are present / before eruption of 3+3 if 2+2 are not present.
- Try to make erupting a permanent tooth through the grafted area so that the cleft is obliterated.

- <u>Early permanent dentition treatment:</u>
- Often correction of a posterior crossbite is necessary.
- Teeth are likely to be malaligned.
- In case of missing teeth:
  - Close the space.
  - Position other teeth as abutments for fixed prosthodontics. (resin-bonded bridge)
- No implants in the cleft area.

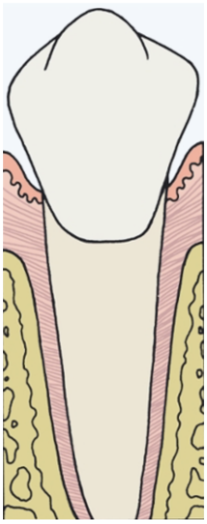
- <u>Orthognathic surgery for patients with CLP</u>
- Often relapse of an anterior and lateral crossbite due deficient maxillary growth.
  → Surgery necessary to bring the mx downward & forward + mn setback.
- Restorative work to replace missing teeth.
- Esthetic surgery / pharyngeal flaps to control the respiration are sometimes indicated.

Reducing uncertainty in planning treatment

- Tx changes are only predictable in the absence of growth.
- The amount and direction of growth is difficult to predict:
  → Best done with templates that show the expected direction and increment of growth at specific points / ages or as a serie of complete templates from which a change at a given point can be deducted.
  (separate templates for sexes, racial groups, categories of malocclusion)
- Cave: Growth that deviated from the norm is likely to continue in a deviated way.
  → Average values are unlikely to be correct for predictions.
- Superimpose cephalograms with profile images to predict tx results.
- Therapeutic diagnosis: = Implement a conservative tx plan initially and evaluate the results after some months for the definitive planning. Tx takes a bit longer, but incorrect decisions are prevented.

Proffit Chapter 8:

Biologic Basis of Orthodontic Therapy

<table>
<tr><td colspan="2">
- Biomechanics: Reaction of the dental and facial structures (biologic system) to orthodontic force (mechanics).
- Tooth moves through the bone carrying its attachment apparatus with him as the socket of the tooth migrates mediated by the periodontal ligament.
- Forces applied to the teeth can also affect bone apposition and resorption at sites distant from the teeth: Sutures of the maxilla, bony surfaces of the TMJ.
</td></tr>
<tr><td colspan="2">Periodontal and bone response to normal function</td></tr>
<tr><td>Periodontal ligament structure
</td><td>
- PDL 0.5 mm wide.
- Network of parallel collagenous fibers that run at an angle:
Attaching further apically on the tooth than on the adjacent alveolar bone to resist expected displacement of the tooth during normal function.

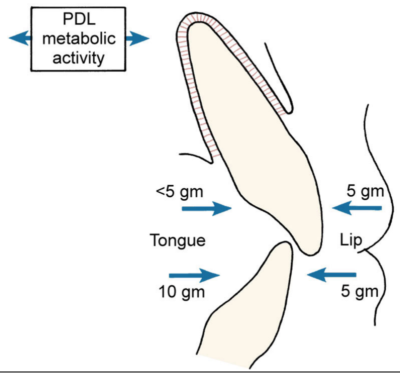
- <u>Cellular elements:</u>
• Undifferentiated mesenchymal cells and their progeny in form of fibroblasts (same cells can work as fibroclasts) and osteoblasts.
• → Mechanical strain induces the differentiation of fibroblasts via calcitonin.
• Cementoblasts
• Osteoclasts and cemtentoclasts:
Cell origin is controversial:
Most are hematogenous origin, some derived from stem cells in the local area.

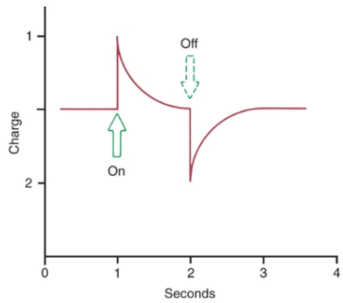
- <u>Blood vessels</u> and cells from the vascular system.

- <u>Neural elements:</u>
• Unmyelinated free endings for the perception of pain.
• Complex receptors for pressure and positional information (proprio caption).

- <u>Tissue fluid:</u>
Derived from the vascular system.
</td></tr>
<tr><td>Response to normal function</td><td>
- Normal tooth contact ≤1s, 1-2 kg up to 50 kg
→ Normal mastication (<1 s) is possible without pain.

<table>
<tr><td>Time (s)</td><td>Event</td></tr>
<tr><td><1 s</td><td>PDL fluid is incompressible.
Alveolar bone bends → piezoelectric signal is generated.</td></tr>
<tr><td>1-2 s</td><td>PDL fluid is expressed.
Tooth moves within the PDL space.</td></tr>
<tr><td>3-5 s</td><td>PDL fluid squeezed out.
Tooth displaces within the PDL, compressing the ligament itself against the adjacent bone:
→ Pain if the pressure is heavy.</td></tr>
<tr><td>Prolonged forces</td><td>Remodeling of the adjacent bone</td></tr>
</table>
- Alveolar bone bends also during normal mouth opening / closing.
→ Distance between 6-6 decreases 2-3 mm.
- Bone bending in response to normal function generates piezoelectric currents that appear to be an important stimulus to skeletal regeneration and repair.
- Prolonged force (orthodontic or by soft tissue stretch) produces a different response by remodeling of the adjacent bone.
</td></tr>
<tr><td>Periodontal ligament in eruption and stabilization of teeth</td><td>
- PDL itself can produce tooth movement.
- Adaption to metabolic events with formation, crosslinking and maturational shortening of collagen fibers.
- Ability to generate a force:
→ Orthodontic forces under the stabilization level are ineffective.
Threshold minimum 5-10 gm/cm^2.
</td></tr>
</table>

		Resting pressures from the lips or cheeks and tongue are usually not balanced. Active stabilization produced by metabolic effects in the PDL probably explains why teeth are stable in the presence of imbalanced pressures that would otherwise cause tooth movement.

Periodontal ligament and bone response to sustained force	
Biologic control of tooth movement: *2 theories → both may play a role, but the chemical messenger theory (pressure-tension) is dominant.*	**1. <u>Biologic electricity: Piezoelectric currents</u>** - **Piezoelectric currents:** • = Deformation of a crystallin structure by external forces (bone bends) produces a flow of electric current as electrons are displaced from one location to another. • Opposite current if the force is released. • Quick decay rate. • Important stimulus for skeletal regeneration / repair and adaption to the functional demand. • Poor relation with response to orthodontic tooth movement.  <u>Pro:</u> - Ions in the fluids of living bone interact with the created electric field: → Electric signal in form of volts & temperature changes → currents can be detected in the extracellular fluids. - Electromagnetic fields can affect cell membrane potentials and permeability: → = trigger for changes in cellular activity. - **Reverse piezoelectric effect:** Application of an electric field can also cause crystal deformation and produce force in doing so. - Possibility for using external electric fields in bone healing and regeneration after injury. <u>Contra:</u> - Sustained force like orthodontic force does not produce piezoelectric or other types of stress-generated signals. Nothing happens as long as the force is maintained. - A vibrating application of pressure would be advantageous if stress-generated signals were important in producing bone remodeling. → Idea of vibrating devices. Studies showed however little or no advantage in using vibration to generate piezoelectric signals versus sustained force for the movement of teeth. - No evidence that moving teeth with magnetic force reduces pain and mobility. **2. <u>Pressure-tension theory: Chemical messengers</u>** - Cellular changes produced by chemical messengers create movement. - Chemical messengers (bind to receptors) can be generated by: o Alterations in blood flow o Mechanical stress: o Integrins in the cell membran connect the extracellular actin with the intracellular cytoskeleton. o Released by damaged cells in the PDL - Alteration in blood flow through the PDL creates changes in the chemical environment (O_2, CO_2): → Stimulation for release of active agents. - Mechanical effects on cells in the PDL cause release of cytokines, prostaglandins and other chemical messengers. - Cells are activated by biologic messengers. - Stages of tooth movement: 1. Initial compression and blood flow alterations associated with pressure within the PDL. 2. Formation and/or release of chemical messengers. 3. Activation of osteoblasts and osteoclasts leading to bone remodeling.

Effect of force magnitude

TABLE 8.2 Physiologic Response to Sustained Pressure Against a Tooth

TIME		Event
Light Pressure	Heavy Pressure	
<1 second		PDL fluid incompressible, alveolar bone bends, piezoelectric signal generated
1-2 seconds		PDL fluid expressed, tooth moves within PDL space
3-5 seconds		Blood vessels within PDL partially compressed on pressure side, dilated on tension side; PDL fibers and cells mechanically distorted
Minutes		Blood flow altered, oxygen tension begins to change; prostaglandins and cytokines released
Hours		Metabolic changes occurring: chemical messengers affect cellular activity, enzyme levels change
~4 hours		Increased cAMP levels detectable, cellular differentiation begins within PDL
~2 days		Tooth movement beginning as osteoclasts and osteoblasts remodel bony socket
	3-5 seconds	Blood vessels within PDL occluded on pressure side
	Minutes	Blood flow cut off to compressed PDL area
	Hours	Cell death in compressed area
	3-5 days	Cell differentiation in adjacent narrow spaces, undermining resorption begins
	7-14 days	Undermining resorption removes lamina dura adjacent to compressed PDL, tooth movement occurs

cAMP, Cyclic adenosine monophosphate; *PDL,* periodontal ligament.

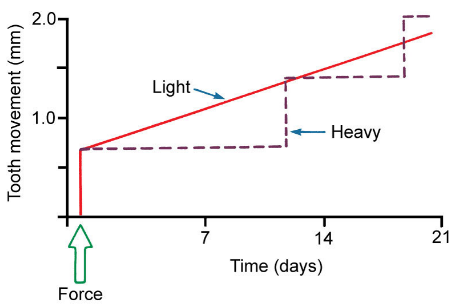
- Response to sustained force against the teeth is a function of the force magnitude.
- Force against a tooth ↑ → PDL perfusion ↓.

Light force:

- Survival of cells within the PDL
- Remodeling off the tooth socket by relatively painless "**frontal resorption**" of the tooth socket.

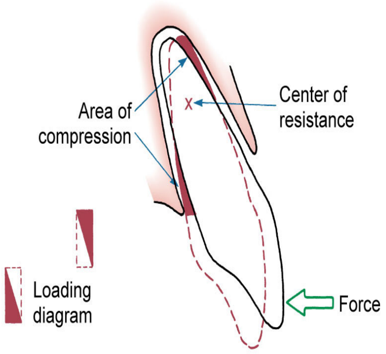
1. Prostaglandin and Interleukin 1-beta levels (IL1β) increase within the PDL within a short time after the application of pressure. (minutes)
   Prostaglandin is released when cells are mechanically deformed = primary response. (mediated by focal adhesion kinase mechanoreceptor in PDL cells)
   → PgE stimulates Osteoblasts & -clasts.
2. PDL cells under stress induce the formation of osteoclasts.
   Concentration of RANKL and OPG ↑.
3. Other chemical messengers particularly members of the cytokine family and nitric oxide (NO) and other cell regulators are involved.
4. Osteoclasts arrive in about 48 h and come in 2 waves:
   1^{st} from the local cell population.
   2^{nd} from distant areas via blood flow (more important).
   → Frontal resorption of the lamina dura at the pressure side.
5. Shortly later: Osteoblasts (recruited locally from progenitor cells in the PDL) form bone on the tension side & begin remodeling activity on the pressure side.

- Tooth movement is more efficient and less painful than with heavy force.
- Tooth movement in clinical practice usually proceeds in a stepwise fashion, because of the inevitable areas of undermining resorption even with light forces.
  → Attainment of a smooth progression of tooth movement is maybe unattainable with continuous forces.

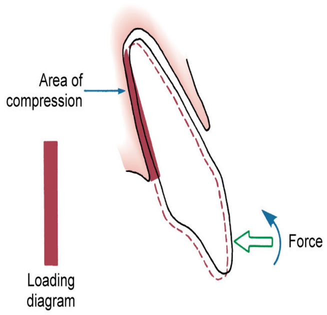
Heavy force:	- Pain and necrosis of cellular element within the PDL. - **Undermining resorption** of alveolar bone near the affected tooth. 1. If the force is great enough to totally occlude blood vessels and cut off the blood supply, a sterile necrosis ensues within the compressed area. 2. Bone remodeling bordering the necrotic area of the PDL must be accomplished by cells derived from adjacent undamaged areas. → Cellular elements begin to invade the necrotic (hyalinized) area. 3. Undermining resorption: Osteoclasts appear within the adjacent bone marrow space and attack the underside of the bone immediately adjacent to the necrotic area. - Always some avascular = hyalinized areas in the PDL: (nomenclature: hyalinized because the tissue looks like hyalin cartilage in the histologic section) → Release pressure at intervals to maintain tissue vitality → Chew chewing gum the first 8h after orthodontic force is applied to reduce pain. - Delay in tooth movement occurs, if hyalinization and undermining resorption occur: ○ Delay in stimulation of cell differentiation within the marrow spaces. ○ A considerable thickness of bone must be removed from the underside before any tooth movement can take place. - Tooth movement with frontal resorption vs. undermining resorption.  With frontal resorption, a steady attack on the outer surface of the lamina dura results in smooth continuous tooth movement. With undermining resorption, there is a delay until the bone adjacent to the tooth can be removed. At that point, the tooth "jumps" to a new position, and if heavy force is maintained, there will again be a delay until a second round of undermining resorption can occur.

Effects of force distribution and types of tooth movement

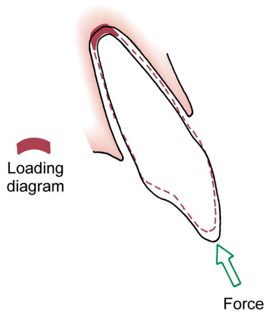
- The biologic effect is determined by the amount of force delivered to a tooth and the area of PDL over which that force is distributed = **force or pressure per unit area.**



Tipping:
- Only ½ of the PDL that could be loaded, actually is.
- Heavy pressure at the root apex and crest of the alveolar bone, nearly zero pressure at the center of resistance
- 50 g



Translation / bodily movement



Intrusion

- Optimum forces for orthodontic tooth movement:

Type of movement	Force (gm)
Tipping	**35-60**
Bodily movement (translation)	**70-120**
Root uprighting	**50-100**
Rotation	**35-60**
Extrusion	**35-60**
Intrusion	**10-20**

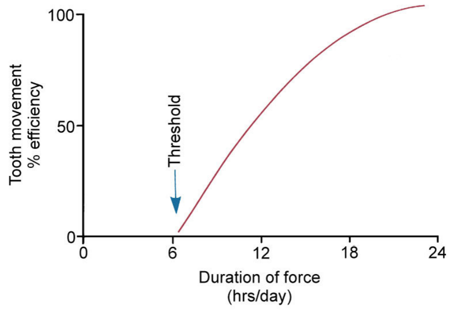
- *Cave: Optimum forces have never been scientifically examined! Values are based only on experience and animal studies.*

- The values depend on the size of the tooth:
  - Smaller values for incisors.
  - Higher values for multirooted posterior teeth.

- The maximum force is often limited by an accompanying tipping movement to the basic movement: i.e. rotation along the long axis would have a greater value, but it is impossible to perform it without tipping.
- Teeth normally move continuous with an individual speed for each patient.
  → If movement interchanges with stops, there is something not correct: Notching of the wire, hyalinization…

Effects of force duration and force decay

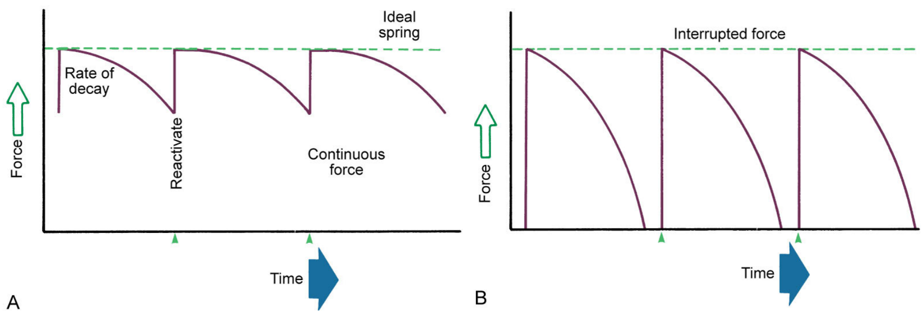
- Continuous force 24 h/day produces the most efficient tooth movement.
- Threshold at about 6 hours to have an effect.

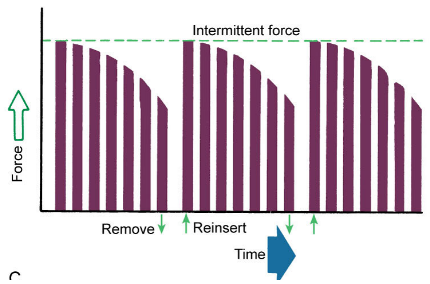


- Removable appliances:
    - Minimum 4-6 h wear time to reach the threshold to initiate tooth movement:
      = Time necessary until cyclic nucleotide levels (cAMP) in the PDL increase and second messengers are produced to stimulate cellular differentiation.
    - Decreasing fractions of time → decreasing amount of tooth movement.
- Increasingly effective tooth movement is produced if force is maintained for longer durations.
- Sustained force:
  Force must not be absolutely continuous, but be present for a considerable percentage of time.
- An ideal spring would maintain the same amount of force regardless of the distance a tooth has moved. With real springs however, the force decays at least somewhat as tooth movement occurs.

  F(x) = -kx. k = spring constant, x = activation

- <u>Classification of force by the rate of decay:</u>
    - **Continuous**:
        - Force is maintained at some appreciable fraction of the original force from one visit to the next (forces are allowed to decline).
        - E.g. MBA, spring.
    - **Interrupted**:
        - Force levels decline to zero between activation.
        - E.g. MBA.
    - **Intermittent:**
        - Force levels decline abruptly to zero intermittently when an appliance is removed and then return to the original level (or less) some time later.
        - If tooth movement occurs, the force declines may up to zero.
          → Intermittent force can also be interrupted.
        - E.g. patient activated appliances: removable plates, HG…





A, Forces that are maintained between activations of an orthodontic appliance, even though the force declines, are defined as continuous.
B, In contrast, interrupted forces drop to zero between activations.
C, Intermittent forces fall to zero when a removable appliance is taken out, only to resume when the appliance is reinserted into the mouth. These forces also decay as tooth movement occurs.

- Heavy continuous forces should be avoided → damage to the teeth and the PDL. (no time for PDL regeneration at the undermining resorption sites)
- Heavy intermittent forces are clinically acceptable though less efficient. (hyalinization, undermining resorption, but some time for regeneration).
- Tooth movement is most efficient when light continuous forces are applied.

- Reactivation interval for orthodontic appliances:
    - Not more frequent than at a **3-week interval**: Undermining resorptions require 7-14 days.
    - Spring appliance with light continuous forces: **6-8 weeks.**
    - Stiffer appliances creating undermining resorptions with force levels that drop to 0:
        - Tooth movement in the first 10 days.
        - + equal or longer period needed for PDL regeneration & repair.

Drug effects on the response to orthodontic force

- No drugs are available at the moment to speed up tooth movement.
  Problem: Local application at the site where tooth movement is desired.

- Most studies examining drug effect on orthodontic tooth movement are animal studies:
    - Species difference
    - Age
    - Relatively short intervention

  → not reliable.

- Experimental **Prostaglandin** injection has shown some effect. Cave: Painful.
- Prostaglandin inhibitors:
    - **Phospholipids → *(Phospholipase A2)* Arachidonic acid → *(Cyclooxygenase)* Prostaglandin, Prostacyclins, Thromboxans**
    - **Phospholipids → *(Phospholipase A2)* Arachidonic acid → *(Lipoxygenase)* Leukotrienes**
    - **Eicosanoids** = Prostaglandines, Prostacyclins, Leukotriens and Thromboxans.

    - Effect of Prostaglandine:
        - Sensibilisation of nozireceptors
        - Stimulation of inflammations
        - Thermoregulation in the hypothalamus → fever

    - **Corticosteroids**:
        - Inhibit the formation of AA.
        - Dose dependent effect, esp. for glucocorticoids. (Proffit says no effect)

    - **NSAID:**
        - Inhibit conversion of AA → Pg by inactivation of the cyclooxygenase (**Cox1** or **Cox2**).
        - Most analgesics (except acetaminophen (Tylenol), paracetamol).
        - No interferences with tooth movement if used in low doses and short duration.
        - Inhibition of tooth movement possible if applied in high doses over long time.

- **Relaxin:**
  Effect is controversial: collagen synthesis ↓, collagen breakdown ↑.

- Drugs that increase brain levels of **acetylcholine** may accelerate tooth movement by affecting circulating hormone levels.

- **Tricyclic antidepressiva**
  Anti-arhymic agents (e.g. Procain)
  Anti-malarial drugs &
  Methylxanthines (to treat asthma) can affect Pg-synthesis and therefore tooth movement.

- **Phenytoin**:
    - Anticonvulsant drug (bei Epilepsie & Herzrhytmusstörungen)
    - Inhibits toot movement in rats.
    - Gingiva hyperplasia.
- **Tetracycline**:
    - Inhibits osteoclast recruitment.
    - **Doxycycline**: apical root resorptions ↓
      Prescribed in case of dental trauma:
      Children >8y (tooth crowns completed): **1st day: 100 mg, 2-10th day: 50 mg**
      Adults: **1st day 200 mg, 2-10th day 100 mg.**
      → Always combine antibiotics with probiotics to reduce candida infections.
- **Estrogens**:
    - Little or no effect on orthodontic tooth movement.
    - Theory: Estrogens increases OPG release → potential inhibition of tooth movement.

- **Bisphosphonates**: inhibit tooth movement
    - = Synthetic analogues of **pyrophosphate** which bind to hydroxyapatite in bone.
    - Inhibit osteoclast mediated bone resorption by inactivating RANKL on osteoblast:
      → slower bone remodeling for tooth movement.
    - Incorporated in the bone for many years, but mostly at the surface in newly built bone.
      Surface = faster elimination → orthodontic tx is possible after 3m without bisphosphonate therapy.
    - Risk for necrosis of the mandibular bone → avoid selective extractions.

Drugs with effect on apical root resorption:
- Thyroid hormone (Thyroxin) ↓
- Doxycycline ↓
- Nabumetadon ↓
- Bisphosphonates ↑ or ↓ (unclear, dose dependent)

Drugs inducing a gingiva hyperplasia:
- Phenytoin
- Ca channel blocker
- Ritalin
- Ciclosporin

Drugs inducing xerostomia:
- Antidepressiva
- Antiepileptics

Drugs changing the microbiota:
- Immunsuppressiva
- Inhaled steroids (asthma)

Inhibition of osteoclasts:
- Tetracyclines
- Bisphosphonates
- Calcitonin (acts directly on osteoclasts → activity ↓ / reduces the calcium blood level)
  (Calcitonin, Vitamin D & PTH regulate together the blood level of calcium)
- OPG (Antagonist to RANKL)
- Denosumab (antibody that impedes the binding RANKL - RANK)
- Estrogens?

Activation of osteoclasts:
- RANKL
- Calcitriol (Vitamin D 1.25$(OH)_2D_3$)
- PTH
- M-CSF
- Prostaglandin (dose depended)
- Leukotrienes

Effect of local injury: Corticotomy

- Idea: (*Frost, 1994*)
  Bone remodeling is accelerated during wound healing via the **regional acceleratory phenomenon = RAP** effect.

- RAP effect (*Prof. Buschang*)
    - Initiated by a pain stimulus
    - Affects soft and hard tissue
    - Vital healing process
    - Can speed up tooth movement
    - Injury ↑ → tooth movement ↓
    - Bone density ↓ → RAP ↑

- Time for bone healing depends on (*Prof. Buschang*)
    - Extent of the injury
    - Blood supply
    - Stability of the segments

- **Corticotomy original concept:**
  1. Flap
  2. Vertical / facially / lingually cuts between and under the teeth that do not penetrate all the way through to the other side → = creating blocks of bone around a tooth for reposition.
  3. Apply force to create greenstick fractures of the bone.

  Cave:
    - Invasive
    - Root apex does not move → teeth are tipped into position, not bodily moved.

  Indication:
    - Ankylosed teeth
    - PFE teeth, if partial eruption took place
    - Impacted canines

- **Corticotomy nowadays**:
  Still a flap with fully exposed alveolar bone, but the recommended forces are lighter. Shift to AOO.

- **Accelerated osteogenic orthodontics AOO:**
    - Areas of decortication are added over the facial surface of the alveolar bone which and covered with bone grafting material.
      → Try to generate new bone that allows facial directed movement of teeth without risk for gingival recessions (no data available to support this claim).

  Cave:
    - After a fracture, enough bone healing to allow release of fixation takes about 6 w, maturation of bone is largely completed in another 2 m.
      → Bone remodeling after corticotomy would be accelerated only for 2-4 m.
      = Little time compared to the overall tx time.
      → Benefit is primarily in reduction of the time to align crowded teeth without extractions.
    - Loss of alveolar bone height if no bone grafting is performed.
    - Unsightly facial bruising.
    - Whitening of the Gingiva.
    - Unfavorable changes in the appearance of the gingiva after the extensive flaps.
    - Possibility of gingival stripping.
    - Not sufficient data for a good documentation that the procedure is safe.

  → *No* qualified tool for accelerated tooth movement.

- **PDL distraction:**
  1. Cuts are made in the wall of the socket of an extracted tooth.
  2. Neighbor teeth are moved into the place with a spring providing heavy force, so that the PDL is extremely stretched (nowadays light forces are preferred).

- Modified corticotomy: **Piezocision**
  1. Gingival incision between crowded incisors only on the facial side (no flap).
  2. Injury to the bone in that area is performed with a vibrating piezoelectric knife.
     (penetration of the cortical bone and extend into the medullar bone)
  3. Tunneling the gingiva over the root allows to add a graft material if desired.

An isolated RCT (*Charavet, 2016*) shows a sign. shorter tx time, but the generalizability of the data is unclear.
Risk of root damage.

→ *No* qualified tool for accelerated tooth movement.

- **Microperforation**:
  Screws are placed through the gingiva into interproximal alveolar bone and then removed:
  → try to create regional accelerated bone remodeling.
    - No data published until now to document the effectiveness.
    - Developed by a commercial company.
    - If effective, the effect would rather be limited to a specific area rather than a whole arch. (effort to drill that many holes)
    - Effect limited to one week, because the insertion depth is very small.

- Space must be closed / "used" immediately after surgery! Otherwise surgery effects are lost.
- Simple tooth extraction: To prevent a round trip of the anterior teeth in premolar extraction cases, slice the tooth who is going to be extracted bevor extraction.

- **Fiberotomy**:
  No influence on the speed of tooth movement.

- **Flap**: (*Prof. Buschang*)
  30% faster tooth movement → proof that soft and hard tissues are important.

- Conclusions of the injury methods:
  Cost-benefit ratio is only favorable for few patients + invasive tx approach & morbidity.

Other physical effects to accelerate tooth movement

- **Vibration** of the teeth:
  - Should stimulate cell differentiation and maturation.
  - **Accelodent**: 30 Hz high frequency vibration 20 min / day.
  - **Propel device**: Higher frequency 5 min / day.

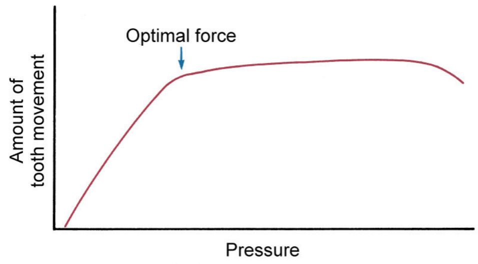
- Application of **light** to the alveolar process (**phototherapy, Biolux**):
  - 800-850 nm wave length (about visible spectrum).
  - 97% energy lost on the way to the alveolar bone.
  - Energy should excite intracellular-enzymes and increase cellular activity in the PDL and bone:
    → Bone remodeling ↑ & tooth movement↑.

- Application of therapeutic **ultrasound** to the teeth and adjacent bone (**Aevo device**)
  - Idea: Increase of the blood flow in treated areas → bone remodeling ↑ & tooth & root resorption ↓.
  - Used in physical therapy to increase blood flow in muscles.

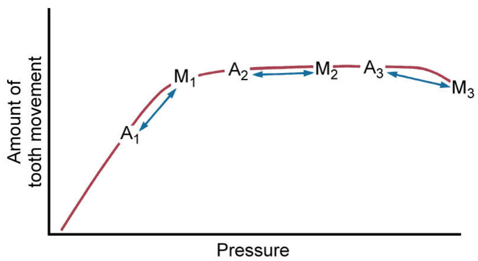
→ ***No evidence of effectiveness for all approaches at the moment***

<table>
<tr><th colspan="2">Anchorage and its control</th></tr>
<tr><td colspan="2">- Anchorage = resistance to unwanted tooth movement.</td></tr>
<tr><td>Relationship of tooth movement to force</td><td>

- Reciprocal effects throughout the dental arches must be carefully analyzed, evaluated and controlled.
- Aim:
Concentrate the force needed for the tooth movement and dissipate the reaction force over as many other teeth as possible → keeping pressure in the PDL of anchor teeth low.
- The threshold for tooth movement is very small: ≥5-10 gm/mm^2.
- Tooth movement increases as pressure increases up to a point, remains at about the same level over a broad range and then may actually declines with extremely heavy pressure.
- Optimum force for orthodontic purposes is the lightest force that produces a maximum or near-maximum response. The ideal force magnitude depends on the way in which it is distributed to the PDL.

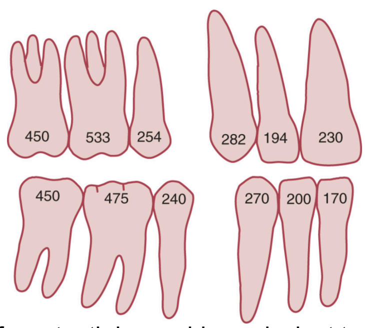


- Too much force destroys the effectiveness of reinforced anchorage by pulling the anchor teeth up on the flatter portion of the pressure response curve.
- Extreme force:
Anchor teeth might move more than the tooth which was desired to move.
(the smaller segment is placed beyond the greatest tooth movement range while the greater segment is still in it)
- Not clear, if a force maximum exists in reality.



</td></tr>
<tr><td>Anchorage situations</td><td>

- Root size↑ → area for force distribution ↑ = anchorage value ↑



The "anchorage value" of any tooth is roughly equivalent to its root surface area. As this diagram shows, the first molar and second premolar in each arch are approximately equal in surface area to the canine and two incisors.

</td></tr>
</table>

	- **Reciprocal tooth movement**: = Forces applied to the teeth and to the arch segments are equal and so is the force distribution in the PDL (must be the same PDL area). - **Reinforced anchorage**: = Adding more resistant units → the reaction force is distributed over a larger PDL area. - **Stationary anchorage**: Pitting bodily movement of one group of teeth against tipping of another. - **Cortical anchorage**: o Cortical bone = more resistant to resorption and remodeling. o Slowdown of tooth movement if a root contacts the cortical bone. (old extraction sides) o The facial and lingual cortical plate limits torque movements. o Cave: ▪ Tooth movement ↓. ▪ Penetration of the corticalis may occurs. ▪ Root resorptions are likely o Torquing molars to increase anchorage for cl.II elastics is no longer advisable. (risk of root resorptions ↑) - **Skeletal anchorage:** Implants (osseointegration is even not necessary), mini screws through the gingiva, bone anchors placed beneath the soft tissue → no movement. By using implants in the bone, it is possible to place force directly against the mx or mn and modify the growth. - **Extraoral anchorage (HG):** o 24 h wear is not possible. o Force against the teeth > optimal force. (heavy intermittent force against light continuous force of the MBA). - **Intraoral anchorage:** In theory additional anchorage can be obtained from the rugae area of the palate. However in fact, this is not very effective. - **Muscular anchorage:** o Lower lip o Periorale Weichteilmanschette - Two stage tx with tipping followed by uprighting can be used as a mean of controlling anchorage.

Deleterious effects of orthodontic force	
Tooth mobility	- PDL space is reorganized (detached from the bone & cementum and reattached later) → PDL space widens during orthodontic tx → tooth mobility ↑. - Some tooth mobility is normal. - Force ↑ = undermining resorption ↑ → mobility ↑. - A tooth with extreme mobility (if moved in a traumatic occlusion) during orthodontic tx should be taken out of the occlusion → corrects usually itself without any damage.

Pain	- Pain mechanism:
	1. Tooth movement
	2. Change of blood flow
	3. Release of transmitters: Cytokines, substance P, Pg
	
	- Pain cascade:
	Stimulus → perception → pain assessment → pain reaction.
	
	- Pain origin:
	Sterile necrosis at the hyalinized areas of the PDL:
	→ provokes inflammation at the apex + mild pulpitis.
	
	- Amount of force ↑ (= hyalinized areas ↑) → pain ↑.
	- If the force is appropriate, little or no immediate pain for the patient is felt at the activation of the appliance.
	- Several hours after reactivation, little pain is normal for 2-4 d. Teeth are sensitive to pressure.
	- Most severe pain = Pain from the initial activation.
	
	- <u>Influences on pain perception:</u>
	• Insufficient information before tx.
	• Adolescents > children & adults. | adults > children.
	• Psychologic mood.
	• Cultural background.
	• Females > males.
	
	- <u>Pain management</u>:
	• **Release pressure**:
	Chew chewing gum the first 8 h after reactivation of the appliance:
	→ Teeth are displaced to allow some blood flow through compressed areas.
	→ No built-up of metabolic products stimulating pain receptors.
	• **NSAID**:
	Cave: Inhibits prostaglandin synthesis.
	• **Acetaminophen** (CH: paracetamol)
	  o Acts centrally, no effect on the prostaglandin synthesis.
	  o Does not reduce the inflammation at the apex:
	  → less effective to control pain.
	  o Prolonged use has potential to cause serious damage of renal function.
	• **Placebo effect**:
	Call patients at home the evening after they got the appliance.
	• **Cognitive behavior therapy:**
	Effective for patients who are willing to try.
	• **Informe patients** in advance about pain and how to handle it.
	• **Low intensity laser:**
	Effective, but application at home not feasible.
	• **Transcutan nerve stimulation:**
	Application difficult, no effect.
	
	- <u>Helps for patients with fear:</u>
	• Sweet stimulus (sugar or artificial)
	• Cold stimulus (napkin on the forehead)
	• Simple images (explain on an x-ray)
	• Sensitive treatment (tell - show - do)
	• Animate patients to speak
	• Make breaks

Allergies	- **4%** of the children have an allergy → most of them grown them out. - **Latex**: • Can become life-threatening. • IgE mediated. - Chx: IgE mediated allergies possible. - Oral allergy syndrome: o Type 1 reaction. o Cross reaction for most cases: Patients are allergic to certain trees, which have similarities with food. - **Nickel**: *Linsten & Kurol, 1997* • **20-40 µ gm/d** nickel is released from an orthodontic appliance versus daily nickel intake of **300-500 µ gm/d** by the nutrition (cacao beans, nuts, apple seeds). • The mucosa reacts different to nickel exposure than the skin: ▪ The skin is more acid than the mucosa → more formation of potential allergenic nickelsulfat. ▪ Cave patch test: Toxicology, dilution of some substances is difficult. ▪ → 20% US-population show skin reaction, but mostly no mucosa reaction. • Nickel test from the saliva are not reliable: dilution, regional differences. • Nickel in orthodontic appliances is more inert than in jewelry. • No difference in nickel release of ss or niti wires. • Nickel release from an orthodontic appliance does not increase the concentration of nickel in the blood. • Exposure of nickel by an orthodontic appliance: ▪ Can introduce a tolerance to later nickel exposure. ▪ Can stimulate a severe nickel sensitivity overreaction. • Piercings can increase the sensibility to nickel. • Incidence of nickel allergy: ▪ Girls: up to 30% (correlation with ear piercing) ▪ Boys: up to 4-19% • Symptoms of nickel allergy: Widespread erythema and swelling of oral tissues 1-2 days after an appliance is placed. • Clinical handling of nickel allergies: ▪ Bond 2 brackets for testing. ▪ Replace NiTi and SS material with titanium brackets and TMA wires. - <u>Allergy types:</u> • **Type1:** • **IgE** mediated: IgE binds at the surface of mast cells → release of inflammation mediators. • Acute. • Skin test, IgE serum test. • Symptoms: Urticaria, angioedema, respiration problems. • Examples: Food allergy, bee allergy, latex. • **Type 2:** • Antibody mediated. • Semi-retarded. • **Type 3:** • Antibody mediated via the serum. • **Type 4:** • Cell mediated: 1. Haptene (part of the antigen) bind to dendritic cells. 2. Cells migrate into the lymph nodes and activate T-cells. 3. Reaction if the antigen binds again.

- Retarded.
- Patch test.
- Symptoms:
  Exanthema, bullose reactions, hemolysis, cytopenia.
- Examples: Drug reactions.

- <u>Anaphylaxis therapy:</u>
  Adrenalin injection: Effect > 1 min.
    - <25 kg: 0.15 mg
    - >25 kg: 30 mg

  Antihistaminika: Effect > 30 min.
    - ≤6 y: 5 mg Xyzal
    - ≥6 y: 10 mg Xyzal

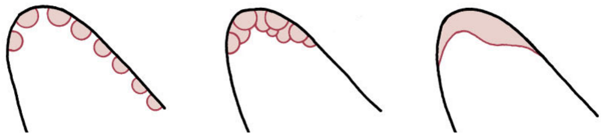
  Cortison: Effect > 60 min.
    - Prendison 2mg / kg body weight

Effects on the pulp

- Mild pulpitis as a modest and transient inflammatory response:
  → No long-term significance.
- Loss of vitality is mostly related to a prior history of trauma, worsened by too heavy force application:
  Large abrupt apex movements can straggle blood vessels as they enter the root.
- Excessive tipping / torquing of incisors can move the apex out of the bone and harm tooth vitality.
- Endodontic treated teeth can be moved normally.
  (PDL is the key factor to movement and not the pulp).
- Severe root resorptions of root treated teeth should not be expected.
  Exception: Teeth with a severe intrusion trauma and root tx.
  (less resorption if $CaOH_2$ filling is maintained during orthodontic tx).
- Trauma teeth with root filling:
  More prone for "natural" RR without orthodontic force application, but not more prone for RR due to orthodontic force.

Effects on root structure

- Some remodeling of the cementum and the adjacent bone is usual:
  → The cementum is marked when it touches a hyalinized area → resorption → reparation.
- Shortening of the root occurs when cavities coalesce at the apex so that peninsulas of root structure are cut off as an island → the islands resorb → net loss of root length although the repair process places new cementum over the residual root surface → roots become shorter, but not thinner although both the sides and the apex experience root resorptions.



- Categories of root resorption: *(Kaley, 1991)*
  1. Slight blunting of the apex.
  2. Moderate resorptions, ≤ ¼ of root length.
  3. Severe resorptions, ≥ ¼ root length.

- <u>Moderate generalized resorptions:</u>
  - Experienced by most of the patients, but in most cases almost imperceptible and clinically insignificant.
  - Tx duration ↑ → Resorptions ↑.
  - Maxillary incisors > other teeth.

TABLE 8.4 Average Root Length Change
Data from Kennedy DB, Joondeph DR, Osterburg SK, etal. *Am J Orthod.* 1983;84:183.

	MAXILLARY		MANDIBULAR	
	Serial Ext Plus	**Late Ext**	**Serial Ext Plus**	**Late Ext**
Central incisor	−1.5	−2.0	−1.0	−1.5
Lateral incisor	−2.0	−2.5	−1.0	−1.0
Canine	−1.0	−1.5	−0.5	−1.0
Second premolar	−0.5	−1.5	−0.5	−1.5
First molar (mesial)	−0.5	−1.0	−0.5	−1.5

ext, Extraction.

- Severe generalized resorptions:
    - Rare, etiology unknown.
    - Some patients are prone to root resorptions even without orthodontic tx, probably due to genetics.
    - Risk ↑ if evidence of root resorption exists already before tx.
    - Risk factors: :
        - Conical roots
        - Pointed apices
        - Distorted teeth form (dilacerations)
        - History of trauma with or without root filling

- Severe localized resorption:
    - Caused by orthodontic tx: Excessive force, prolonged duration.
    - Maxillary incisors 3% affected, vs. <1% for all other teeth.
    - Make an OPT 6-9 m into tx to evaluate the resorption at that time.
      → Good predictor for the amount of future root resorptions.
      Good prediction if: (*Artun, 2009*)
        - 6 m, no incisor > 1 mm apical root resorption
        - 12m, no incisor > 2 mm apical root resorption

TABLE 8.6 Risk Factors for Severe Root Resorption, Maxillary Incisors

Data from Kaley JD, Phillips C. *Angle Orthod.* 1991;61:125–131.

Factor	Probability	Odds Ratio
Lingual plate approximation	.001	20
Maxillary surgery	.002	8
Torque	.01	4.5
Extraction	.01	.5
Mandibular surgery	.05	3.6

Lingual plate approximation largely explains the other risk factors.

- Patient related risk factors:
    - Genetic (IL-1 polymorphisms)
    - Personal disposition (makes up to ½ to $^2/_3$)
    - Prior apical root resorptions
    - Trauma
      (more root resorptions in general, but not more apical root resorptions)
    - Systemic factors:
        - Drugs:
          Nabumeton ↓, Doxycycline ↓, Bisphosphonates ↑ / ↓, Thyroxin ↓
        - Hormone deficit
        - Hypothyroidisms (thyroxin deficit)
        - Hypopituitarism
        - Asthma

- Treatment related risk factors:
    - Length of the tx
    - Force magnitude
    - Force direction (intrusion, torque)
    - Force application protocol (continuos, intermittent…)
    - Amount of apex movement
    - Root morphology
    - Proximity to the compacta

- Effect of root resorptions on attachment loos. *(Kalkwarf, 1986):*
    - **4 mm apical root resorption = 20% attachment loss.**
    - **3 mm apical root resorption = 1 mm crestal bone loss.**
    - **After 2 mm, every additional 2 mm = 1 mm crestal bone loss.**

- Retention:
    - Root length <10 mm post-orthodontics:
      → increased mobility possible → splinting is indicated.
    - Root length ≥10 mm post-orthodontics:
      → Teeth remain stable if the periodontium is healthy.

Effects of tx on the height of alveolar bone	- Almost never excessive loss of crestal bone height:
	  o Average < 0.5 mm
	  o Never > 1 mm
	  o Greatest changes at extraction sites.
	  o Exception:
	  Tooth movement in the presence of active periodontal disease.
	- Position of the teeth determine the position of the alveolar bone.
	- Tooth movement can be used to create the alveolar bone needed for an implant or treat intraosseous pocket.
	E.g.: extrusion of a hopeless teeth to create bone formation.
	→ Gingival border moves with the tooth but the mucogingival border not always → width of keratinized tissue ↑.
	- Early extraction of teeth or congenitally missing teeth = risk for alveolar bone defects which cannot become overcome by later orthodontic tx, if another tooth is not quickly moved into the site.5
	- Bone height tends to be lost if a tooth is intruded.
	- Intrusion of periodontally involved teeth:
	  o Pocket depth could be reduced only if teeth could be intruded without compensatory changes (difficult).
	  o Reattachment of the PDL or more extensive bony support does not occur. Only a long junctional epithelium is created.

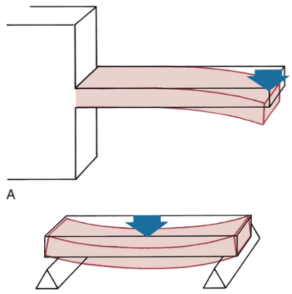
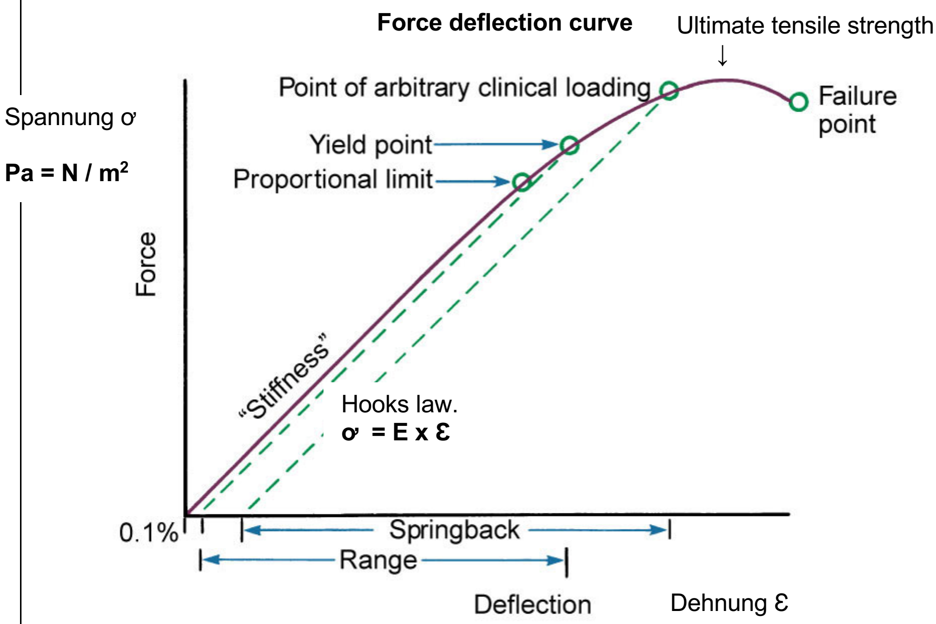
Effects of tx on the Parodont	- Recessions ↑: Δ + 0.03 mm (clin. not sign.) - Alveolar bone dehiscence: Δ -0.13 mm (clin. not sign.) - Probing depth ↑: Δ +0.23 mm (clin. not sign.) - Plaque control ↑ - Gingivitis ↓ - Tooth with bands never recover to their pre-tx periodontal indices + shift of the microflora towards an anerobe spectrum. → Orhtodontics can lead to a slight loss of attachment, but improve the oral hygiene. - *Ghijselings 2014*: Not all periodontal parameter return to pre-tx level.

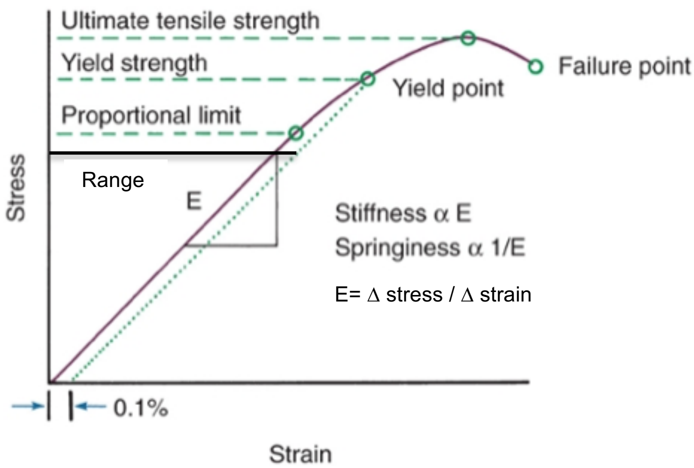
Enamel demineralization	- Incidence white spot lesions: **50-70%**
	  o After orthodontics: **≥72%** → **2.3%** cavitis | **4.2** lesions per patient
	  o Without orthodontics: **63%**
	
	- Some demineralizations are found nearly in every orthodontic patient.
	- Check with light-induced fluorescence for a more accurate diagnosis.
	- After debonding some natural remineralization occurs, but the lesions usually don't regenerate completely.
	- Regeneration of the demineralization is possible in the first year and in the 1st to 2nd year, but afterwards there is normally no further improvement.
	
	- Risk factors: Multifactorial
	  o Young age at the start of tx
	  o Poor oral hygiene at the start of tx
	  o Citations for poor hygiene during tx
	  o Nutrition
	  o Drugs → xerostomia (antiepileptics, antidepressiva)
	  o Long treatment
	  o Bond / cement failure around brackets / bands
	  o Extensive etching
	  o Fixed buccal appliance (compared to a lingual appliance)
	
	- Prevention:
	  o F- containing tooth paste.
	  o Fluoridated water.
	  o 0.05% sodium fluoride rinse.
	  o F- varnish every 6 m (or more with high risk patients).
	  o Short term daily chx rinse program (14 days). Cave: staining.
	  o CPP-ACP: Casein phosphopeptid amorphes calcium phosphate.
	  → Has the potential for remineralization.
	  o Maintenance of a good oral hygiene at least 3 m before the start of orthodontic tx.
	  o Oral hygiene on a high level for min. 3 months before orthodontic tx.

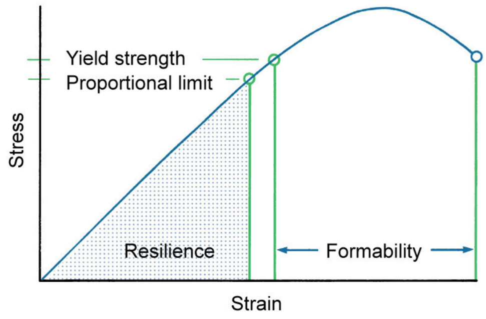
	- F- releasing bonding material: No good evidence that they are effective against white spot formation around brackets. - Glass-ionomer cement: Absorbs F- when it is provided and then gradually discharges it. - Glattflächenversiegler: Controversial discussed. - <u>Therapy:</u> o Wait 2 months after appliance removal for remineralization with normal oral hygiene. o Duraphat tooth paste 5000 ppm/F- o Infiltration: Icon® o Acid abrasion o Bleaching o Restoratiove tx: Fillings, veneers, crowns. - <u>Caries index</u> 0. ø caries 1. Caries pm/molars occlusal 2. Caries pm/molars approximal 3. Caries anterior teeth 4. Caries on buccal surfaces 5. Completely destroyed carious teeth

Proffit Chapter 9:

Mechanical Principles in Orthodontic Force Control

Basic properties of elastic materials	
Stress	= Internal distribution of the load, defined as force per unit of an area. **N/m^2 = Pa** (Pascal)
Strain (load directed along the long axis)	= Internal distortion produced by the load, defined as deflection per unit length = **$\Delta L/L$.** - Stress-Strain response to an external load defines the elastic behavior. - External force and deflection are measured with a beam. → Internal stress and strain can be calculated from these values considering the length & the cross-sectional area of the beam. - General shapes of force-deflection (Belastung rechtwinklig zur Längsache) and stress-strain (Belastung in Längsachse)
Force deflection curve (load directed perpendicular to the long axis)	- Differentiate: cantilever vs. supported beam.  - Important properties of a beam material for orthodontics: • **Strength** **Strength = Stiffness x Range** • **Stiffness** • **Range** - The properties can be represented by a stress-strain or force-deflection diagram. (general shape of the curve is similar)  Δ **L / L** in **%** - **Strength**: • **Strength = Stiffness x Range** • Measured in units of stress: SI unit = Pascal (Pa) → **1 Pa = 1 N/m^2** • English unit = gm/cm^2 **→ 100 gm/cm^2 = 1 N/cm^2 = 10.197 Mpa** = 145 psi

	- **Proportional limit**: • Highest point where stress and strain still have a linear relationship known as **Hooke's law: $\sigma = E \times \varepsilon$** • Determination of the point is difficult. - **Elastic limit: Unit N/mm^2 or %** • Lies between the proportional limit and the yield point. • The deformation is fully reversible, but the force/deflection ratio no longer proportional. - **Yield strength**: • Intersection of the stress-strain curve with a parallel line offset at 0.1% strain. • Strain were 0.1% plastic deformation occurs. (defined, because precise definition of the proportional limit is difficult) • If a wire is deflected after the yield point (here point of arbitrary clinical loading) springback occurs, but the wire no longer returns to its original shape. - **Range (mm)**: (dt. Arbeitsbereich) • Distance along the X-axis to the point at which permanent deformation occurs (usually taken at the yield point). - **Failure Point**: Wire breaks. - **Ultimate tensile strength:** • Maximum load which the wire can sustain: → An increase of the strain does not increase the stress. • Reached after some permanent deformation. (greater than the yield strength) • Maximum force the wire can deliver if used as a spring. - **Springback:** • Measured along the x-axis: = Extent to which a wire goes back to its original force after deflection • Useful springback occurs, if the wire no longer returns to its original shape when it is deflected beyond the yield point.
Stress-strain curve	 - Stress and strain are internal characteristics that can be calculated from measurements of force and deflection → curves look similar. Extra points which can be taken from the stress-strain diagram representing the strength: - **Modulus of elasticity: Unit = Pa** (often GPa) • Stiffness (αE) and springiness (α1 / E) are proportional to it - **Stiffness**: • = Flexural rigidity • **Stiffness = E x I** I = 2nd moment of inertia (dt. Flächenträgheitsmoment) Round wires: **$I = \pi r^4 / 4$** Rectangular wires: **$I = bh^3 / 12$**

	• Given by the slope of the linear portion of the curve • Proportional to the modulus of elasticity: αE - **Springiness:** • **Springiness = 1 / Stiffness** • Force-deflection curve more horizontal → wire springier. • More vertical curve → wire stiffer. • Proportional to the modulus of elasticity: *α1/E*  - **Resilience: Unit = J/m^3** • **=** Area under the stress-strain curve up to the proportional limit. • Represents the energy storage capacity of the wire. (combination of strength and springiness). • Dt: Bei Entlastung mögliche Rückführung / Elastische Verformung eines Objektes in Relation zur einwirkenden Kraft. - **Formability**: (dt. Duktilität) = Amount of permanent deformation (bending) that a wire can withstand before failing.
Wire sizes	- Wire sizes are specified in thousandths of an inch. • **1 inch = 25.4 mm | 1 mm = 0.004 inch** • Calculation ○ **mm → inch: / 25.4** ○ **inch → mm: x 25.4** • 0.016 inch =16 mil. (x1000)
Ideal orthodontic wire	- High strength - Low stiffness - High range - High formability - Wieldable (schweissbar) or solderable (lötbar) - Biocompatible - Reasonable in cost - Low E-Model: ○ Light forces also when wires with great diameters are uses → good tooth control. ○ Forces ± constant - Long range of action: ○ Big activations without plastic deformation. ○ Good control of the tooth movement. ○ Few appointments for reactivation. - Ultimate tensile strength high. ○ Fabrication of springs / activation bends.

Orthodontic archwire materials

Precious metal alloys

- **Gold**:
  - Tolerated intraoral.
  - Too soft
- Alloys from gold with platinum / palladium / cooper are useful for orthodontics.
- Precious metals are obsolete since the introduction of stainless steel.
  Exception: Cast appliances (custom fit bonding pads in lingual appliances).

TABLE 9.1 Comparative Properties of Orthodontic Wires

	Modules of Elasticity (GPa)	Material Stiffness Relative to Steel	Set Angle (Degrees)[a]
Gold (heat-treated)	83	0.41	12
Stainless steel *Truchrome*—Rocky Mountain	200	1.00	NA
Australian stainless steel *Australian*—TP Labs	193	0.97	12
Cobalt–chromium *Elgiloy*—Rocky Mountain	193	0.97	16
Cobalt–chromium (heat-treated) *Elgiloy*—Rocky Mountain	200	1.00	35
Beta-titanium *TMA*—Ormco	72	0.36	87
A-NiTi *Nitinol SE*—Unitek	83[b]	0.41	NA
M-NiTi *Nitinol*—Unitek	33	0.17	42
Triple strand 9 mil *Triple-flex*—Ormco	27[c]	0.13	62
Coaxial 6 strand *Respond*—Ormco	8.6[c]	0.04	49
Braided rectangular 9 strand *Force 9*—Ormco	10[c]	0.05	56
Braided rectangular 8 strand *D-Rect*—Ormco	8.6[c]	0.04	88
Braided rectangular A-NiTi *Turbo*—Ormco	3.4[c]	0.02	88

[a]Degrees of bending around -inch radius before permanent deformation.
[b]From initial elastic part of force–deflection curve.
[c]Apparent modulus, calculated.
A-NiTi, Austenitic nickel–titanium; M-NiTi, martensitic nickel–titanium.

Stainless steel

- Typical composition of stainless steel: (18/8 ss)
  - **74% SS**
  - **18% Chromium** (Korrosionsschutz)
  - **8% Nickel** (verbessert Verarbeitung)
  - **< 0.2% C Kohlenstoff** (verbessert Kaltverformungs-Eigenschaften)

- Better strength and springiness with equivalent corrosion resistance compared to gold.

- Properties can be controlled over a wide range:
  - **Annealing** (glühen) → Steel is softened.
  - Yield strength can be enhanced at the cost of formability.

  - **Wärmbehandlung:**
    - **Spannungsarmglühen:**
      - Reduktion der inneren Spannungen, keine Bildung eines neuen Gefüges.
      - Federrate und E-Modul konstant.
      - Proportionalitätsgrenze ↑
    - **Rekristallisationsglühen (Weichglühen):**
      - Härte ↓ / Federrate ↓ / E-Modul ↓

	▪ Treibende Kraft: Spannung an den Korngrenzen / Bildung eines neuen Gefüges ○ **Ausscheidungshärtung:** ▪ Funktioniert nur für Legierungen, die im Zustandsdiagramm eine Mischungslücke aufweisen, z.B. Elgiloy. ▪ Durch bestimme Wärmezufuhr erhöht man die Härte = E ↑. ▪ Homogener Mischkristall → Entmischungszone (Gitterverspannungen) → intrakristalline Ausscheidung. • **Cold working** → Steel is hardened. ○ Wire strained beyond the elastic limit → plastic deformation. If the strain is removed, the stress returns to 0, but plastic deformation is set into the wire. ○ At subsequent reloading: E-Modul ↑ Elastic limit ↑, Ultimate tensile strength ↑ BUT the distance between those points ↓ = Ductility ↓
Cobalt-chromium alloys (Elgiloy)	- Composition: ○ **40% Cupper** ○ **20% Chrome** ○ **15% Steel** ○ **15% Nickel** ○ **7% Molybdenum** ○ **2% Mangan** - Softer and therefore more formable than SS. - Wire can be hardened to the level of stainless steel by heat tx after being shaped. - Disappeared: More expensive than steel, extra step of heat tx required.

d

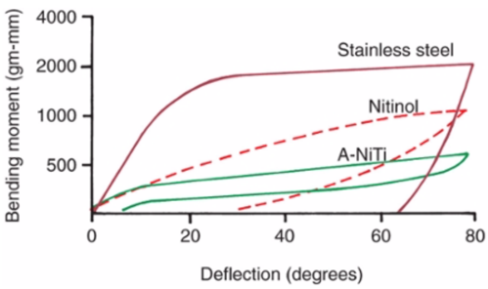
Nickel-titanium alloys

55% Ni
45% Ti

- Apply light force over a large range of activation.

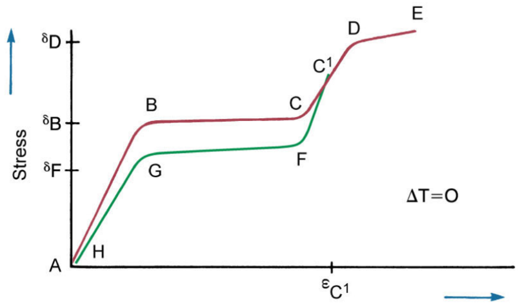
- Exist in 2 crystal structures:
    - At lower temperature, higher stress: **Martensit** form more stable.
    - Higher temperature, lower stress: **Austenitic** form more stable.
    - Transition between the two structures is fully reversible and occurs at low temperature (room temperature).
      Note: Temperature can be modified ± 100°C by slight changes of the alloy composition.
      → Heating Niti wires with a lighter, allows to bend circles.
    - **Thermoelasticity** = Temperature-induced change in th crystal structure. Difficult to exploit in orthodontics.
      (temperature cannot be controlled during alignment).
- **Shape memory**:
    - *Thermal* reaction.
    - A shape is given to the material at a temperature above the m-a transition. When the material is cooled down it can be plastically deformed in the martensitic state. The original form is however restored, when the material is heated to regain an austenitic structure.

- **Superelasticity (=Pseudoelasticity):**
    - *Mechanical* reaction.
    - NiTi wires withstand very large reversible strain due to the m-a-transformation → nonlinear stress-strain curve due to a reversible change in the internal structure after a certain amount of deformation.
    - "Normal" materials can be reversibly deformed only by stretching interatomic bonds.
    - Materials displaying superelasticity are austenitic alloys that undergo a transition to martensite in response to stress.
      (the transition temperature must be lower than room temperature for the austenite phase to exist clinically)
    - The archwires exert about the same force whether they are deflected a relatively small or large distance → ideal for leveling.



Bending moment versus deflection plotted for 16-mil orthodontic wires (solid red, stainless steel; dashed red, stabilized martensitic nickel–titanium [M-NiTi]; green, austenitic NiTi [A-NiTi]). Note that after an initial force level is reached, A-NiTi has a considerably flatter load–deflection curve and greater springback than M-NiTi, which in turn has much more springback than steel.

- Bending of NiTi wires is not possible because they do not undergo plastic deformation until they are remarkably deformed. NiTi wires can be shaped and their properties altered with heat tx (memorymarker pliers) → performed for lingual orthodontics.



Stress strain curve illustrating superelasticity due to the a-m transition for a A-NiTi wire

- ***A-B***: *Purely elastic deformation of the austenitic phase (in this phase A-NiTi is stiffer than M-NiTi).*
- ***B:*** *Minimum stress at which transformation to the martensitic phase starts to occur.*
- ***C:*** *The transformation is completed.*

<table>
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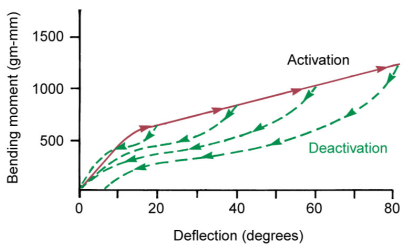
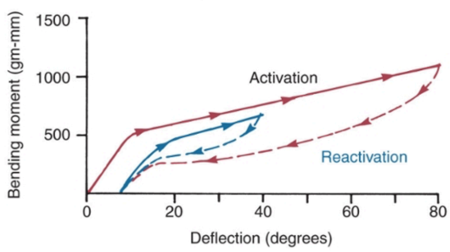
- ***C-D:*** *Martensitic structure deforms elastically.*
- ***D:*** *Yield stress of the martensitic phase is reached, and the material deforms plastically.*
- ***E:*** *Failure occurs.*
- ***C¹-F:*** *Elastic unloading of the martensitic structure occurs if the stress is released before reaching point D.*
- ***F:*** *Minimum stress on which the stress-induced martensitic structure on unloading can exist, and at that point the reverse transformation to austenite begins,*
- ***G:*** *Austenitic structure is completely restored.*
- ***G-H:*** *Elastic unloading of the austenite phase. A small portion of the total strain may not be recovered because of irreversible changes during loading or unloading.*

- **M-NiTi:**
  - = Original NiTi wires.
  - E = 28-41 MPa
  - Stabilized in the m-form. (ø phase transition effect)
  - Indicated for later stages of tx, when flexible but larger and stiffer wires are needed.

- **A-NiTi:**
  - E = 80 MPa (→ stiffer than M-NiTi if purly elastic deformed)
  - Superelasticity and/or memory effect due to m-a-transition.
  - Wire bending is not possible / only with memory making pliers *(Sander, 1996).* (shape and properties can be changed by heat tx)
  - Ideal for orthodontics: Long range of activation with relative constant force.
  - Rectangular A-NiTi does not have enough stiffness for torque movements.
  - Examples: Sentinel, Copper NiTi

  - Unloading curve changes at different activations, i.e. the unloading stiffness is affected by the degree of activation.
    (not the case for M-NiTi, Beta-Titanium or ss)





  - **Hysteresis**:
    - Unloading curve differs from its loading curve (energy loss).
    - = The delivered force of the wire is not the same as the force applied for the activation / different stress for the same strain.
    - → Force delivered by an A-NiTi wire can be changed during clinical use by releasing and retying it.
      (force is higher for a A-NiTi wire that had previously been activated (upper deactivation curve)

- **Copper NiTi:**
  - Introduced by *Andreasen & Hillemann, 1971.*
  - Strength ↑
  - Hysteresis ↓
  - Addition of Cu allows precise setting of the temperature transition range.

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<tr>
<td>Beta-titanium (TMA)</td>
<td>

- Composition:
  - ***79% Titan***
  - ***11% Molybdenum***
  - ***6% Zirconium***
  - ***4% Zinn***

- Titanium exist in 2 forms:
  - **Alpha-titanium**: Hexagonal.
  - **Beta-titanium**: Cubic, 17% more volume.
  - Transformation temperature is normally at 882°C.
    Modification / stabilization possible by adding certain elements (e.g. Molybdenum).

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</table>

- Properties:
    - Intermediate between stainless steel and M-NiTi.
    - Combination of strength and springiness.
    - Good formability.

      → Excellent for auxiliary springs, intermediate and finishing archwires.

Composite plastics

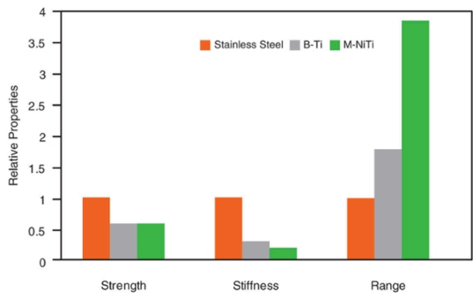
- Desirable properties in laboratory.
- Problems with stability and performance under intraoral conditions.

Comparison of contemporary archwires

- **Hooke's law: σ = E x ε** (stress is proportional to strain up to the elastics limit) Applies to all orthodontic wires except A-NiTi (non-linear response).

- **Strength ratio** = strength A / strength B
- **Stiffness ratio** = Stiffness A / Stiffness B
- **Range ratio** = Range A / Range B

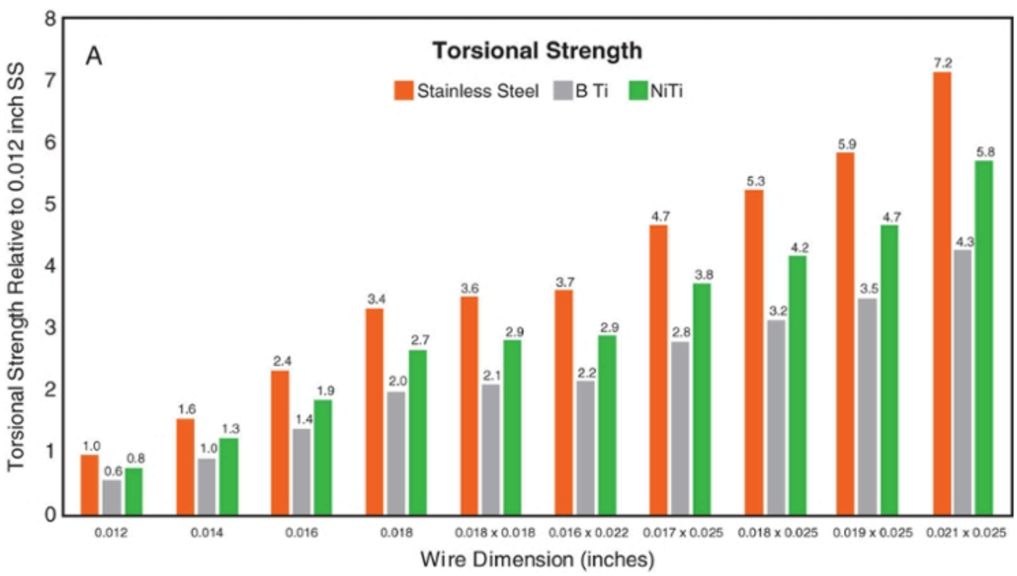
- Cave:
    - Bending describes round wires in orthodontic application, but bending and torsional stress exists when a rectangular wire is placed into a rectangular attachment on teeth.
    - Ratios apply to the linear portion of the load-deflections curve. They do not describe the behavior of wires which are stressed beyond the elastic limit but have a useful springback characteristic.

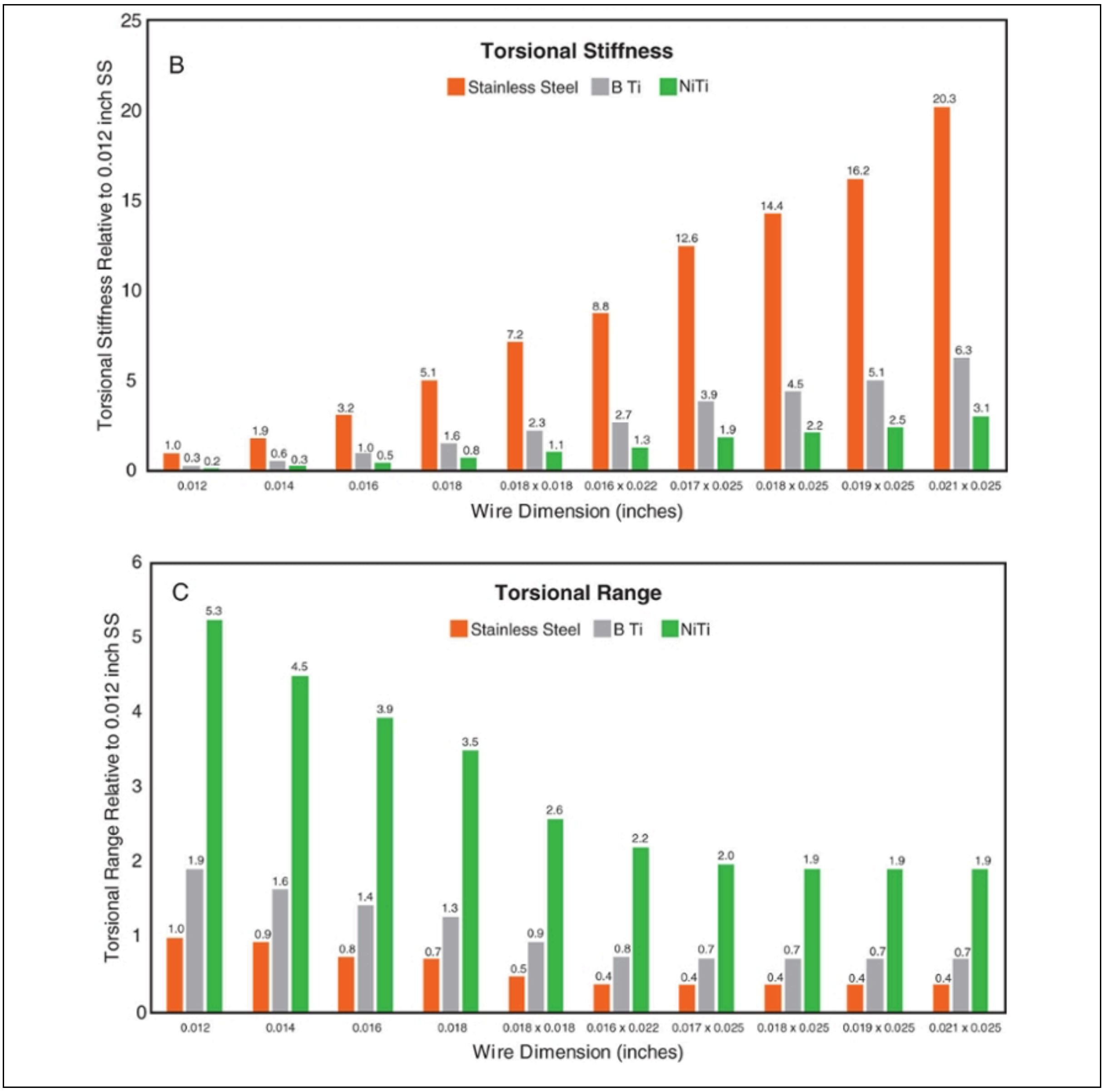


	SS	TMA	NiTi
E-Modul GPa	200	80	40
Resilienz MJ/m^3	20	14	21
EL-Grenze %	0.6	0.7	8
EL-Grenze N/mm2	1050	500	500
Bruchdehnung %	6	30	12

- **Nomograms**: Fixed charts that display the mathematic relationships via adjusted scales. Nomograms of each set are drawn to the same base.

  → Wires of different materials and different sizes can be compared.




B
Torsional Stiffness
Stainless Steel
B Ti
NiTi
Torsional Stiffness Relative to 0.012 inch SS
Wire Dimension (inches)
0.012
0.014
0.016
0.018
0.018 x 0.018
0.016 x 0.022
0.017 x 0.025
0.018 x 0.025
0.019 x 0.025
0.021 x 0.025
1.0 0.3 0.2
1.9 0.6 0.3
3.2 1.0 0.5
5.1 1.6 0.8
7.2 2.3 1.1
8.8 2.7 1.3
12.6 3.9 1.9
14.4 4.5 2.2
16.2 5.1 2.5
20.3 6.3 3.1
C
Torsional Range
Stainless Steel
B Ti
NiTi
Torsional Range Relative to 0.012 inch SS
Wire Dimension (inches)
1.0 1.9 5.3
0.9 1.6 4.5
0.8 1.4 3.9
0.7 1.3 3.5
0.5 0.9 2.6
0.4 0.8 2.2
0.4 0.7 2.0
0.4 0.7 1.9
0.4 0.7 1.9
0.4 0.7 1.9

Effects of elastic properties of beams

Geometry:
Size & shape

- Changes related to size and shape are independent of the material.

- **Round cantilever beams**: (e.g. springs in a removable appliance)
    - **Strength**:
      Changes as the 3th power of the ratio of the larger to the smaller beam
    - **Springiness**:
      Changes as the 4th power of ratio of the smaller to the larger
    - **Range**:
      Changes directly as the ratio of the smaller to the larger

$$\text{Strength} \quad d \rightarrow 2d = 8 \quad \mathbf{x^3} \quad \left(\frac{2d}{d}\right)^3$$

$$\text{Springiness} \quad d \rightarrow 2d = 1/16 \quad \mathbf{1/x^4} \quad \left(\frac{d}{2d}\right)^4$$

$$\text{Range} \quad d \rightarrow 2d = 1/2 \quad \mathbf{1/x} \quad \left(\frac{d}{2d}\right)$$

- **Supported Beams**
  (This are generalizations, the precise ratios are different from those for cantilever beams)
    - Stronger and less flexible than cantilever beams.
    - Primary determinant of properties = dimension in the direction of bending
    - **Strength**:
      Increase as the cubic function (x^3) of the increase in beam size.
    - **Springiness**:
      Decrease as a 4th power function of the increase in beam size.
    - **Range**:
      Proportionately decrease with the beam size.
    - **Torsion**:
      (important only for rectangular wires that can be twisted into a slot)
      Smaller wire → less strength in torsion.

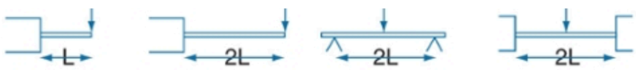
- Upper and lower limits of stiffness and strength establish the wire sizes useful for orthodontics.
- Useful sizes for wires vary from one material to another.

Geometry:
Length & attachment

- **Bending**:
  Length of a cantilever x 2 →
    - **Strength: decreases proportionately (1/x).**
    - **Springiness: increases as the cubic function (x^3) of the ratio of the length.**
    - **Range: increases as the square (x^2) of the ratio of the length.**
    - **Torsion: Torsional strength is not affected by the length.**

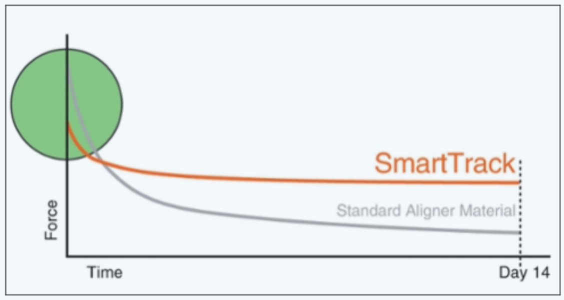
- **Supported beam**:
  Beam length increase x 2 →
    - **Strength: proportional decreases.**
    - **Springiness: exponential increase.**
    - **Range: exponential increase.**

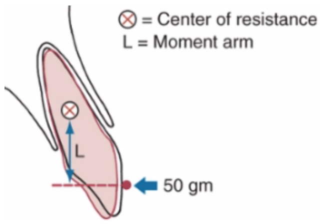
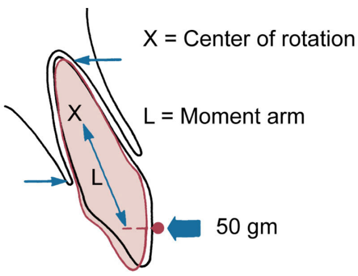
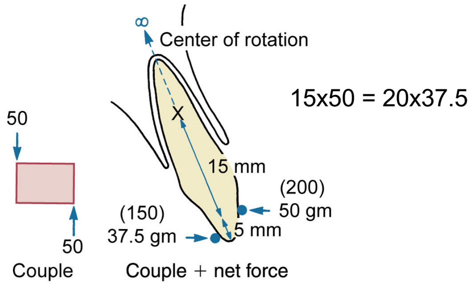
- The attachment affects the properties of a beam.
  → Supported beams (like an archwire) are 4 times as springy if they can slide on the abutments.

Beam


Strength	1/2	1/4	1	2
Stiffness	1	1/8	1	4
Range	1	4	1	1/2

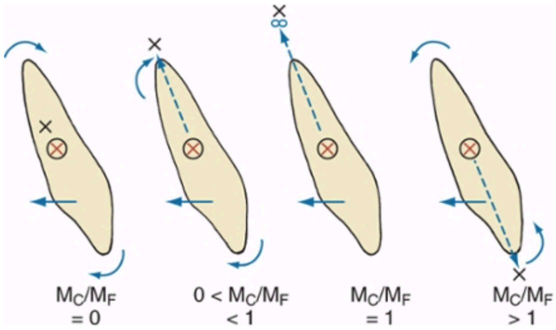
	- Hebelarm: • Kraft nimmt in der 3. Potenz ab bei einer Längenänderung. • Das Moment nimmt proportional ab zur Längenänderung.
Control orthodontic force by varying materials and size / shape of archwires	- Change the length (springiness ↑↑, strength ↓). - Combine 2 or more strands of a small and therefore springy wire: • Strength ↑, springiness ↓ • Properties depend on the characteristics of the individual wire strands and how tightly they are woven together. • → Genesis of the "twin wire" appliance. • Multistrain wires are widely displaced for most applications by NiTi wires. - Use a sequence of wires with about the same size from different materials. - Spring design: • Adequate strength → use steel wire. (TMA ~= ½ force of ss) • Increase the length to obtain more desirable mechanical properties.

Other sources of elastic force	
Clear aligners	- Material can store enough energy to create tooth movement. - The thermostretching process of the material during fabrication can influence the aligners thickness and therefor maybe their force delivery characteristics. - Elastic range limited to ~ **0.2 mm**. - Subject to stress relaxation and water absorption. - Invisalign smart track material: Relative constant force delivery over 14 days. 
Rubber	- Great elastic range. - Water absorption. - Disintegration intraoral: Gum rubber deteriorates in the mouth within a couple of hours. - Elasticity is lost after 12-24 h. - No longer used. - **Superseded rubber by latex:** • → Performance life 4-6x longer compared to rubber only. • Standard nowadays instead of rubber. Exception: latex allergy.
Plastic material	- Elastomers deteriorate in elastic performance, but perform quite well for: • Holding archwires in place. • Closure of small spaces. - Forces decay rapidly → interrupted force.
Magnets	- Produced from rare earth materials which are potentially toxic. - No cytotoxic effect is observed, if magnets in sealed cases are placed intraoral. - Little if any biologic effect from small magnets to generate orthodontic force. - Force between a pair of magnets follows the inverse square law: → Force levels are quickly too small / large as soon as teeth move.

Design factors in orthodontic appliances	
Force	- = Load applied to an object. - Unit = Newton (mass x acceleration of gravity. **1 N = 1kg x 1m/s^2**. - Force of gravity = 9.81 m/s^2 - Clinically measured in weight units. **1N = 100 gm**. → Cave: Force ≠ mass. - Forces in orthodontics consist of a: • Magnitude N / grams in orthodontics • Direction • Point of force application
Newton Laws	**1. Trägheitsprinzip:** Ohne Krafteinwirkung verbleibt ein Körper im gleichbleibenden Zustand. **2. Aktionsprinzip:** Die Beschleunigung eines Körpers ist proportional zur einwirkenden Kraft. **3. Actio - Reactio = Gesetz der Mechanik.** ∑ Momente = 0 | ∑ Kräfte = 0. (Die Summer aller Kräfte & Drehmomente in einem geschlossenen System ist = 0.)
Center of resistance	- = Point at which the resistance to movement can be concentrated for mathematical analysis. - Determined by the nature of the external constraints. → The surface geometry is more important than the distribution of the density. - For an object in the free space, center of resistance = **center of mass**. - For a tooth, Cres = approx. midpoint of the embedded portion of the root. (Note: Single rooted teeth: borderline between the cervical & middle root third, 4/10) - Force through the Cres creates pure bodily movement (=translation) without any rotation. 
Moment	- **Moment = force x moment arm** Unit: gram millimeter. - **Moment arm** = perpendicular distance from the point of force application to the center of resistance. - Moment: • = A measure for the tendency to rotate an object around a point. • Generated by forces acting distant (not trough) the center of resistance. • Always created if the line of action of an applied force does not pass through the center of resistance. - Force application closer to the Cres = moment arm ↓ → moment ↓.
Couple	- = Two forces equal in magnitude and opposite in direction, but not on the same line. → Pure moment (the translational effects of the forces are canceled). - The combination of a force + a couple can change the way an object rotates while it is being moved.
Center of rotation	- = Point around which rotation occurs when an object is being moved. - Can be controlled and located by application of two forces simultaneously. - Eccentricity of the force ↑ = Distance between Crot & Cres ↓   - Definition of the Crot: 1. Contact 2x2 moving points and draw the perpendiculars in the middle 2. Cross-section of the two perpendiculars = Crot.

Mc/Mf rations and control of root position

- Control of root position during tooth movement needs a force to move the tooth (Mf) and a couple to produce the counterbalancing moment for the control of the root position (Mc).
  → A two-point contact is necessary for control of the root's position.
- Rectangular archwires in a rectangular bracket slot :
  - The entire force system can be produced with a single wire.
  - Addition of torque can increase the counterbalancing movement.
- Round wires in bracket slots:
  - An auxiliary spring is needed to produce a torqueing couple.

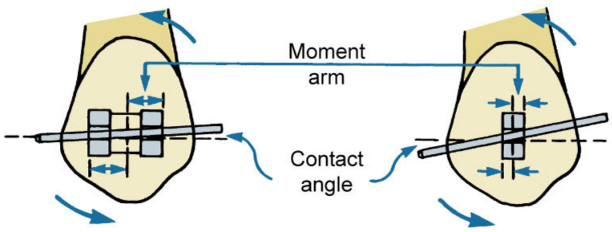


$M_C/M_F = 0$	Pure tipping (tooth rotates around center of resistance)
$0 < M_C/M_F < 1$	Controlled tipping (inclination of tooth changes but the center of rotation is displaced away from the center of resistance, and the root and crown move in the same direction)
$M_C/M_F = 1$	Bodily movement (equal movement of crown and root)
$M_C/M_F > 1$	Torque (root apex moves further than crown)

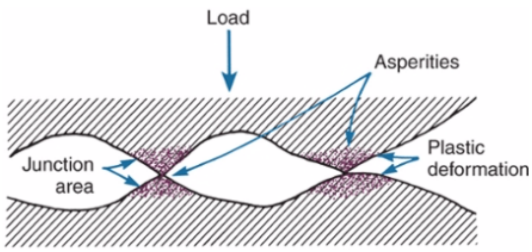
Movement	M/F ratio	Center of rotation
Uncontrolled tipping	0	Apical of the center of resistance
Controlled tipping	-7	Apex
Rotation (couple)	∞	Center of resistance
Translation	-10	∞
Torque	-11.5 to -12	Incisal

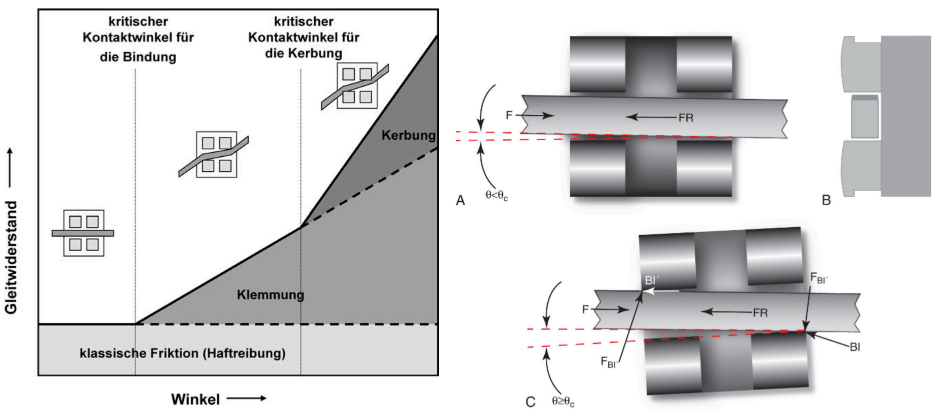
- **Moment to force ratio:**
  - *Definition Proffit:*
    = The ratio between the moment created when a force is applied to the crown of a tooth (the moment of the force [MF]), and the counterbalancing moment generated by a couple within the bracket (the moment of the couple [MC]).
  - The moment of force is determined by the magnitude of force and the distance from the point of force application to the center of resistance.
  - MF = h
    MF = Wieder-Aufrichtemoment geteilt durch die kippende Kraft.
    h = Hebelarm des Aufrichtemoments.
  - «Abstand zwischen Bracket und Angriffspunkt einer Einzelkraft, die die entsprechende Wirkung erzielen würde».
  - Clinical situation: MF = 8-10 mm for a tooth with a bracket:
    100 gm net force needs a balancing moment of 800-1000 gm to obtain bodily movement. Adjustment necessary for:
    - Long roots
    - The amount of alveolar bone support (periodontal involved teeth)
    - Point of force application different than with usual conditions.

- **Net force**: = force felt by a tooth. Important for tooth movement.
  → Resistance to sliding subtracted from the force applied to the brackets.
  Drescher 1989:
  The applied force must be x2 for ss wires and x6 for TMA wires to overcome friction.
  For a couple created in a bracket, friction is rarely a factor.

	- Clinic: Torque application needs time for expression and is proportional to bh^3. → Start early when torque is needed.
Root control with clear aligners	- Two-point contact for mesiodistal and buccolingual root movement is created with attachments. - The clinical effectiveness of these attachments is not clear. - Example: To provide a moment for lingual root movement on an upper incisor, a plastic ridge provides a lingual force on the facial surface near the gingival margin while a facial force is applied on the lingual surface near the incisal edge.
Bracket width	- Mesiodistal root movement is generated across the bracket in contrast to facial-lingual tooth movement which is created within the bracket. - **<u>Wider brackets</u>** (all other things being equal): Pro • Longer moment arm: Moment arm = half of the width of the bracket. → Less force is needed to create a moment → Easier to generate the moments needed to bring roots together at extraction sites / control mesiodistal position of roots. • Smaller contact angle: → Binding ↓ = advantageous for space closure by sliding. (Binding is affected by the force with which the bracket contacts the archwire and the contact angle between the wire and the bracket) Contra • Smaller inter-bracket space between adjacent teeth: → Shorter archwire length between supports: stiffness ↑, range ↓. - Maximum bracket width = half the width of a tooth. (extremely wide brackets are contraindicated)  - **<u>Narrow brackets:</u>** • Indicated for malaligned teeth: → The greater inter-bracket span increases the springiness of any wire.

Bracket slot size in the edgewise system	- <u>22 Slot:</u>
	• Angle's original edgewise appliance = 22 x 28 mil bracket slot.
	  ○ Designed for the use with gold archwires and narrow brackets.
	  ○ Sliding was not important (non-ex concept), but application of torque.
	• Beneficial for sliding mechanics:
	  ○ Minimum **2 mil clearance** is necessary to minimize friction for sliding teeth along an archwire. More clearance is maybe even is desirable.
	  ○ → Use of undersized wires in edgewise brackets to minimize friction.
	  ○ A 18 mil ss wire is more stable than a 16 mil ss wire.
	• Torque application is difficult:
	  ○ Springiness and range are too small for a 21 mil wire.
	  ○ Need of exaggerated inclination or torquing auxiliaries if smaller wires are used.
	  ○ Difficulties can be overcome nowadays with the modern archwires.
	
	- <u>18 Slot:</u>
	• Shift to 18 mil slots when brackets were redesigned for the use with ss wires instead of gold wires.
	• Good torque control.
	(forces slightly greater than in the original edgewise appliance)
	• Brackets must be bonded very precisely (little tolerance).
	• Smaller wires must be used → more vulnerable to mastication force etc.

Mechanical aspects of anchorage control	
Friction in fixed appliance tx	- **Friction**: **= Force necessary to shear all junctions** **+ Resistance caused by the interlocking of roughness** **+ Plowing** (dt. pflügender) **component of the total friction force.** → In practice: if the two materials are relatively smooth and not greatly dissimilar in hardness, friction is largely determined by the shearing component. (shear strength = dr. Querkraft) - **F_F = μ x F_N** μ = coefficient of friction - Derives from electromagnetic forces between atoms. - Influencing factors: • Proportional to the force, with which the contacting surfaces are pressed together ~= N (normal force). • The extent of how much asperities of the harder material plow into the surface of the softer. → Friction is more important when peaks are large or pointed, • Nature of the surfaces at the interface: ○ Rough or smooth ○ Chemically reactive or passive ○ Modifications by lubricants - Independent of: • Velocity • Area of contact (Contact exists only at the asperities = Peaks of the surface irregularities The true contact area is determined to a considerably extent by the applied load and is directly proportional to it.)  - **Friction coefficient:** • Proportional to the shear strength of the junctions. • Inverse proportional to the yield strength of the material. (determines the extent of plastic deformation at the asperities). - Types of friction: • **Internal**: Between particles at deformation of liquid or solid objects. • **External**: Between touching surfaces of solid objects. ○ **Static** ○ **Kinetic:** ▪ Normally smaller than static friction. ▪ Less important in orthodontics, because tooth movement is normally not continuous: → Stick-slip phenomenon may occur: = Movement in jumps. Surfaces sticks until enough force is built up to shear the junctions and sticks again.
Friction related to surface qualities of wires	- Surface roughness: steel < B-Titanium < NiTi (because of the surface defects and not the quality of polishing) - *Drescher 1989*: Surface roughness TMA > Niti. - Little / no correlation between coefficients for friction and surface roughness of orthodontic wires. (friction TMA > Niti) - Surface chemistry has a major influence on friction: • Titanium content ↑ → surface reactivity ↑

	• Alteration of the surface of titanium wires by implantation of ions to improve performance for alignment / sliding. (successful for B-Titan hip implants, but no improvement performance in orthodontics → no longer available)
Friction related to surface qualities of brackets	- <u>Stainless steel brackets:</u> • Cast or milled from ss and polished. → Smooth surface comparable with ss wires. - <u>Titanium brackets:</u> • Polishing is difficult → rougher → sliding can be difficult. • Chemical surface qualities can inhibit sliding. (esp. in combination with B-Titanium wires) • May useful for patients with an allergy to nickel. - <u>Polycrystalline ceramics brackets:</u> • Rough but hard material → penetration of the surface of a steel wire is possible → wire damaged! • Increased resistance to sliding. → Solution: Ceramic brackets with metal slots and/or rounded corners. - <u>Composite plastics brackets:</u> • Nonallergenic. • Tooth color. • The surface is in theory less troublesome than for ceramic brackets. • Fabrication is difficult. → Advantages in relation to ss may are not worth the additional expense.
Elastic and inelastic binding in resistance to sliding	- **Resistance to sliding** is determined by: 1. **Friction:** - When the wire contacts the walls or the bottom of the brackets. - Only important in the very early alignment, negligible as soon as the tooth can tip. 2. **Elastic / inelastic binding:** - Elastic deformation. - When the wire contacts the corners of the bracket: → a moment is generated that opposes further tipping → elastic binding between the bracket and the wire. - Angle at which the wire contacts the corner of a bracket ↑ = force between the wire and bracket ↑. 3. **Notching:** - Plastic deformation. - Stops tooth movement, until displacement of the tooth during function releases the notch. - Notching and binding are responsible for the main resistance to sliding. - Control and minimization of resistance to sliding is important for anchorage control.  *(A) and (B) The force (F) to move a bracket along an archwire initially will be resisted only by friction (FR) because of contact of the wire with the bottom or sides of the bracket slot. (C) Because the root of a tooth resists movement, the tooth tips until the corners of the bracket contact the wire, and at that point, elastic binding (BI) of the wire against the corner of the bracket adds to the resistance to sliding.*

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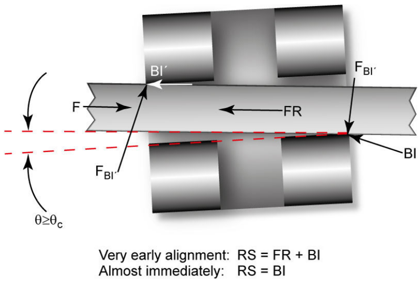
<tr><td></td><td>

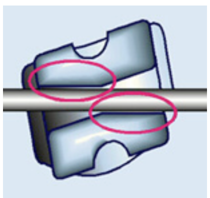
Because binding creates most of the resistance to sliding (RS) as the angle of contact between the wire and the corner of the bracket increases, resistance to sliding in very early alignment is the sum of elastic binding (BI) and friction (FR), but almost immediately the proportion of resistance from binding exceeds friction by so much that the frictional component can be disregarded—for all practical purposes, the resistance to sliding is due just to binding</td></tr>
<tr><td>Magnitude of resistance to sliding</td><td>- The combination of binding and friction is approximately equal to the amount of force needed for tooth movement.
→ Total force needed to slide the tooth = 2x as great as expected.

Drescher 1989:
The applied force must be x2 for ss wires and x6 for TMA wires to overcome friction.

- Replacement of an elastomeric ligature with a bracket cap (to tie a wire so that it is not forced against the bottom of the bracket) does not lead to faster space closure, as resistance to sliding is mainly defined by binding.

Burrow, 2009: No difference conventional & self-ligating bk.
o Friction:
If Angle = 0°:
▪ Self-ligating bk < conventional bk
▪ Passive clip < active clip
o Binding:
Self-ligating bk = conventional bk
o → Binding is mainly responsible for the resistance to sliding,

- Estimation of the resistance to sliding is difficult:
→ Too much force application to be sure that tooth movement occurs can create unwanted tooth movement of the anchorage teeth.
- Friction-free mechanics:
Retraction spring (if only one tooth is attached) / closing loop (two archwire segments connected) and arch tied tightly → archwire segments move taking the teeth with them instead of the teeth moving in relation to the archwire.</td></tr>
<tr><td>Methods to control anchorage

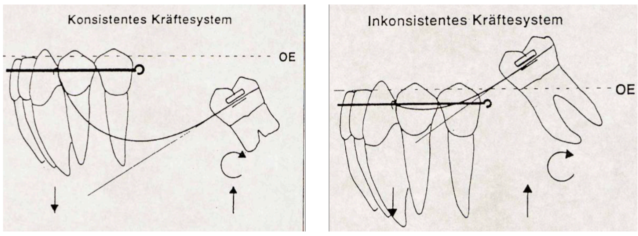
</td><td>- <u>Reinforcement:</u>
• Include as many teeth as possible in the anchorage unit (constant force).
• Cross-arch anchorage:
= Include teeth from the opposite dental arch with elastics (intermittent force).
• Extraoral force (even more intermittent).
• PDL ratio anchorage / tooth movement unit:
- Minimum 2:1 without sliding
- Minimum 4:1 with sliding

- <u>Subdivision of the desired movement = original Tweed technique</u>
• Two step space closure: (“ablösen”)
Moving one tooth (canine) after the other (incisors) in the same direction.
• Pro: The reaction force is dissipated over a largeer PDL area in the anchor unit. (only if the force is kept light)
• Contra: Longer tx time.

- <u>Tipping / uprighting = Begg Technique</u>
1. Tip the tooth in the desired direction (M/F tipping < M/F translation).
(Special brackets with rounded angles to keep the contact angle between the wire and bracket small → less binding)
2. Upright the tooth.

- <u>Skeletal anchorage:</u>
• TAD’s: Implants, manipulates, screws.
• Osseointegration is not required.
• <u>Direct use:</u>
o = Teeth to be moved are directly attached to the bone anchors.
o The location of the bone anchor must be carefully considered to control the line of force.</td></tr>
</table>

	• Indirect use:
	  o Other teeth are attached to the bone anchors to hold them in position while they serve as anchorage.
	• Impact of bone density:
	  o Required force ↑ → need for bone density ↑.
	  o Bone density at a special site is maybe not sufficient for a single screw, but can be sufficient for a plate.
	  o Bone density palate > bone density alveolar bone.
	  o Adequate bone density for most orthodontic procedures is not attained until early adolescence (±11 y)
	
	- Anchorage control in space closure
	• Typical extraction space closure after extraction of the 1st premolar:
	  o 60% movement of the anterior teeth
	  o 40% forward movement of the posterior segment
	  o Independent from which technique is applied.
	
	- Appliance philosophy: = Approach to build anchorage control in the appliance design.

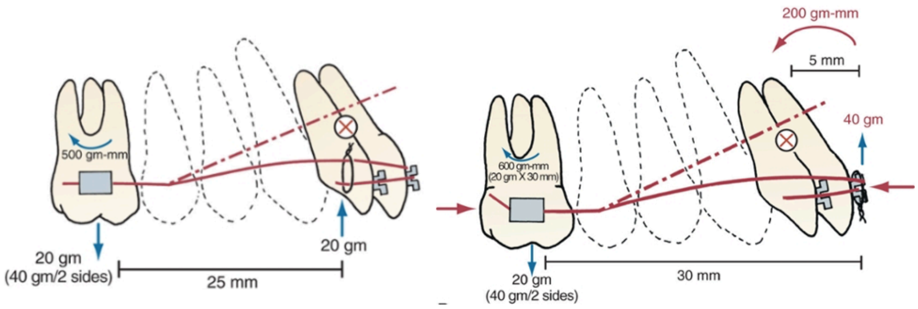
Determinant versus indeterminate force systems	
Law of equilibrium	- For every force there is an equal and opposite reactive force. - The sum of the moments around any arbitrary point is equal to zero.
Newton's laws	**1. Trägheitsprinzip:** Ohne Krafteinwirkung verbleibt ein Körper im gleichbleibenden Zustand. **2. Aktionsprinzip:** Die Beschleunigung eines Körpers ist proportional zur einwirkenden Kraft. **3. Actio - Reactio = Gesetz der Mechanik.** $\sum$ Momente = 0 | $\sum$ Kräfte = 0. (Die Summer aller Kräfte & Drehmomente in einem geschlossenen System ist = 0.)
Determinant force system (one couple system)	- = Moments and forces can be discerned, measured and evaluated. - The elastic deformation of the wire is neglected. - Determinant system: A couple is created at one end of an attachment with only a force (no couple) at the other end. → The wire serves as a spring inserted and tied into a tube or bracket at one end so that there is only one point of contact on the other (cantilever). - Advantageous when control of the force magnitude is necessary to produce the desired biologic responses in orthodontics. - Examples: Cantilever, Burston intrusion arch.
Indeterminate force system	- Too complex system for precisely calculating all forces and moments involved. - Elastic deformation is considered. - The biologic response further influences the action of an orthodontic appliance. - Examples: Straightwire appliance.
Consistent / inconstistent force systems	- Einteilung von Kräftesystemen nach Nebenwirkungen. *(Schwindling)* - Beispiel: Modell der mesioinklinierten Molarenaufrichtung. Die Aufrichtung führt neben dem Tip-back Moment zu einer Extrusion am Molaren. • Konsistentes Kraftsystem: Richtung der auftretenden Kräfte (Beispiel Extrusion) erwünscht ist. • Inkonsistentes Kraftsystem: Richtung der auftretenden Kräfte *nicht* erwünscht.  - Oft genügt es die Kraft von der anderen Seite zu applizieren, um ein inkonsistentes Kraftsystem in ein konsistentes zu überführen.

<table>
<tr><th colspan="2">One couple systems</th></tr>
<tr><td>1. Cantilevers:</td><td>
- Requirements:
• One end of the wire is placed in a bracket / tube that typically attaches to a tooth which is part of a stabilizing segment.
The teeth of the anchor unit are considered as one multi-rooted tooth with a single center of resistance. →The teeth must be tightly tied together.
• The other end of the wire is tied to a tooth or group of teeth that are going to be moved, with a single point of force application.

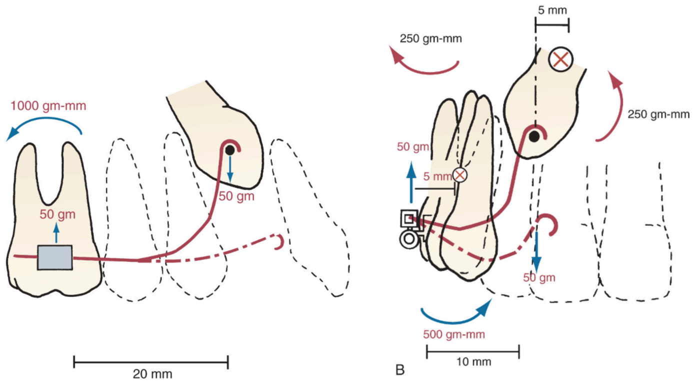
- Indicated to bring severely displaced teeth into the arch

- Advantages:
• Long range of action.
• Minimal decrease in force as tooth movement proceeds.
• Excellent control of force magnitude (flat load / deflection diagram).
• M/F remains constant also when tooth movement occurs (both decrease prop.)
• Force proportional to length3, moment proportional to the length.
→ Large moments and small forces can be achieved.

- Disadvantages:
• Distortion by the patient possible:
→ Possible movements in the wrong directions.
• Force on an unerupted tooth rotates the crown lingually as the tooth is brought towards the occlusal plane.
</td></tr>
<tr><td>2. Auxiliary intrusion arches:</td><td>
- Intrusion arches must exert a light force → low reactive force against the anchorage unit is low.
Sifakes, 2009:
The force of a Burston intrusion arch is in theory too small to move the anchorage unit.
- Tying the molars together with a palatal bar prevents them from buccal or lingual tipping.

- Intrusion arch tied behind 2+2:
→ Force applied in line with the center of resistance → no moment to rotate the incisors.
- Intrusion arch tied in the midline:
→ Proclination or
→ Lingual root torque, if the arch is cinched back behind the molars (strain on the anchorage)


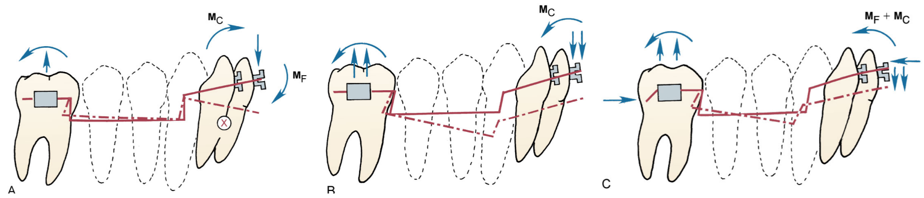
An intrusion arch made from rectangular wire, which fits into a rectangular tube on the molars and is tied to one point of contact on the incisor segment, is an example of a determinate one-couple system. If the archwire is activated by pulling it down and tying it to the incisor segment so that it delivers 40 gm of intrusion force (10 gm per incisor, 20 gm per side), and if the distance from the molar tube to the point of attachment is 30 mm, each molar will feel a 20-gm extrusive force in reaction and a 600 gm-mm moment to tip the crown distally. At the incisor segment, the force will create a 200 gm-mm moment to rotate the incisor crowns facially. At each molar, the extrusive force also would create a moment to roll the crown lingually. If the buccal tube were 4 mm buccal to the center of resistance, the magnitude of this moment would be 80 gm-mm.
</td></tr>
</table>

3. Auxiliary extrusion arches:	- Extrusion arches are rare. - 4-5x more force needed than for intrusion → higher reactive force against the anchor teeth.  ***A** cantilever spring, made from a rectangular wire that fits into a rectangular tube (or bracket) on one end and is tied to one point of contact on the other, produces a determinate one-couple system in which the forces and moments can be known precisely. (A) Lateral view of the force system created by a cantilever spring to extrude an impacted maxillary canine. If the distance between the molar tube and a button on the canine to which the spring is tied is 20 mm, placing a 50-gm extrusive force on the canine creates a 50-gm intrusive force on the molar and also a 1000 gm-mm moment to rotate the molar crown forward around its center of resistance. (**B**) Frontal view of the same force system. Consider the buccolingual (torque) moments created by the force on the molar and canine. If the center of resistance of the canine is 5 mm lingual to the button on its crown, a 50-gm extrusive force creates a 250 gm-mm moment to rotate the crown lingually (which usually is not desired; red arrow). At the molar, if the center of resistance is 5 mm lingual to the tube on the buccal surface, the 50-gm intrusive force creates a 250 gm-mm moment to rotate the crown facially (red arrow). But if the impacted canine is 10 mm lingual to the buccal surface of the molar, activating the spring also twists it, creating a 500 gm-mm torquing moment to rotate the molar crown lingually (blue arrow). The result at the molar is a net 250 gm-mm moment to torque the molar crown lingually and roots buccally. If the rectangular spring were tied into a bracket on the canine, a moment to torque its root facially could be generated, but the resulting two-couple system would be indeterminate.*

Two couple systems

1. Utility arches for intrusion by Ricketts

- = Intrusion arch made from a rectangular wire tied into the incisor brackets.
- ***A:*** *The brackets are anterior of the center of resistance of the incisors:*
  → The moment of the intrusive force tips the crowns facially when it is activated and an additional moment (M_C) in the same direction is created by the couple within the bracket as the inclination of the wire is changed when it is brought to the brackets. The moment of this couple cannot be known, but it is clinically important because it affects the magnitude of the intrusion force.
- ***B:*** *Placing a torque bend in the utility arch creates a moment to bring the crown lingually, controlling the tendency for the teeth to tip facially as they intrude, but it also increases the magnitude of the intrusive force on the incisor segment and the extrusive force and couple on the molars*
- ***C:*** *Cinching back the utility arch creates a force to bring the incisors lingually and a moment of this force opposes the moment of the intrusion force. At the molar, a force to bring the molar mesially is created, along with a moment to tip the molar mesially. Especially if a torque bend still is present, it is difficult to be certain which of the moment will prevail or whether the intrusion force is appropriate. → With this two-couple system, the vertical forces easily can be heavier than desired, changing the balance between intrusion of the incisors and extrusion of the molars.*



- Prevention of facial tipping of the incisors:
  - Apply a force to retract the incisors by cinching or tying back the intrusion arch:
    → Creates a moment in the other direction.
    → Cave:
    - A moment of the force at the incisors opposes the intrusion.
    - A force to bring the molars forward and additionally mesial tip them is created.
  - Place a twist in the anterior segment to torque the incisors lingually.
    (effect can be accentuated by cinching the end of the wire at the molar tube)
    → Intrusive & extrusive force ↑

- *Daviodvitch & Rebellato, 1996:*
  Kraftsystem 3. Ordnung kann die vertikalen Gleichgewichtskräfte neutralisieren oder verstärken.

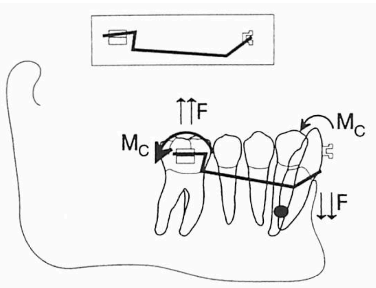


Bild 5: Schematische Darstellung eines Utility-Bogens, der an den Enden nicht umgebogen ist, mit einer V-Biegung für linguale Kronen-/labiale Wurzelrotation des Schneidezahnsegments (labialer Wurzeltorque). Das Kräftepaar zweiter Ordnung an den Molaren und das Paar dritter Ordnung an den Schneidezähnen weisen in die gleiche Richtung, und die an beiden Zähnen wirkenden Gleichgewichtskräfte addieren sich. Die Intrusionskraft an den Schneidezähnen verdoppelt sich, während die Proklination reduziert wird.

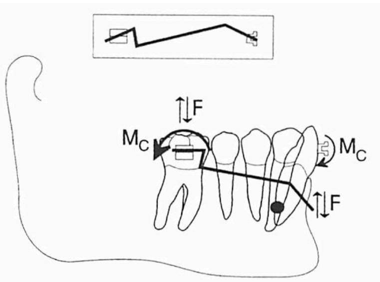


Bild 6: Schematische Darstellung eines an den Enden nicht umgebogenen Utility-Bogens mit einer V-Biegung für labiale Kronen-/linguale Wurzelrotation des Schneidezahnsegments. Das Kräftepaar an den Molaren und das Kräftepaar an den Schneidezähnen sind entgegengesetzt gerichtet. Daher sind auch ihre Gleichgewichtskräfte entgegengesetzt gerichtet, so daß die vertikalen Kräfte an Schneidezähnen und Molaren reduziert werden.

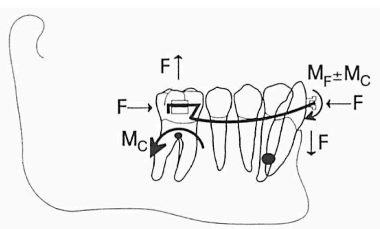
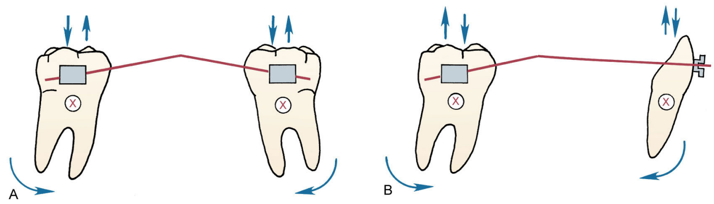
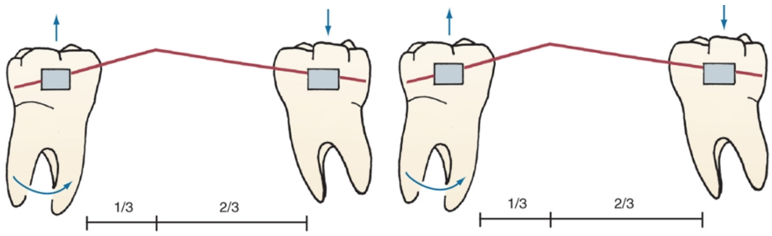


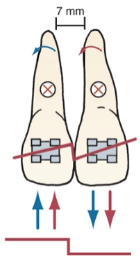
Bild 7: Ein aktivierter Utility-Bogen, eingesetzt in die Brackets der Schneidezähne und Molaren. Der Bogen wurde umgebogen, so daß ein zusätzliches neues Kräftesystem entsteht, das an den Molaren nach mesial und an den Schneidezähnen nach lingual gerichtet ist. Das neue Kräftesystem verläuft weder an den Molaren noch an den Schneidezähnen durch C_{Res}, so daß ein neues M_F an beiden Zähnen erzeugt wird. An Molar und Schneidezähnen wirkt eine Kombination aus dem M_F der Umbiegung und des M_C des aktivierten Utility.

2.	**Symmetric V-bends** (Burston VI geometry)	- **Equal and opposite couples at the brackets → Equilibrium forces at each bracket are equal and opposite → cancel each other out.** - Not necessarily halfway between two teeth or two groups of teeth, the important quality is, that it creates equivalent couples at both ends. → Affected by: o Bracket width o Bracket alignment - If applied between units with unequal resistance (posterior and anterior teeth), the bend must be placed closer to the unit with the greater resistance. - ø equivalent tooth movements, if the anchorage of one section is much greater than the other. 
3.	**Asymmetric V-bends**	- **Unequal and opposite couples and net equilibrium forces that intrude one unit and extrude the other.** - The absolute magnitude of the involved forces cannot be known, but the relative magnitude of the forces can be determined. → Placing the short segment of the wire in the bracket is a good way to visualize the direction of the equilibrium forces. - The bracket with the larger moment (→ extrusion) has a greater tendency to rotate: → indicates the direction of the equilibrium forces. - If the bend is moved closer to one of two equal units: o Moment of the closer unit ↑ (extrusion) o Moment of the distant unit ↓ (intrusion) o Equilibrium forces ↑ - $^{1}/_{3}$ of the distance between 2 brackets (point not found in every study): = Geometry IV. o No moment on the distant bracket, only a single force. o Point of dissociation. - If the bend is closer than $^{1}/_{3}$ to one unit: = Burston geometries I/II/III. o Moments at both brackets in the same direction (instead of opposite). o Equilibrium forces increase further. o If the bend is placed to parallel the roots of the adjacent teeth, it will not do so. - The equilibrium forces increase steadily as the beam moves off-center.  - Define the moments and equilibrium forces clinically: o Tooth closer to the V-bend = Extrusion o Tooth closer to the V-bend = Greater moment o Greater moment = Extrusion o If a straight archwire is placed over two slots: The greater angle between the wire and slot indicates the tooth with the greater moment. → The greater moment defines the direction of the equilibrium forces.

Percentage of Total Span to Closest Bracket	Moment Far Tooth/Moment Near Tooth	Force General Condition	DATA FROM EXPERIMENT 16 STEEL, 7-mm SPAN, 0.35-mm BEND	
			Force (gm)	Moment (gm-mm)
Step Bend				
Any	1.0	XX	347	1210/1210
V-Bend				
0.5	−1.0	None	0	803/803
0.4	−0.3	X		
0.33	0	XX		
0.29			353	2210/262
0.2	0.3	XXX		
0.14			937	4840/1720
0.1	0.4	XXXX		

X, XX, XXX, XXXX indicate relative force levels generated at the various V-bend locations.

4. Step bends



- **Creation of two couples in the same direction regardless of location of the bend between the brackets.**
- Parallel step bend = Burston geometry I.
  ø parallel step = Burston geometry II.
- The location has little effect on the magnitude of the moments & equilibrium forces.
- The forces are increased compared to the forces which would be produced by a symmetric V-bend. (because the couples are in the same direction)
- Labor study: Forces from 0.35 mm step bend in a 16 mil SS wire:
  - 347 gm intrusive & extrusive force:
    → Force magnitude is too great for intrusion = extrusion is the result from step bend in a continuous archwires.
  - 1210 gm - mm couples in the same direction.

Forces and couples created by interbracket bends

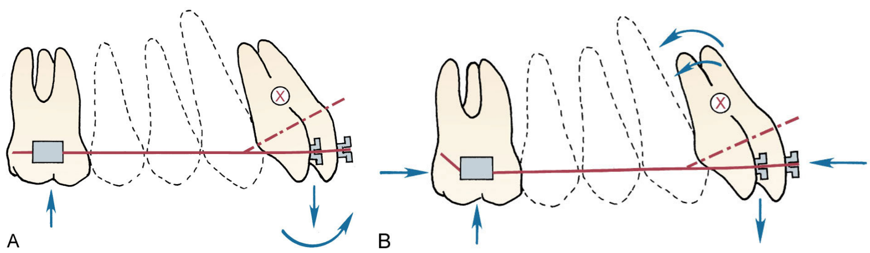
- Interbracket-distance ↑ → F ↓ + M ↓ → = easier to control a 2-couple systems. (distance from the first molar to the lateral incisor needed to obtain the light force necessary for intrusion)
- Interbracket-distance ↑ → position of the V-bend is less critical.

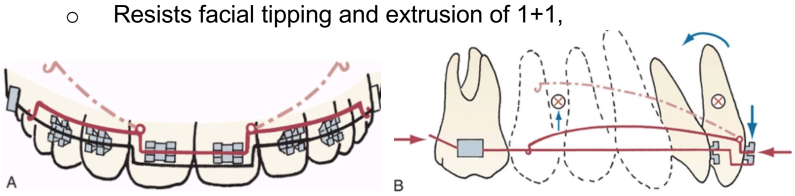
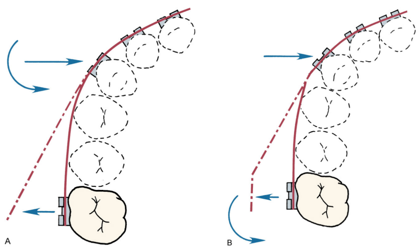
- <u>2 x 4 two-couple wires:</u>
  - 3D effects are produced when the wire goes around the arch from the molars to the incisors.
  - Finite analysis (*Isaacson, 1995*) have shown that the general principles of 2D analysis remain valid when a 3D analysis is done.
  - However, differences exist for long span wires e.g. utility arch:
    - The V-bend at the molar produces a smaller moment and is associated with smaller equilibrium forces than the same V-bend located at the same distance from the incisor segment.
    - If the V-bend moves closer than $^{1}/_{3}$ of the distance to the molar or incisors, the reversal of the moment (that the moment is in the same direction) does not occur.
    - → Effects of utility arches with complex bends are even less predictable.

5. Two couple archwires to change incisor inclination

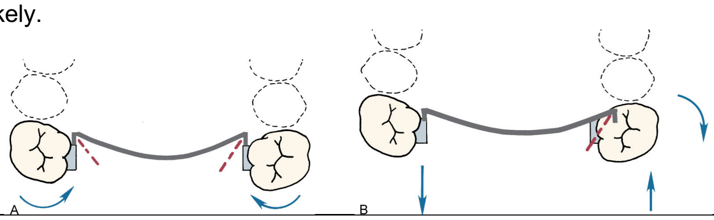
- Archwire free to slide forward through the molar tube:
  - Anterior tipping and extrusion of the incisors. (V-bend closer to the incisors)
  - Indication: Anterior crossbite.

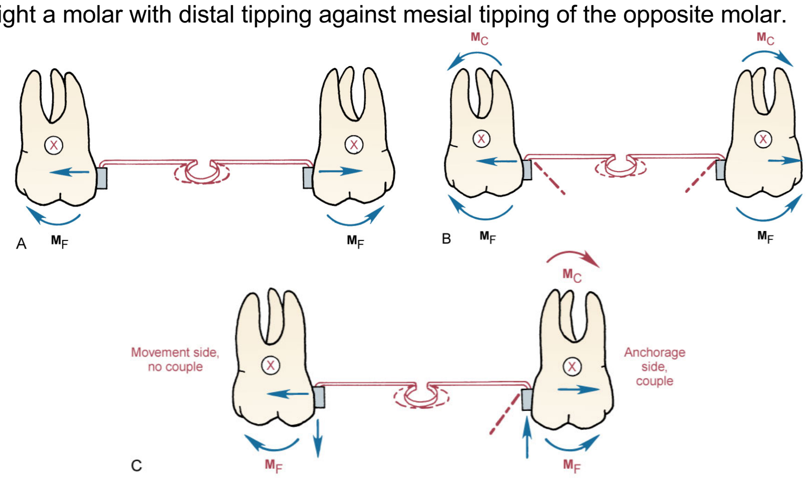
- Archwire cinched behind the molar:
  - Lingual root torque and extrusion for the incisors.
  - Mesial (Row-bow effect) / intrusive / roll facially forces on the molars.



<table>
<tr><td>6. One-couple torquing arch by Burston</td><td>- Components:
• Lateral full dimension stabilizing segments (17x25 ss, 18 slot).
• Accessory wire (17x25 TMA, 18 slot) tied into the brackets 1+1 (or 2+2) and activated by bending it down and hooking it between 6+6 and 5+5 to produce the desired moment.
• Facultative heavy stabilizing archwire in all the teeth, but the central incisors (and may the lateral incisors):
o 17x25 TMA, 18 slot.
o Contoured so that it steps below the brackets of 1+1 (21+12) and contacts the facial surface of these teeth.
o Cinch back behind the molars.
o Resists facial tipping and extrusion of 1+1,
</td></tr>
<tr><td>7. Posterior crossbite corrections: transversal movement of posterior teeth.</td><td>- Canines must be incorporated into the anterior anchor segment. (Premolars cannot be tied to the archwire)
- <u>Asymmetric expansion or constriction feasible</u>:
• Outward bend few mm behind the canine bracket results primarily in expansion of the molar with little rotation ($^1/_3$ position of the 2-couple system)
• Outward bend behind the canine + toe-in bend at the molar
→ Expansion and mesial-out rotation of the molar.

- Large range of activation → teeth can be moved a considerable distance with a single activation (valid for all 2- couple systems).
- Cave: Not fail-safe.</td></tr>
<tr><td>8. Lingual arches as two couple systems</td><td>- Often employed to prevent tooth movement rather than to create.

- <u>Bilateral toe-in bends at the molars:</u>
• Equal and opposite couples.
• Mesiodistal forces are canceled.
• Teeth are rotated to bring the mb cups facially.
• A flexible rather than a rigid archwire is needed.
• Ingervall, 1996:
Moments are never symmetric, even if the lingual arch is activated symmetric.
→ Cold working of the wire changes it's characteristics + influence of the occlusion.

- <u>Unilateral toe-in bend:</u>
• Rotates the molar on the side of the bend.
• Creates a force to move the other molar distally.
(Systemdrehung in Gegenrichtung)
• Mesial movement of the molar on the side of the bend is limited from the contact with other teeth. (sign. distal movement of both teeth is unlikely)
• Net distalization of both molars by bends of this type on first one side, then the other, have been claimed. Sign. distal movement of both teeth is however not likely.
</td></tr>
</table>

	- <u>Bilateral expansion of molars by opening a loop in the middle:</u>
	• Moment of expansion tips the crowns facially.
	
	- <u>Symmetrical torque application while the molars are expanded:</u>
	• Provides bodily movement rather than tipping.
	
	- <u>Unilateral crossbite:</u>
	• Buccal root torque (lingual crown torque) on one side pitted against buccal tipping on the other side.
	• = Twist in the wire on one side creates stationary anchorage to tip the opposite molar facially.
	• Particularly effective if the wire is rounded on the movement side. = Conversion to a one couple device.
	• *Ingervall, 1995:* Asymmetric expansion with tipping against torque.
	  ○ Risk to develop a crossbite on the torque site.
	  ○ Extrusion at the site with more expansion.
	  ○ Intrusion at the side with less expansion (torque side).
	
	- <u>2nd order correction:</u>
	Upright a molar with distal tipping against mesial tipping of the opposite molar.
	
	
	Note:
	- Buccal root torque:
	• Intrusion
	• Mesial tipping (root distal, crown mesial)
	- Palatal root torque:
	• Extrusion
	• Distal tipping (root mesial, crown distal)

Segmented arch mechanics	- Using one- / two-couple systems: → Engineering analysis can provide an approximation of the forces and moments engaged. - Lingual arches (0.036'' / 0.032'' x 0.032'' ss). - Stabilizing wire segments in the brackets of anchor teeth (21x25 ss) for stabilization. - Sliding of archwires through brackets is avoided, because the resistance to sliding introduces uncertainties in the calculation of forces and moments. (Sliding is applied only for the final stages). - Pro: • Tooth movements become possible which are impossible with continuous arches. (unless TADs are used) - Contra: • Greater complexity of the appliance, danger to overlook something. • Chairtime ↑ • Not fail-safe: No control mechanism for the distance over which a tooth can be displaced if something goes wrong. - Skeletal anchorage replaces nowadays the need for segmented mechanics.
Continuous arch mechanics	- = Extremely complex multi-couple force system. - An initial small movement of one tooth changes the whole system. - Forces and moments are not well defined. - Excellent fail-safe properties. - Chairtime ↓