<table>
<tr><td colspan="2">Mechanical aspects of anchorage control</td></tr>
<tr><td>Friction in fixed appliance tx</td><td>
- Friction:
= Force necessary to shear all junctions
+ Resistance caused by the interlocking of roughness
+ Plowing (dt. pflügender) component of the total friction force.

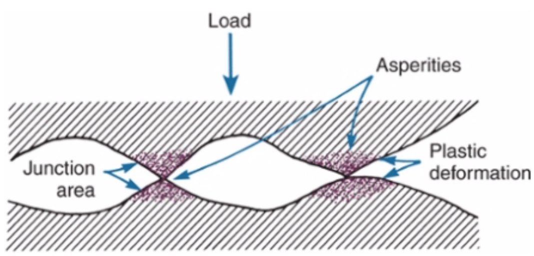
→ In practice: if the two materials are relatively smooth and not greatly dissimilar in hardness, friction is largely determined by the shearing component.
(shear strength = dr. Querkraft)

- $\mathbf{F_F = \mu \times F_N}$ 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:
o Rough or smooth
o Chemically reactive or passive
o 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.
o Static
o 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.
</td></tr>
<tr><td>Friction related to surface qualities of wires</td><td>
- 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 ↑
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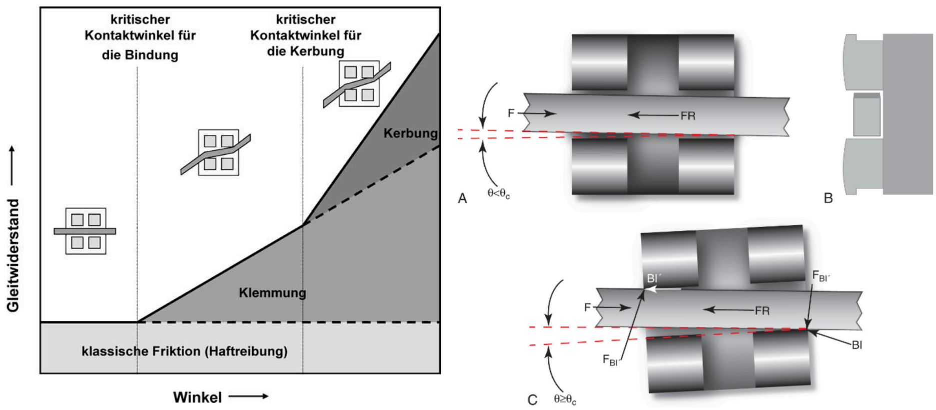
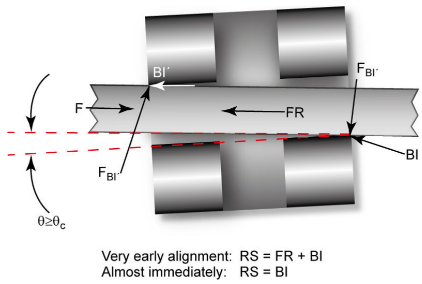
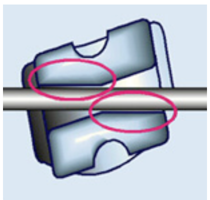
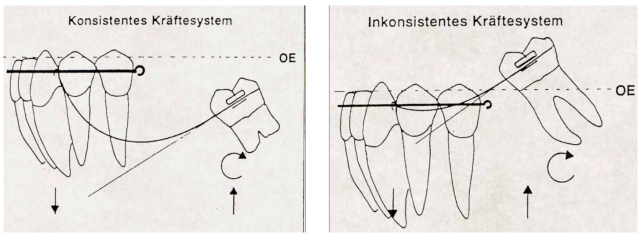
	• Alteration of the surface of titanium wires by implantation of ions to improve performance for alignment / sliding. (successful for B-Titan hip implants, but no improvement performance in orthodontics → no longer available)
Friction related to surface qualities of brackets	- <u>Stainless steel brackets:</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.*

	 *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*
Magnitude of resistance to sliding	- 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.
Methods to control anchorage 	- <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.

	• <u>Indirect use:</u>
	    o Other teeth are attached to the bone anchors to hold them in position while they serve as anchorage.
	• <u>Impact of bone density:</u>
	    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)
	
	- <u>Anchorage control in space closure</u>
	• Typical extraction space closure after extraction of the 1^{st} 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.

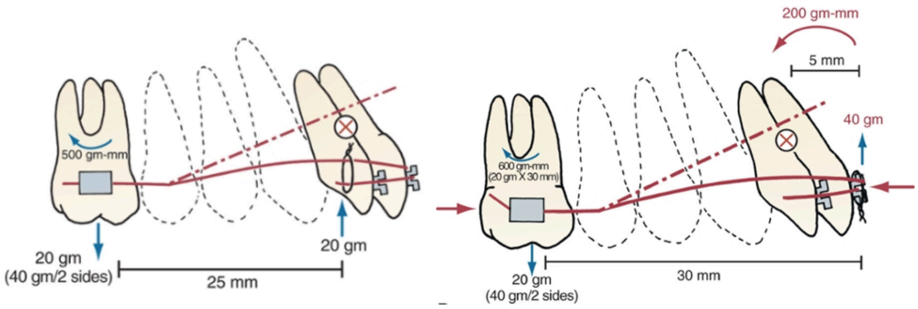
<table>
<tr><th colspan="2">One couple systems</th></tr>
<tr><td>1. Cantilevers:</td><td>- Requirements:
• One end of the wire is placed in a bracket / tube that typically attaches to a tooth which is part of a stabilizing segment.
The teeth of the anchor unit are considered as one multi-rooted tooth 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>
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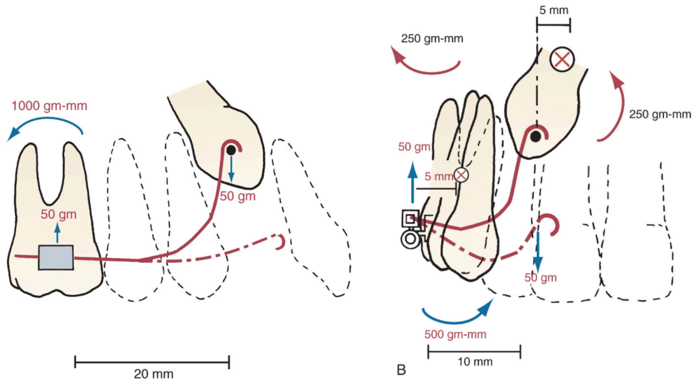
3.	**Auxiliary extrusion arches**:	- Extrusion arches are rare. - 4-5x more force needed than for intrusion → higher reactive force against the anchor teeth.  ***A** cantilever spring, made from a rectangular wire that fits into a rectangular tube (or bracket) on one end and is tied to one point of contact 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.*