I would like to touch on Three Subjects Today

1

Why is Normal Alignment Normal?

Where is the Deformity in Limb Malalignment?

How Much is the Deformity?

2

Discuss Osteotomy for Limb Malalignment

3

The Mystery of Anterior Knee Pain

Limb Alignment
Limb Mal-alignment

How to Locate the Deformity in Mal-alignment

How to Design a Limb

Look to Pauwels the father of modern orthopaedic biomechanics who tells us the limbs are designed the way they are to transfer the weight of the body through the center of the Knee Joint to the ground and to allow motion

INVITED ARTICLE

IATROPHYSICS TO BIOMECHANICS

FROM BORELLI (1608-1679) TO PAUWELS (1885-1980)

PAUL MAQUET

From Liège

In his *Traité de l'homme et de la formation du foetus*, published in 1675, René Descartes considered the human body as a material machine directed by a rational soul (which he located in the pineal gland). His work was, perhaps, the first attempt to contain all animal physiology in a mechanistic theory. The famous *De motu animalium* of Giovanni Alfonso Borelli is, however, the very first comprehensive treatise on biomechanics, although at that time it was called iatrophysics, meaning physics applied to medicine. Borelli held the chair of mathematics at the University of Pisa where he worked closely with Malpighi who was professor of theoretical medicine. Their collaboration is an excellent example of the effectiveness of co-operation by scientists from different disciplines. Malpighi is quoted as saying: "What progress I have made in philosophising stems from Borelli. On the other hand, dissecting living animals at his home and observing their parts, I worked hard to satisfy his very keen curiosity". Borelli had published two earlier books *De vi percussionis* in 1667 and *De motionibus naturalibus a gravitate pendentibus* in 1670, both paving the way for the *De motu animalium*, the first part of which was published in Rome in 1680, just after his death, and the second in 1681.

In the first part Borelli analysed the function of the locomotor apparatus in man, quadrupeds, birds, fishes, worms, flies, etc, all from a mechanical standpoint. He calculated the forces developed by the muscles and those transmitted across the joints during activities such as carrying a load, walking, running, jumping, skating, swimming, and flying. He recognised that the muscles, acting with generally short lever arms, balance the body-weight which usually acts with a much longer lever arm so that the joints must transmit forces at least equal to and usually several times greater than the weight of the body or that part of it which they sustain (Fig. 1). The so-called balance of Pauwels (1935) (Fig. 2) had in fact been clearly described before 1680.

Borelli was probably also the first to determine experimentally the centre of gravity of man, by having

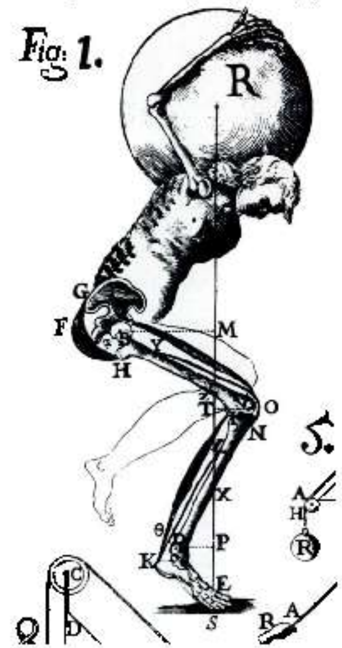

Fig. 1

From Borelli: how muscles balance the body and a load carried on the neck.

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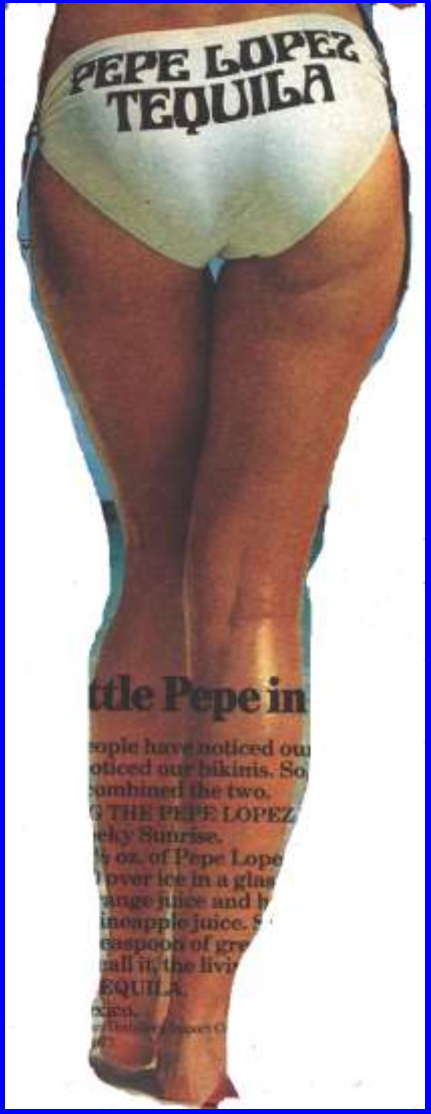
Thier Bosset, 25, B-1920 Aywaille, Belgium

0301-620X/92/3379 $2.00
J Bone Joint Surg [Br] 1992; 74-B:335-9.

Pauwels asked the question:

Why are legs shaped the way they are?

Why are legs shaped the way they are?



Pauwels showed how the limb was designed to allow weight transfer within biological tolerance levels.

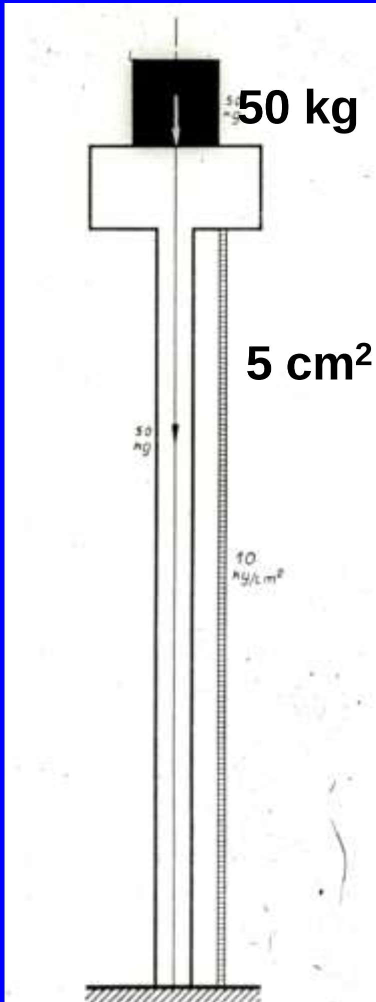


Fig. 1

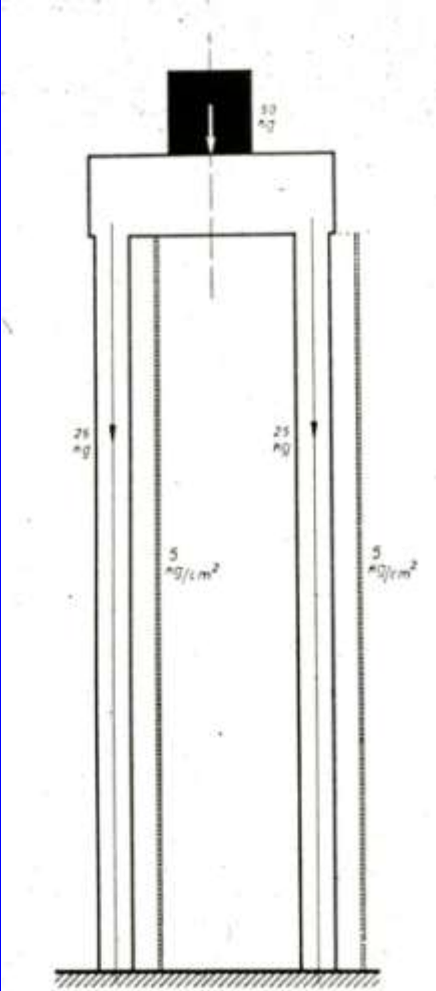


Fig. 2

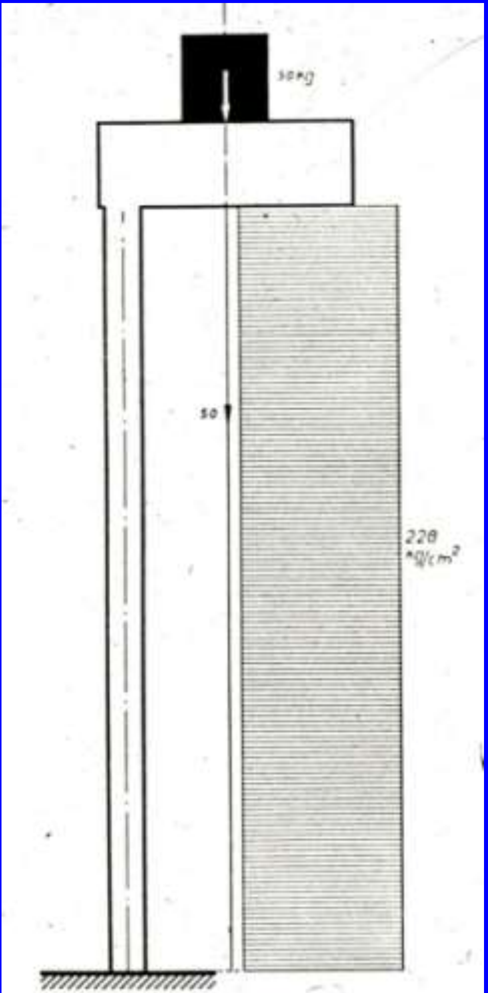


Fig. 3

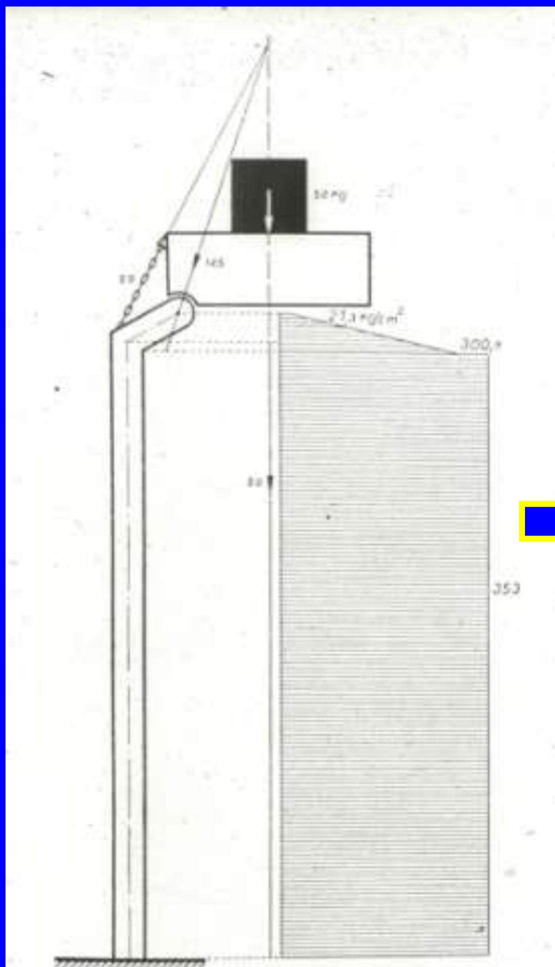


Fig. 4

353Kg/cm^2

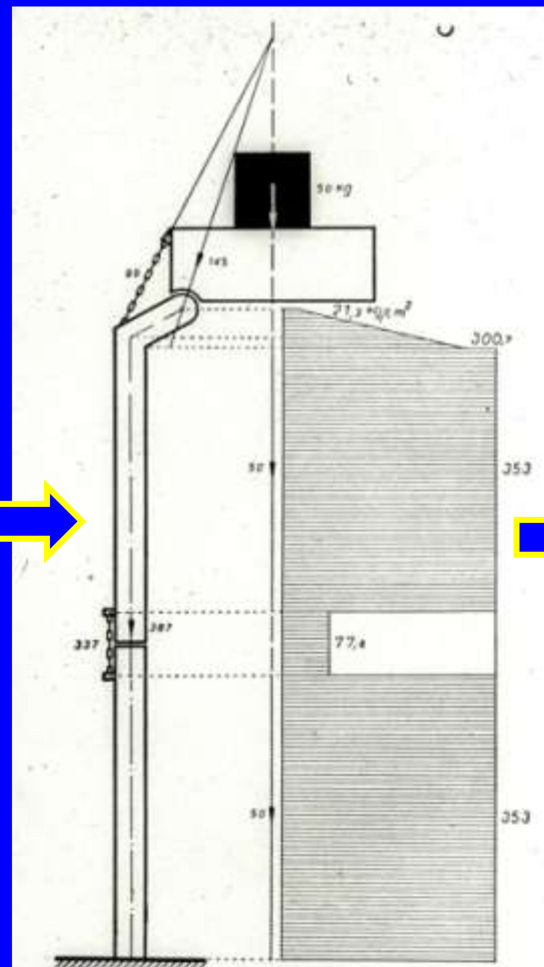


Fig. 5

77Kg/cm^2

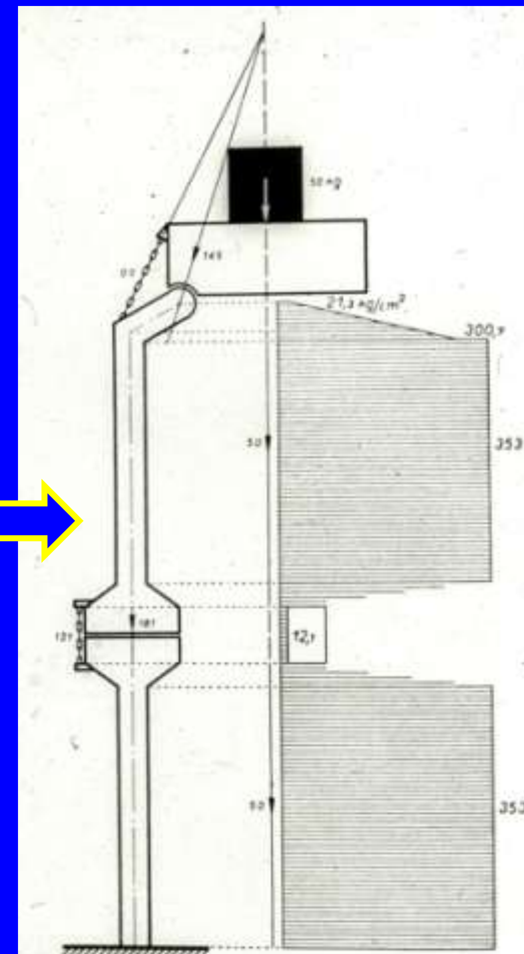


Fig. 6

12Kg/cm^2

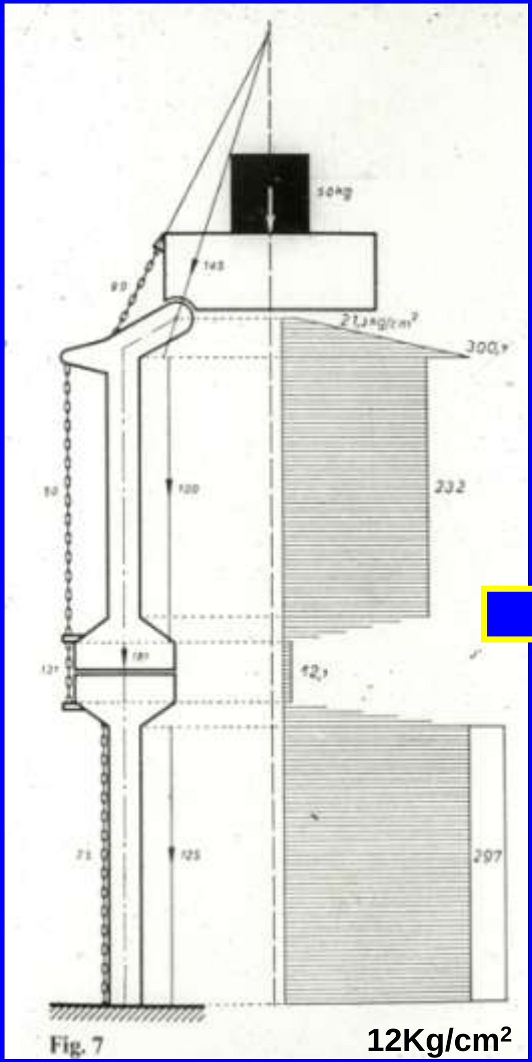
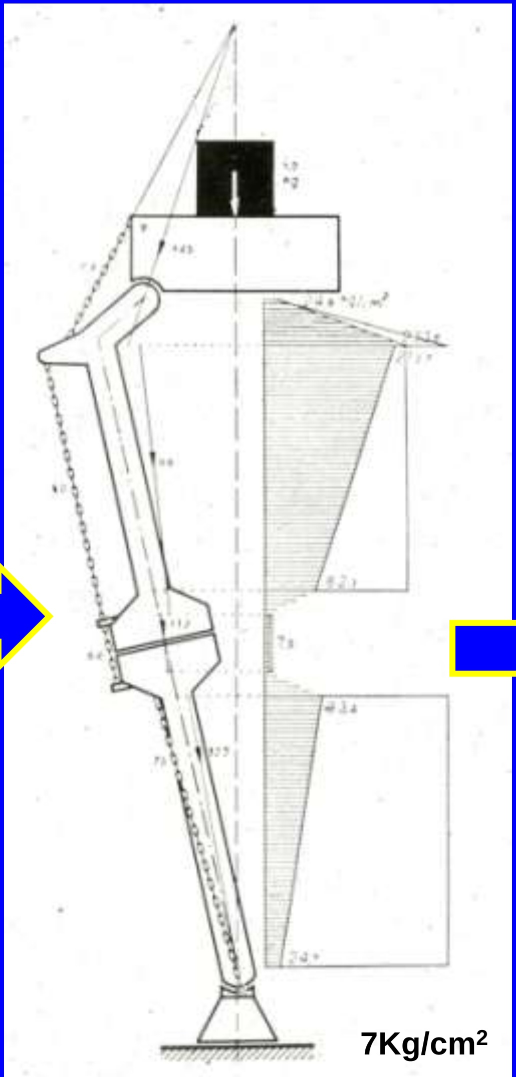


Fig. 7
12Kg/cm²


7Kg/cm²

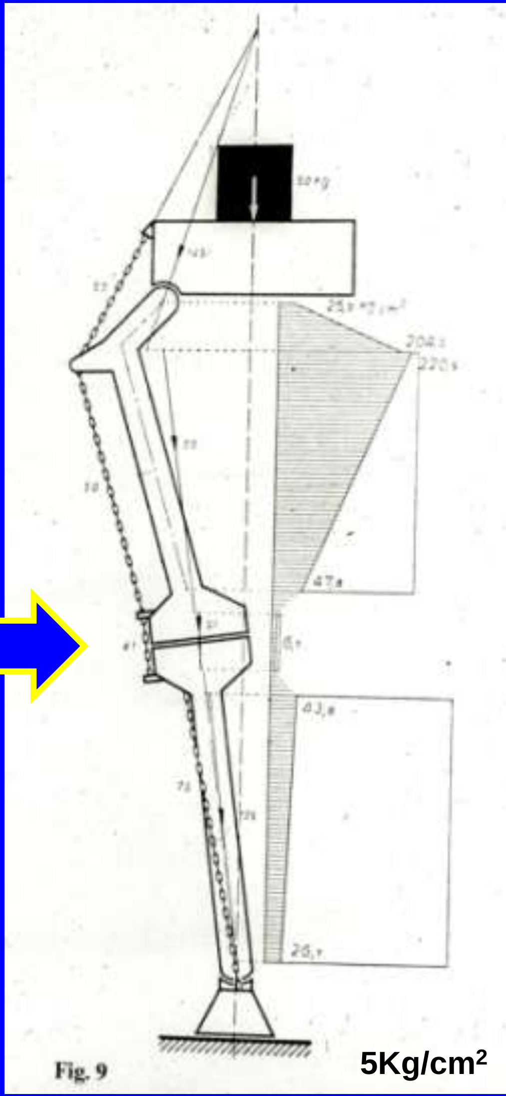
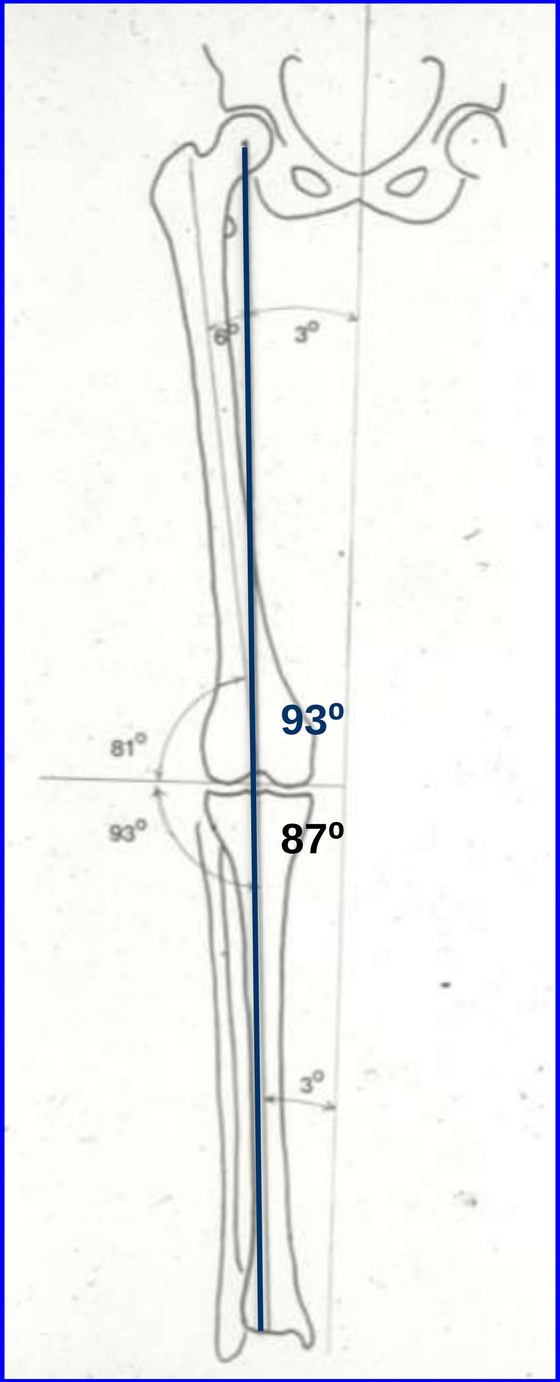


Fig. 9
5Kg/cm²



Legs are shaped to

To move the knee joint beneath the center of gravity,

to increase the contact area which transmits the body weight to the ground

And to allow a horizontal joint surface.

Which Brings us back to the Point of this First Talk

What is normal Alignment?
and
Where is a Limb Mal-alignment Deformity Located?

The **Mechanical Axis** is
a line drawn from
the center of the femoral head
to
the center of the talus

It normally passes through the knee joint a few mm medial to the center of the knee joint

This is Slight Varus

The Normal Limb has the knee joint moved toward the center line of the body

by inclining the mechanical axis inward from the vertical

by a valgus tibial femoral angle

with a horizontal joint line.

Normal Alignment

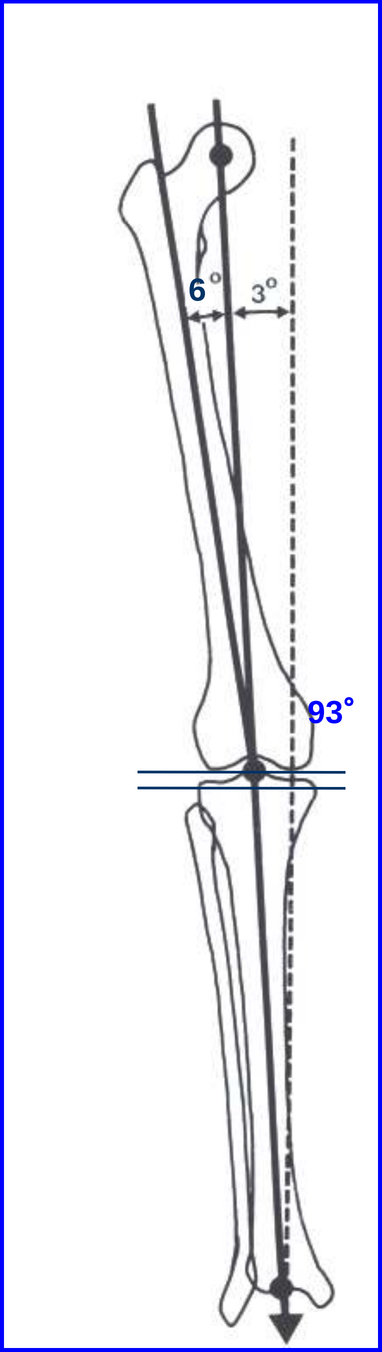
Mechanical Axis goes through the center of the knee

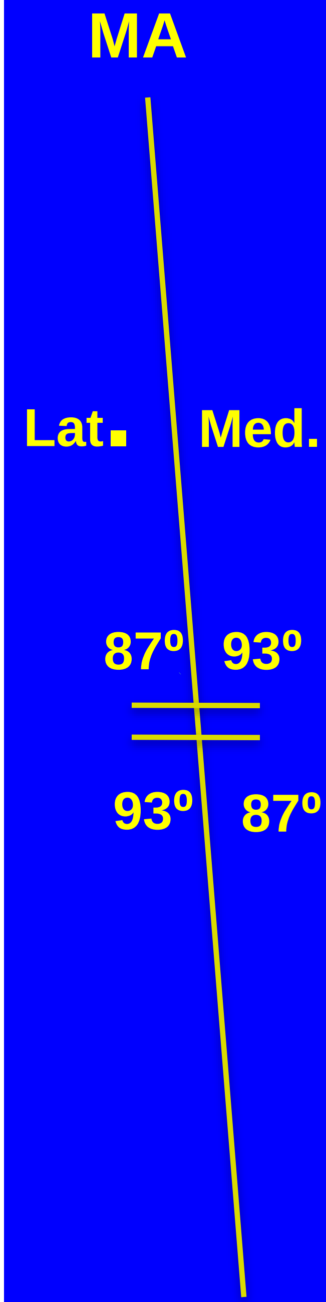
Mechanical Axis = 3^{o} from Vertical

Joint Line is Horizontal

Therefore the Angle Between Femoral Head & Distal Femur = 93^{o} on Medial Side

Proximal Tibia to Ankle = 87^{o} on Medial Side





To Understand Alignment Deformity

Ask 4 Questions

Answer 4 Questions!

1. Where is the Mechanical Axis?

2. Is the Deformity Varus or Valgus?

3. What is the Total Deformity?

4. Is the Deformity located in the Femur? Tibia? Joint?

Locate
Center of Head of Femur

1. Where is the Mechanical Axis?

Locate the Center of the talus

Connect Center of Femoral Head to Center of Talus

This is *Mechanical Axis*

***2.* Is it Varus or valgus?**

***If* Varus it is Medial to Knee**

***If* Valgus it is Lateral to Knee**

Varus

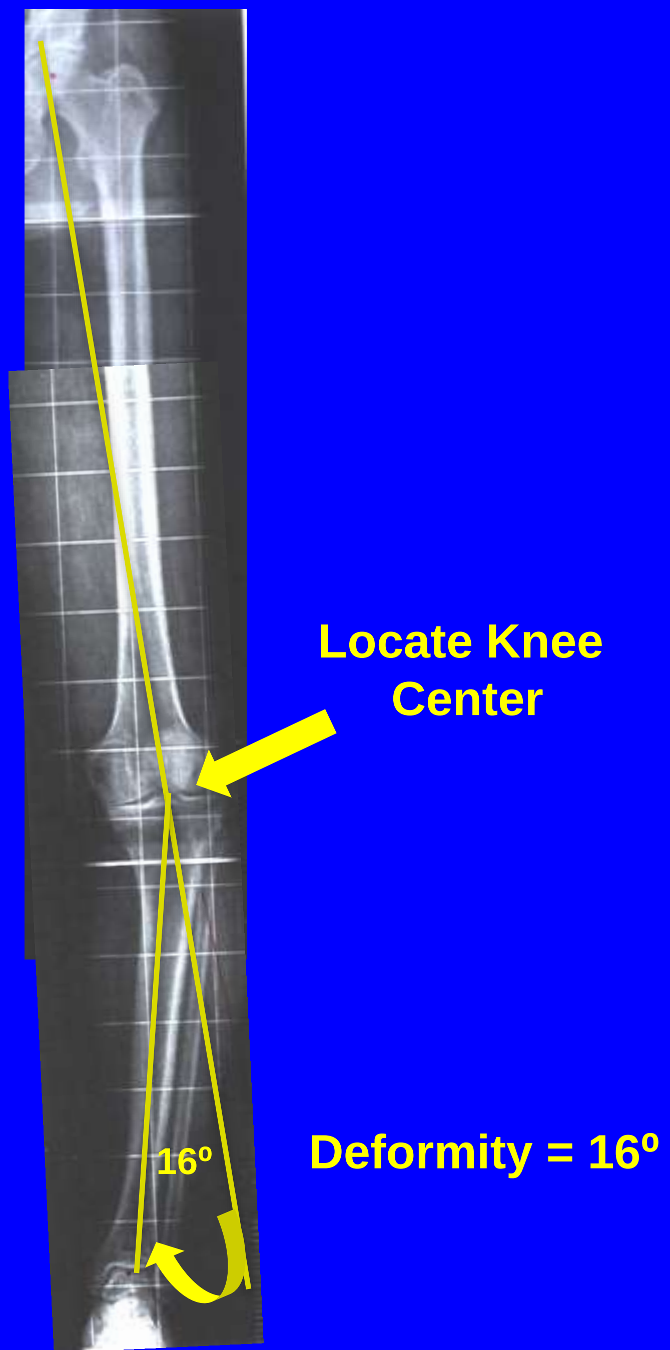
The Mechanical Axis is Medial to The Knee Joint center

3. What is the Total deformity?

Draw a Line from Hip Center through the Knee Center

Draw a 2nd Line from Knee to Ankle Center

The Angle between these lines is the Total Deformity



Is there a Deformity in the Joint?

Draw Line Tangent to Distal Femur
Draw line Tangent to Proximal Tibia

This is Angle of Deformity at the Joint

Joint Deformity
May be Ligament Laxity
May be Cartilage Loss
May be Both

Question 4:
Is the Deformity in Femur or in Tibia or in the Joint?

Draw line from Hip Center to Distal Femur Center on the Tangent Line
Should be 93^{o} (on Medial Side)

Step 7

Draw Line from Ankle Center to Knee Center on the tibial tangent line
Should be 87^{o} (on Medial Side)

Normal:
Medial Femur = 93^{o}
Medial Tibia = 87^{o}
Joint = 0^{o}

This Case:
Femur: 93^{o}-87^{o}=6^{o}
Tibia: 87^{o}-80^{o}=7^{o}
Joint: = 3^{o}

Total = 16^{o}
Deformity

Normal Limb:

Medial Femur = 93^o

Medial Tibia = 87^o

Joint = 0^o

This Case - the Deformity:

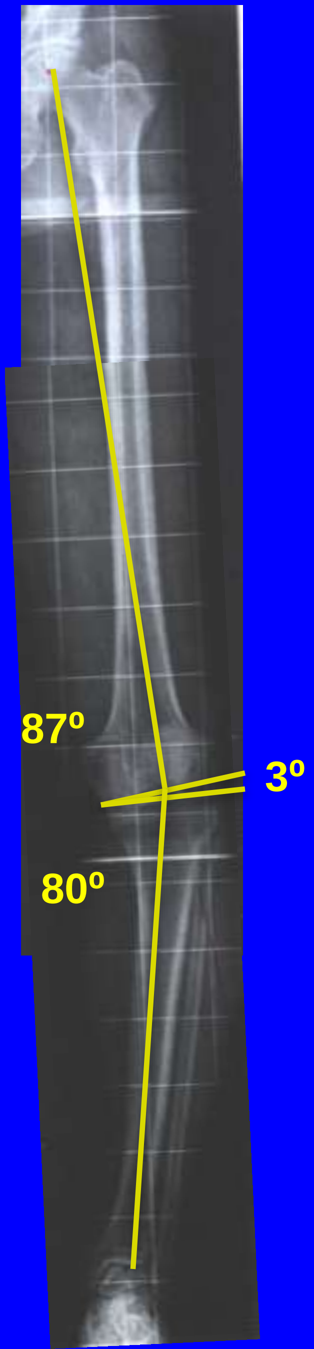
Femur: 93^o-87^o =6^o

Tibia: 87^o-80^o =7^o

Joint: = 3^o

Total = 16^o

Femur 6^o + Tibia 7^o + Joint 3^o



Summary of Deformity Analysis

Answer 4 Questions

1. Where is the Mechanical Axis?
2. Is it Varus or Valgus?
3. How Great is the Deformity?
4. Is the Deformity in the Femur?

   in the Tibia?

   in the Joint?

The Total Deformity = Femur + Tibia + Joint

Measure and Locate the Deformity in 6 more cases

Case 2

Where is the Mechanical Axis?

Where is the Mechanical axis?

Lateral

Obviously a Valgus Deformity

How Much is The Deformity?

19^o

Where is this 19^o Deformity?

Measure Femoral Deformity
Measure Joint Deformity
Measure Tibial Deformity

Case 2

Deformity 19^o

Femur (medial) = 119^o

119^o - 93^o = 26^o (valgus)

Joint = 2^o (valgus)

Tibia (medial) = 78^o

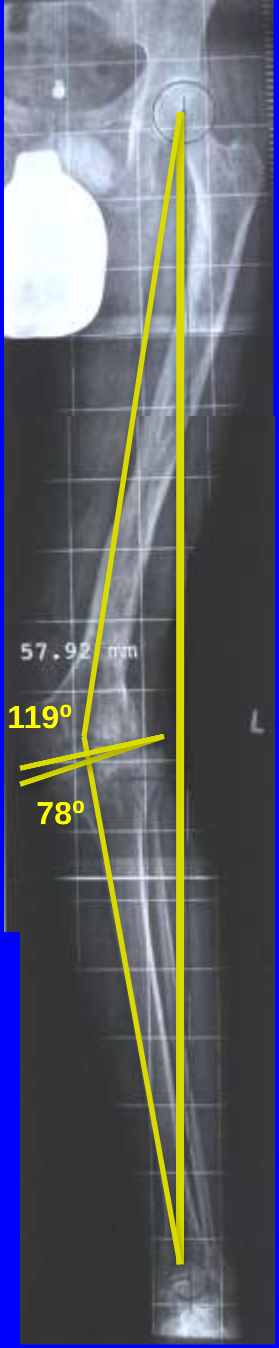
87^o -78^o = 9^o (varus)

Total: 26^o + 2^o - 9^o = 19^o

The Femur is in 26^o of Valgus

The Joint has 2° of Valgus

The Tibia is in 9^o of Varus



Case 3

What is the Deformity?

Case 3

Valgus Deformity

How Much is the Deformity?

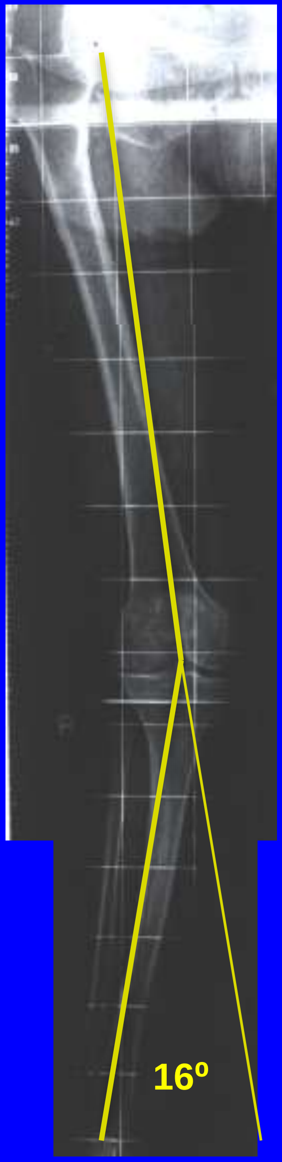
Case 3

Deformity = 16º

Valgus

(It is written that a valgus deformity should be corrected by a Distal femoral osteotomy. Is the deformity in the femur?)

Where is the Deformity?



Case 3

Valgus Deformity 16^{o}

Femur (medially) = 94^{o}

$94^{o} - 93^{o} = 1^{o}$ (valgus)

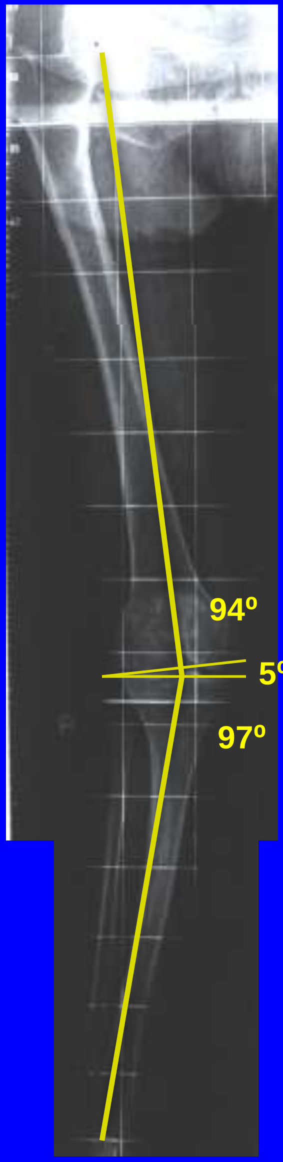
Joint = 5^{o} (valgus)

Tibia(medially) = 97^{o}

$97^{o} - 87^{o} = 10^{o}$ (valgus)

Total $1^{o} + 5^{o} + 10^{o} = 16^{o}$

Deformity is 1^{o} Femur, 5^{o} Joint, 10^{o} Tibia



Case 4

What is the Deformity?

Case 4

Varus Deformity

How Much Deformity?

Case 4

Deformity = 13^{o}

Where is the Deformity?

(Is HTO Indicated?)

Case 4
Varus Deformity 13^o

Femur = 88^o

$93^o - 88^o = 5^o$ (varus)

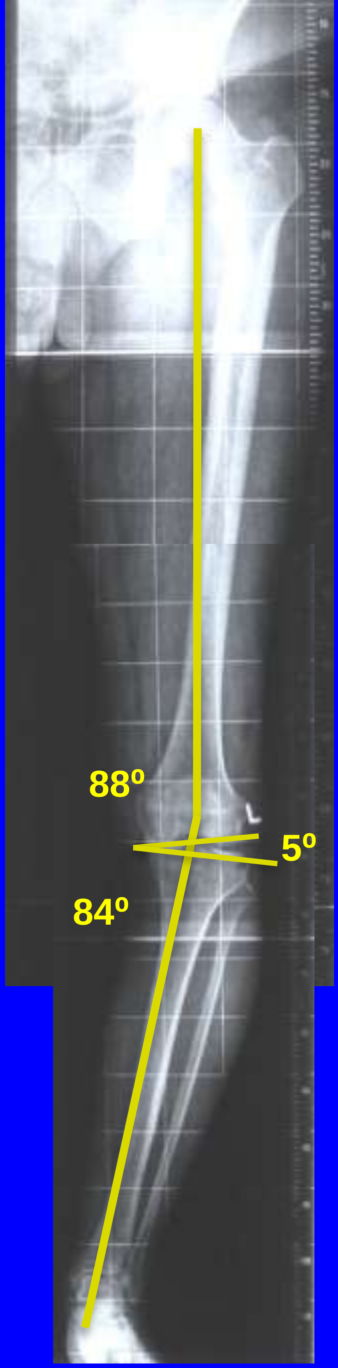
Joint = 5^o (varus)

Tibia = 84^o

$87^o - 84^o = 3^o$ (varus)

Total $5^o + 5^o + 3^o = 13^o$

Femur = 5^o+ Joint = 5^o+ Tibia = 3^o



Case 5

What is the Deformity?

Case 5

Valgus Deformity

How much is the deformity?

Case 5

Deformity = 32º

Where is the Deformity?

Case 5

Deformity = 32^{o} valgus

Femur (medially) = 87^{o}

$93^{o} - 87^{o} = 6^{o}$ (varus)

Joint = 4^{o} (valgus)

Tibia (medially) = 121^{o}

$121^{o} - 87^{o} = 34^{o}$ (valgus)

Total $-6^{o} + 4^{o} + 34^{o} = 32^{o}$

Tibia = $+34^{o}$, Femur = -6^{o}, Joint = $+4^{o}$

Tibia is Valgus

but

Femur is Varus

Case 6

Varus or Valgus?
How much?
Where?
Femur?
Joint?
Tibia?

Case 6

Mechanical Axis Varus

How Much Varus?

Case 6

15^{o} Varus

Where is the Deformity?

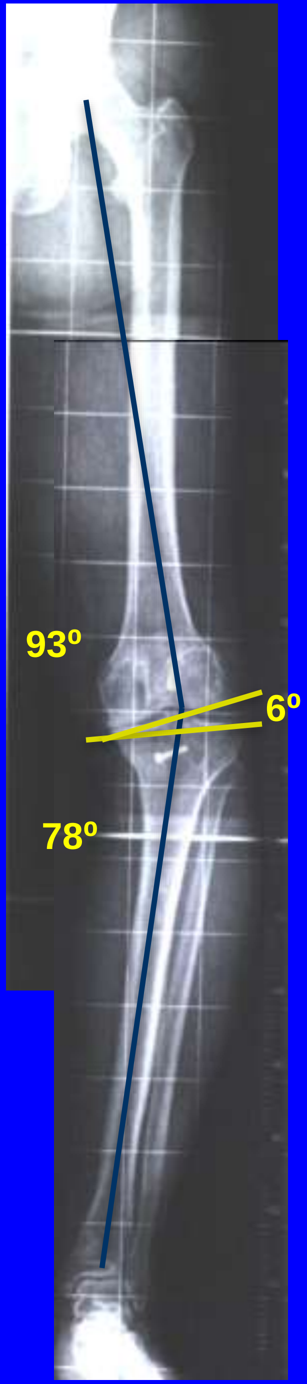
Femur?
Joint?
Tibia?

Case 6

Deformity 15°

Femur (medially) = 93°
no deformity
Joint = 6° (varus)
Tibia (medially) = 78°
87° - 78° = 9° (varus)

Total 0° + 6° + 9° = 15°
Femur 0° + Joint 6° + Tibia 9°



76 Yr Male After Revision Total Knee Recurrent Dislocation Patella

Unstable –Can’t Walk Patella stays Dislocated

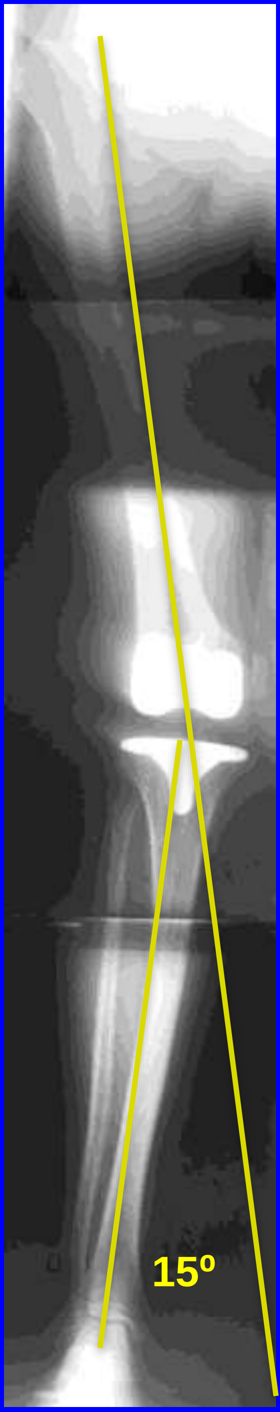
Dislocating Patella after Revision TKA

Recurrent Dislocation Patella

What is Alignment?

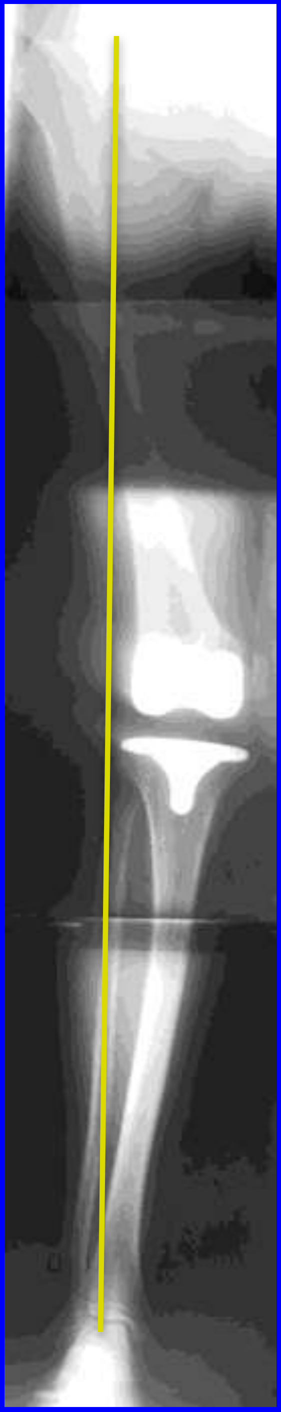
Valgus

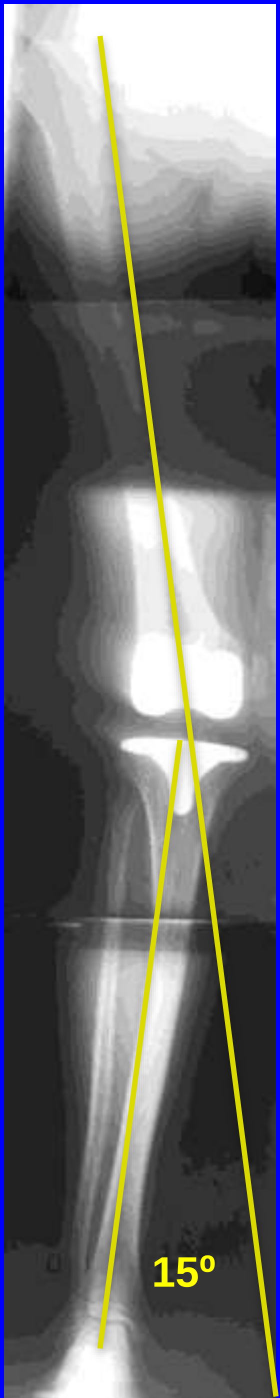
How Much?



Recurrent Dislocation Patella

15^{0} Valgus Deformity

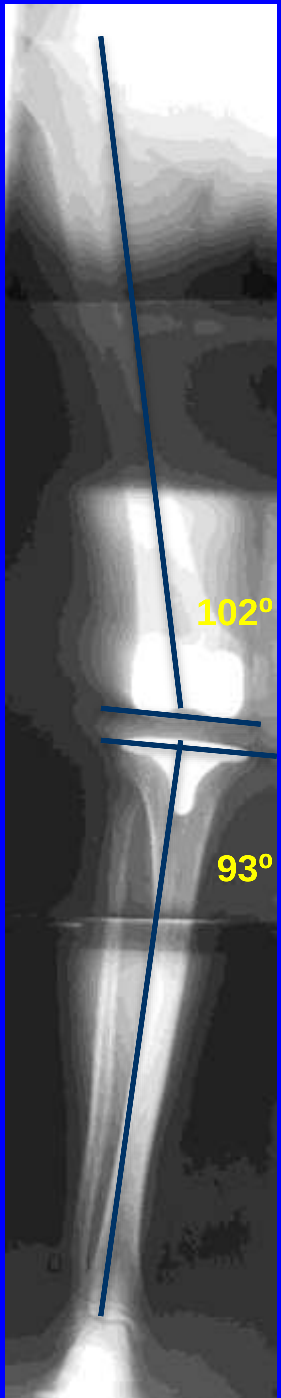


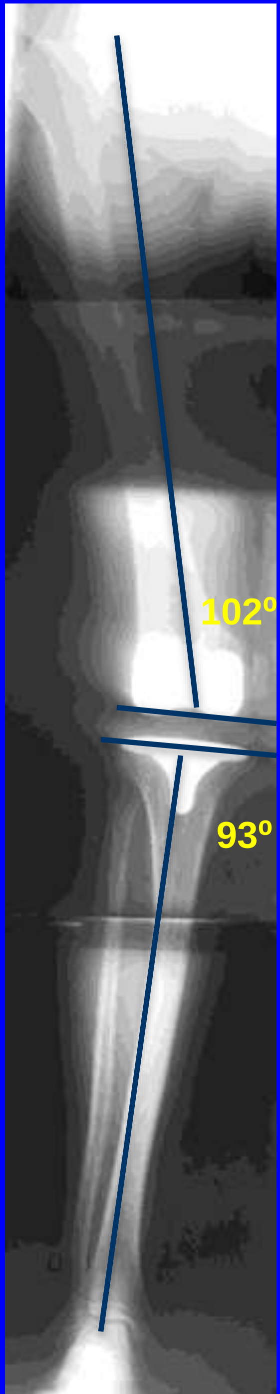


Recurrent Dislocation Patella

Where is the Deformity?

Femur = 93º - 102º = 9º
Joint = 0º
Tibia = 93º - 87º = 6º





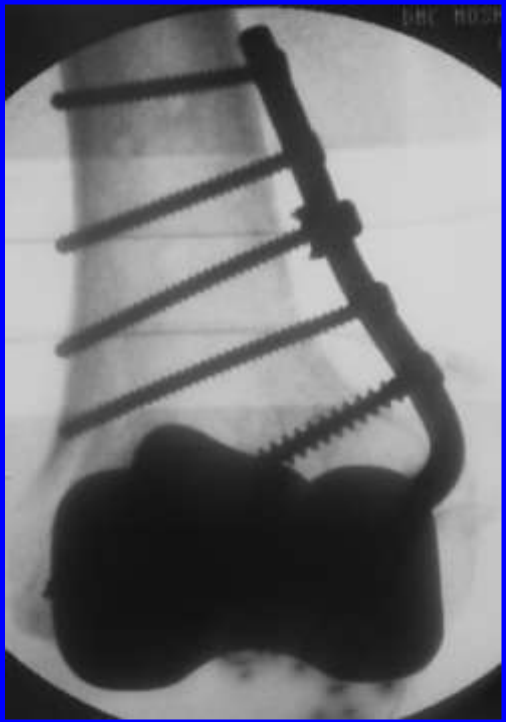
Deformity

Femur = 93° - 102° = 9°

Joint = 0°

Tibia = 93° - 87° = 6°

Femur 9° + Joint 0° + Tibia 6°



Correct by

Osteotomy Femur 9°

+

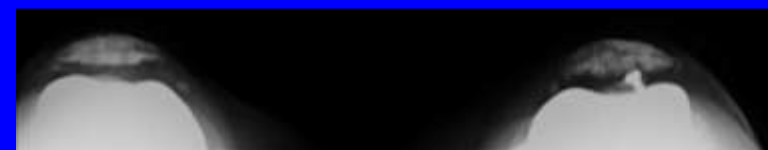
Osteotomy Tibia 6°

+

MPFL Reconstruction

Very Happy with result

11 mo Post Op



Double Osteotomy for Patellar Dislocation

Summary

Deformity Calculation

1. Draw the Mechanical Axis
2. Calculate the Total Deformity (Angle from Hip-Knee-Ankle)
3. Draw the Joint Deformity (Angle Bottom Femur & Top Plateau)
4. Draw the Femoral Deformity
5. Draw the Tibial Deformity
6. Add: Femoral Deformity + Joint Deformity + Tibial Deformity = Hip-Knee-Ankle Angle (= Total Deformity)

Osteotomy
There are many ways to Plan

Objective is to have the Mechanical Axis pass through the knee joint so the body weight loads the healthy compartment and unloads the arthritic compartment

One Plan: Move the Mechanical Axis to where you would like it to be
Surgeon’s Choice

Planning Osteotomy

1. **Decide which bone you want to correct - Femur or Tibia? You must know where the deformity is!**
2. ***Draw a new mechanical axis* where you want it to pass through the knee joint – surgeon's choice - For correction on the femur draw from the talus through knee. For a correction on the Tibia draw from the femoral head center through the knee joint**
3. **Decide where you want to put the osteotomy – surgeon's choice Normally put osteotomy where the deformity is. Mark the apex of the correction.**
4. **Femoral Osteotomy: Draw from the femoral head to the apex of correction angle. Draw a second line from the apex of correction to the new mechanical axis the same distance away.**
5. **Tibial Osteotomy: draw from the Talus to the apex of correction to the new mechanical axis.**

One Method:

1. Draw the New (Desired) Mechanical Axis
2. Select the location for osteotomy,
3. Select the location for the apex of the cut.
4. Draw Lines from the Talus Center to the apex of the correction angle then from the apex to the new mechanical axis

This is the correction angle

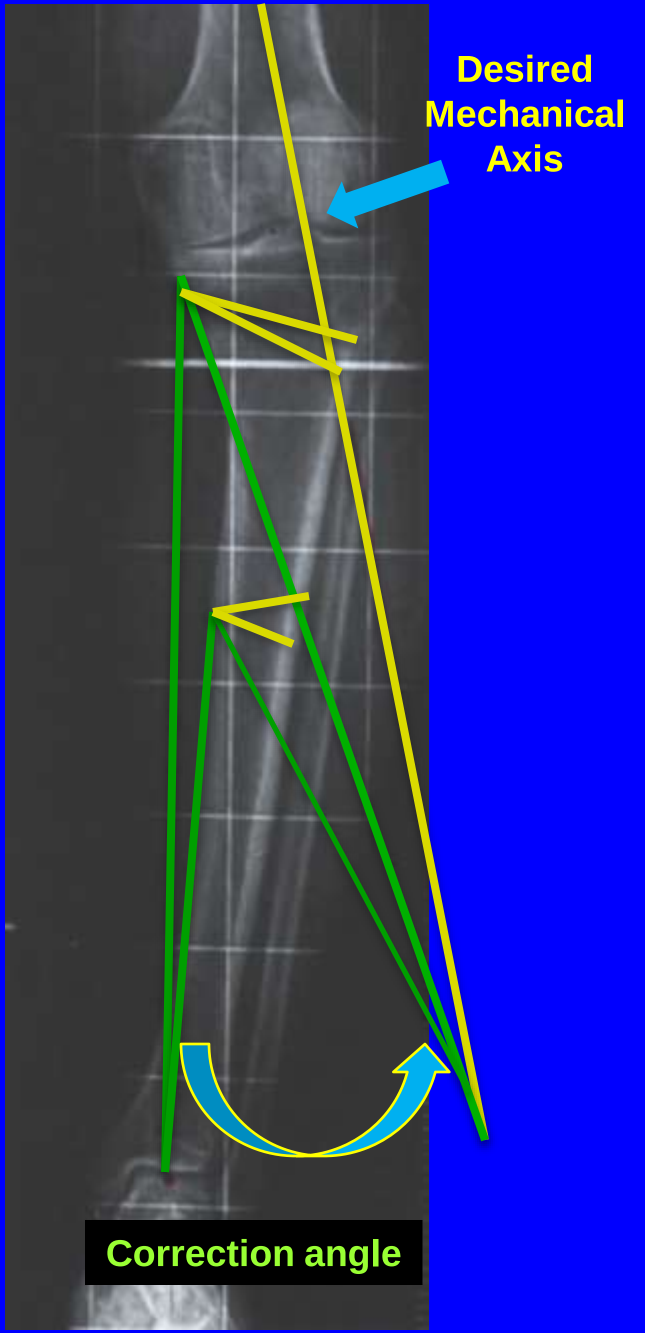
To Determine the Angle needed for correction Closing Wedge:

1. Select the *location for the osteotomy*. Select the point about which fragments will be rotated (the apex of the angle of correction).

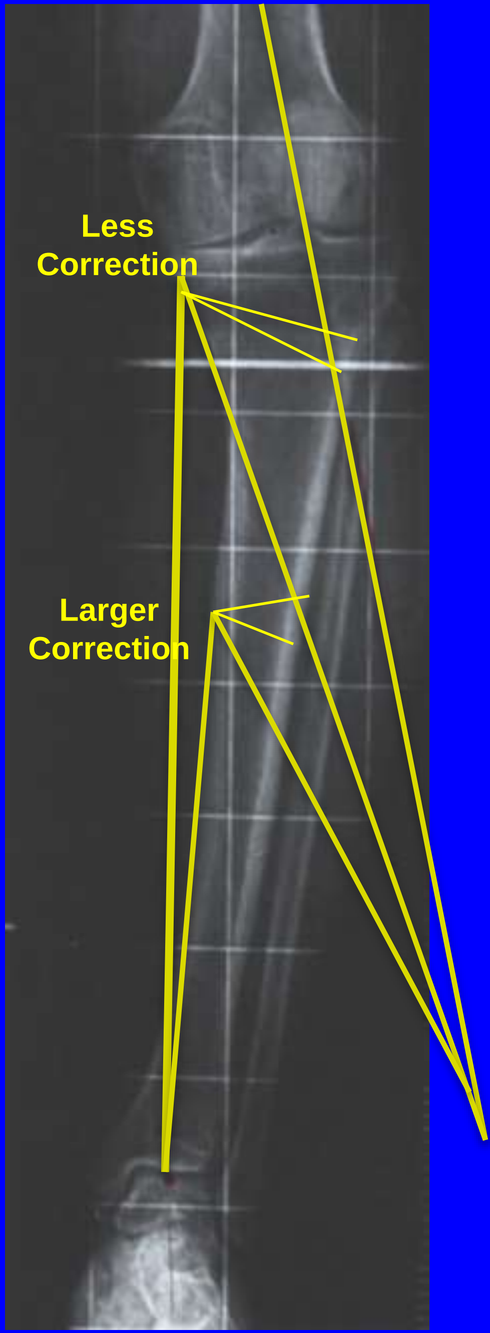
2. Draw the *desired mechanical axis*. Where do you want the new mechanical axis to cross the knee joint?

3. Draw lines from the center of the talus to the pivot point (apex of correction angle) and from the apex to the intersection with the new mechanical axis.

This is Correction angle



The Farther The Osteotomy is from the Deformity The Larger the Correction Needed



For Correction at the *Femur* – Draw the New (Desired) Mechanical Axis from the Talus through the knee joint proximally

The Correction Angle is From the Femoral Head to Osteotomy Apex to New Mechanical Axis

For Closing Wedge Moving into Valgus Apex is on Medial Side

For Opening Wedge Moving into Valgus Apex is on the Lateral Side

Summary Osteotomy Planning

Objective: Restore Normal Alignment
+ 2-4^{o}Overcorrection

- You Can Not Correct the Joint Deformity with Osteotomy , To compensate for a Joint Deformity add extra deformity to the osteotomy
- Pick the bone (Femur or Tibia) with the Most Deformity
- Double Osteotomy often good choice when deformity in both Tibia and Femur

Conclusion

- Osteotomy attempts to provide a mechanical solution to a biological failure

- Goal is to put the Mechanical Axis through the center of the knee slightly more to the healthy side

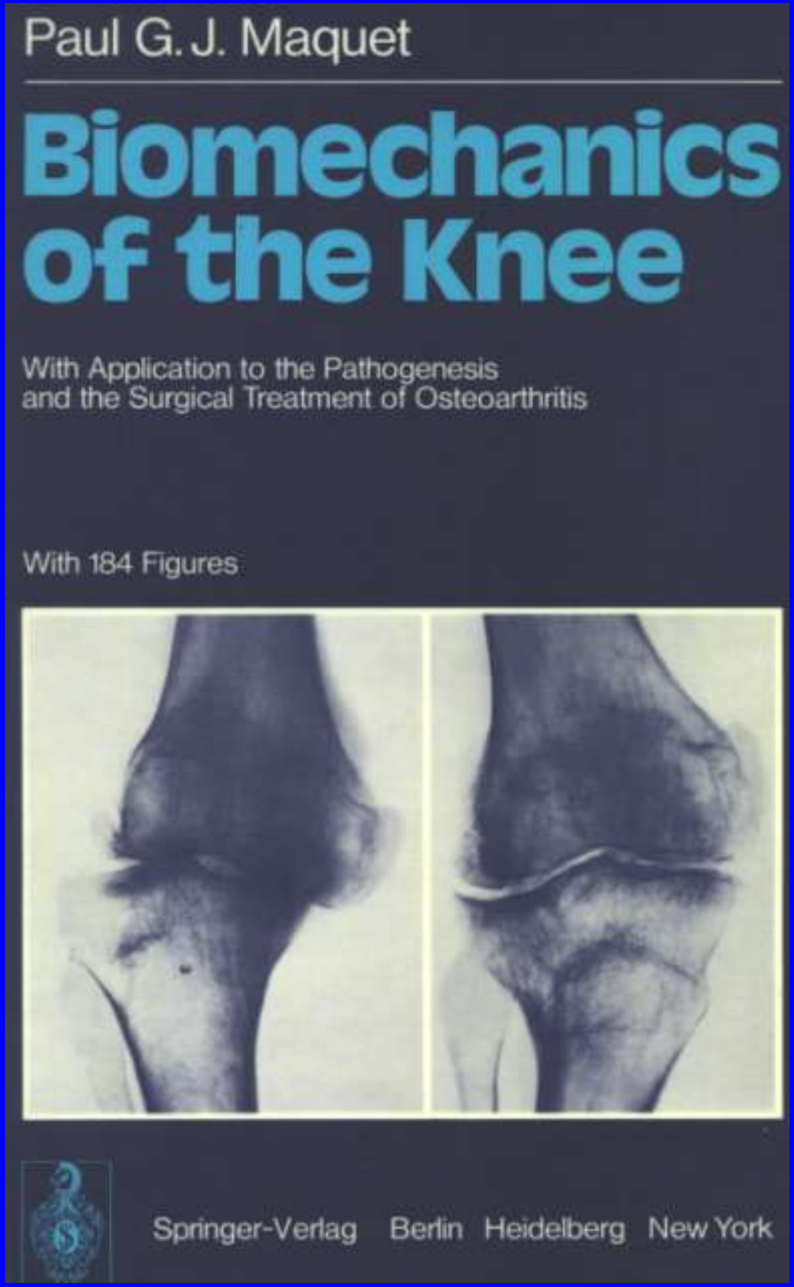
Stop

- **Pauwels worked in Aachen**
- **Maquet worked in Liege**

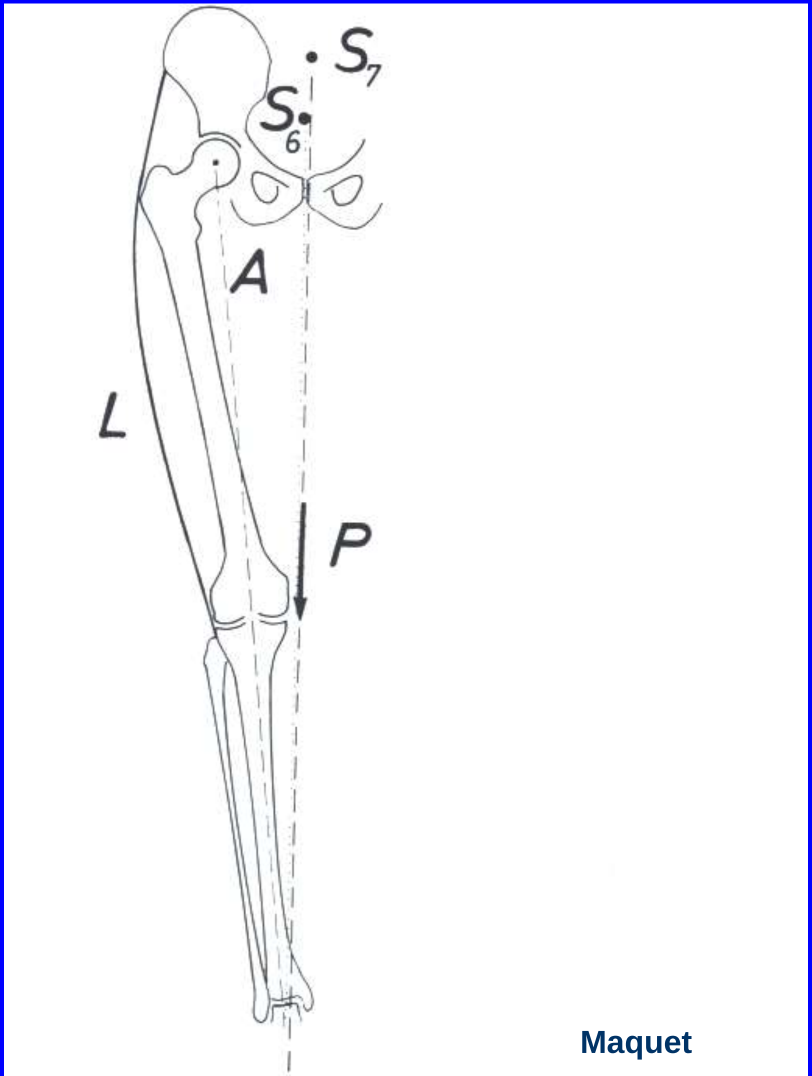
20 Km apart

- Paul Maquet as a young surgeon routinely reviewed his cases with Pauwels.

- Maquet's Book is a masterpiece of understanding limb alignment.



Forces Crossing the Knee



P is the Weight Bearing line (the “P” Vector)

L is the lateral muscle vector

A is the Mechanical Axis

S_7 is the Center of Gravity of the Body

S_6 Center of Mass standing on one foot

R = P + L

(R = resultant vector acting across the knee joint)

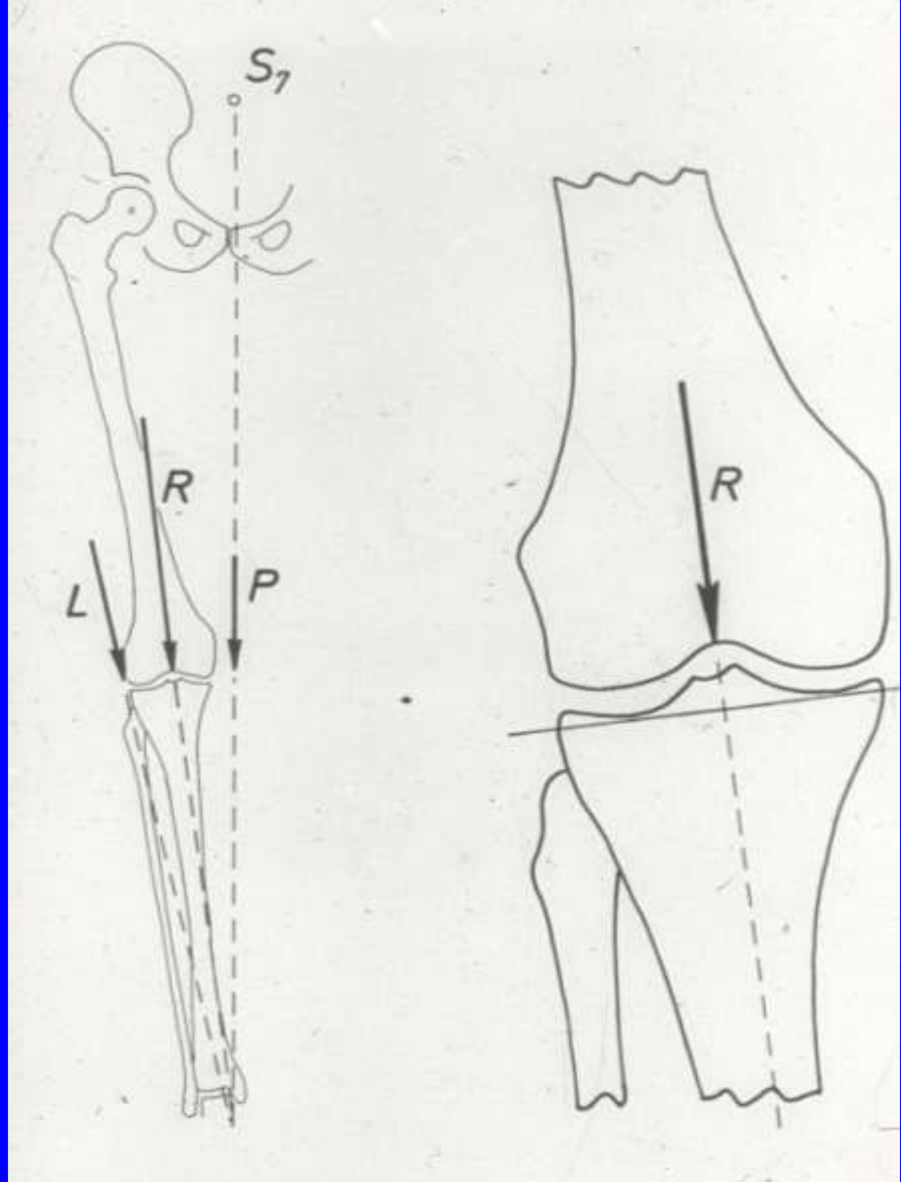
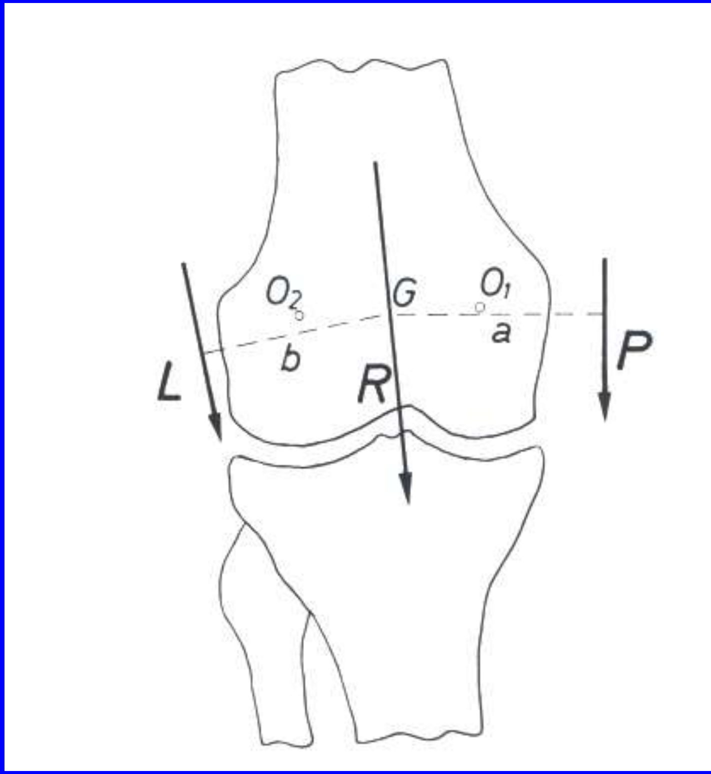


Fig. 72. Normal knee. Force *R* acts at right angles to the plane tangential to the tibial plateaux

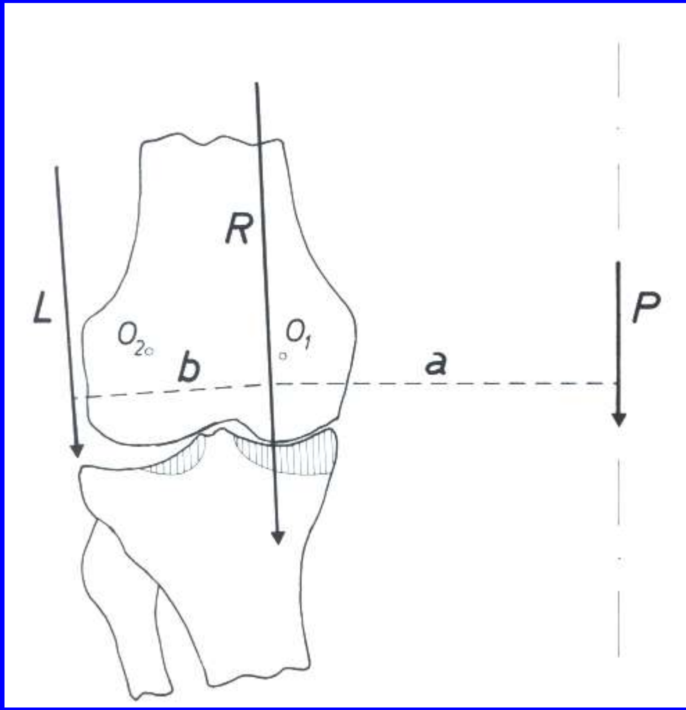
Maquet

P (body weight) and L (lateral muscle pull) combine to yield resultant R

Normal R @ medial spine

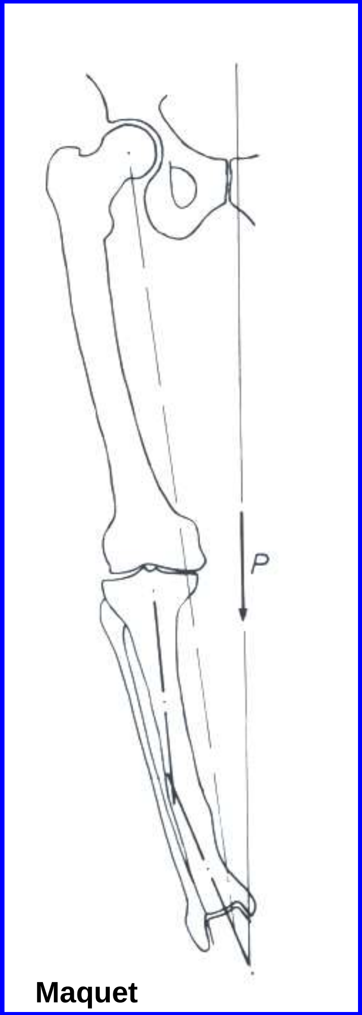


Too Much Weight 'P'
Or
Too Little Muscle 'L'



Maquet

“R” Shifts Medially



- Varus Malunion
- Congenital Varus
  - Femur
  - Tibia
- Lat Ligament Laxity
- ACL Laxity
- Medial Cartilage Loss

Pauwels' Challenge: Begin with a Column *and* Design a Lower Limb

Calculations based on 50 kg centered on a 5cm^2

In this drawing force = *10 kg/cm^2*

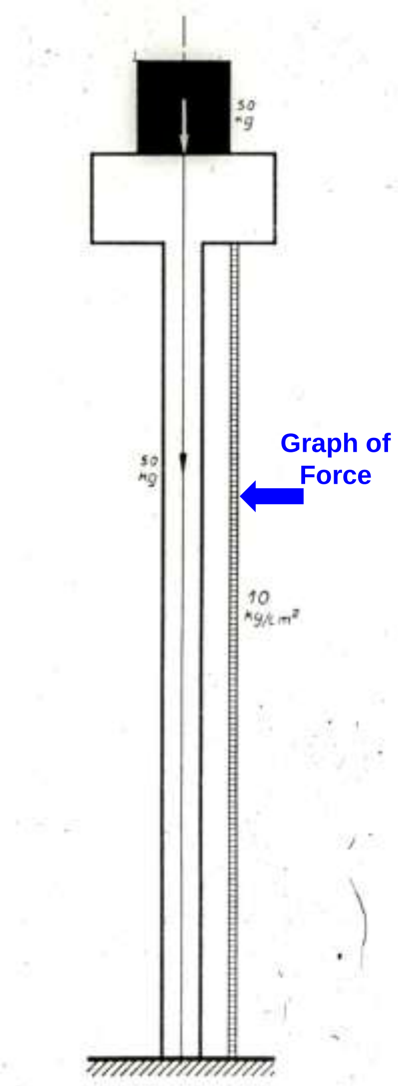


Fig. 1

Two Limbs

=

Half the Load

5kg/cm²

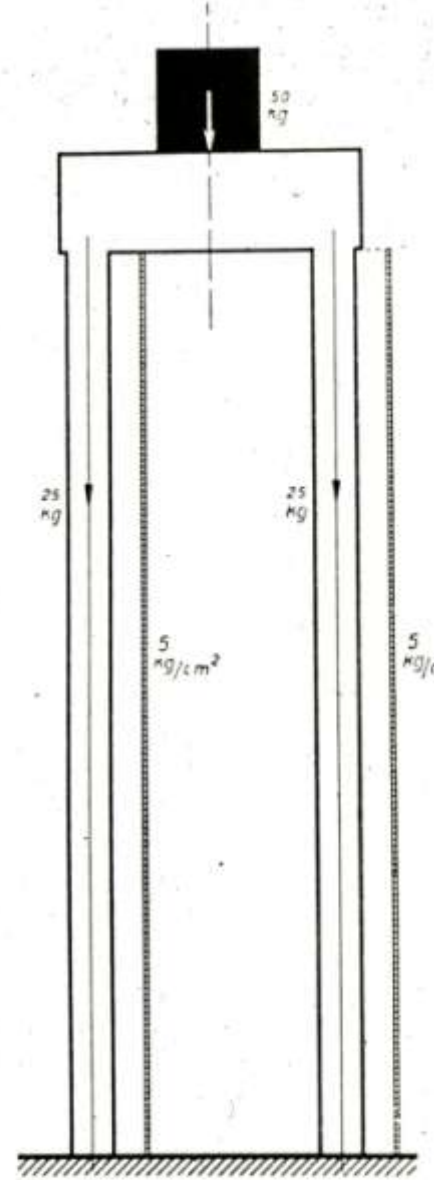


Fig. 2

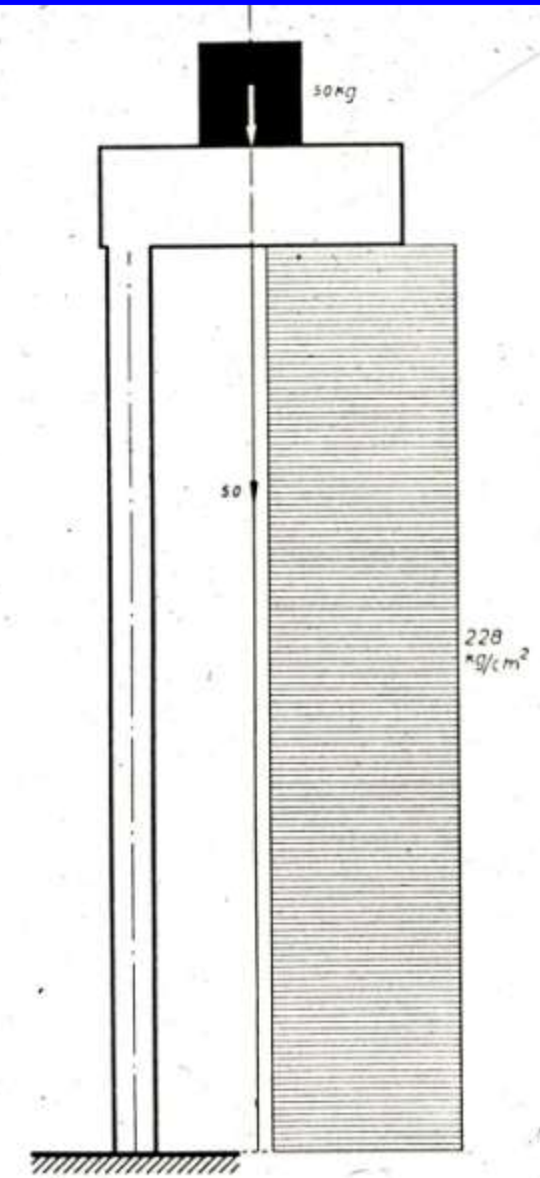


Fig. 3

Adding a Hip increases the load in the column 35 times

353kg/cm^2

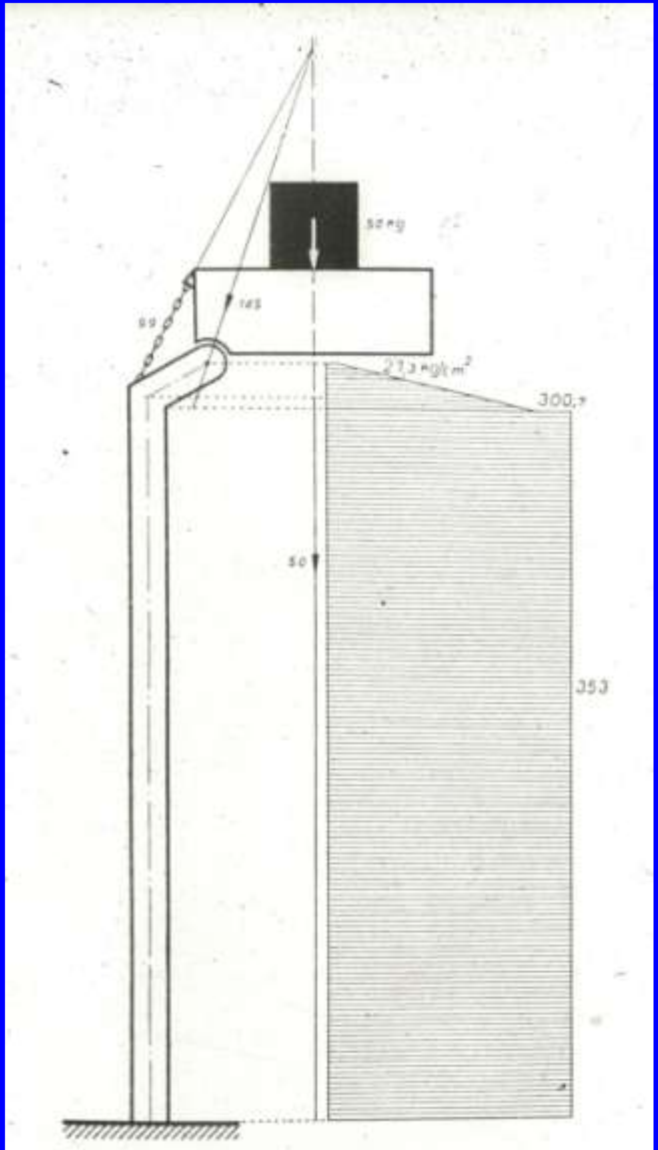


Fig. 4

Adding a Knee Joint decreases the load in the column 5 times but shifts it to the Ligaments

77kg/cm²

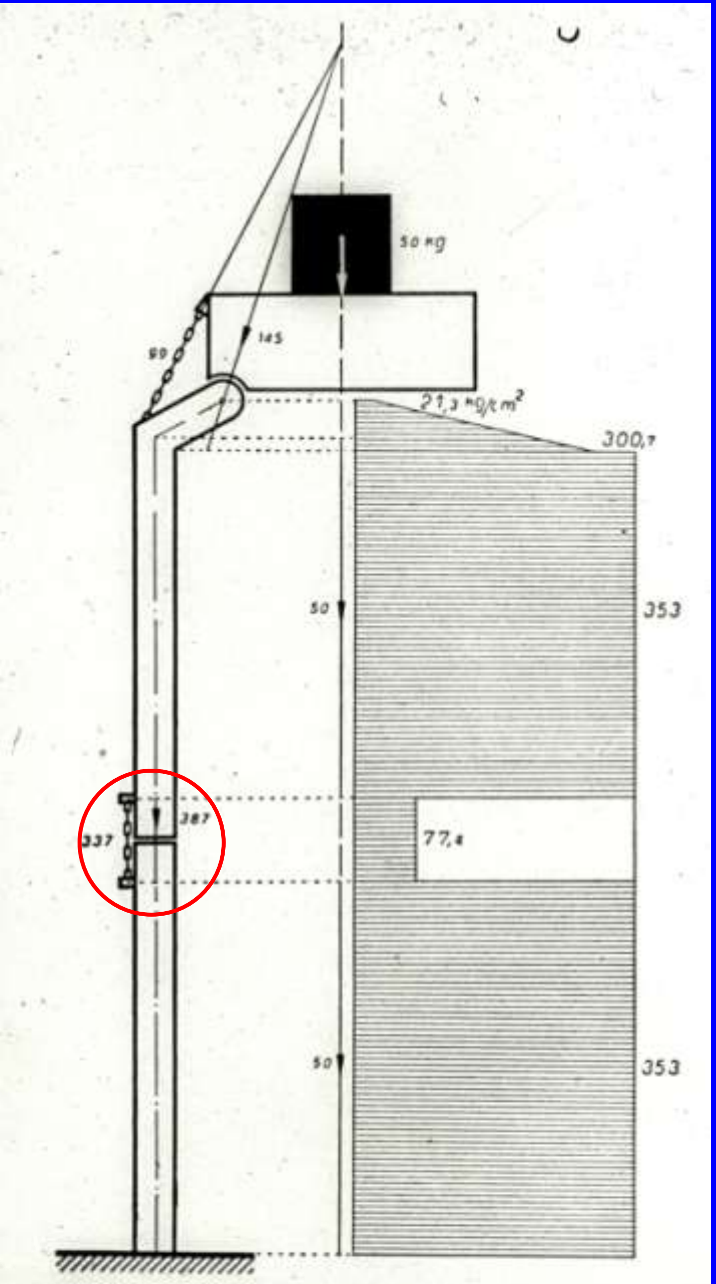


Fig. 5

Increasing Knee Surface Area decreases Unit Pressure and Ligament Tension

$12 kg/cm^2$

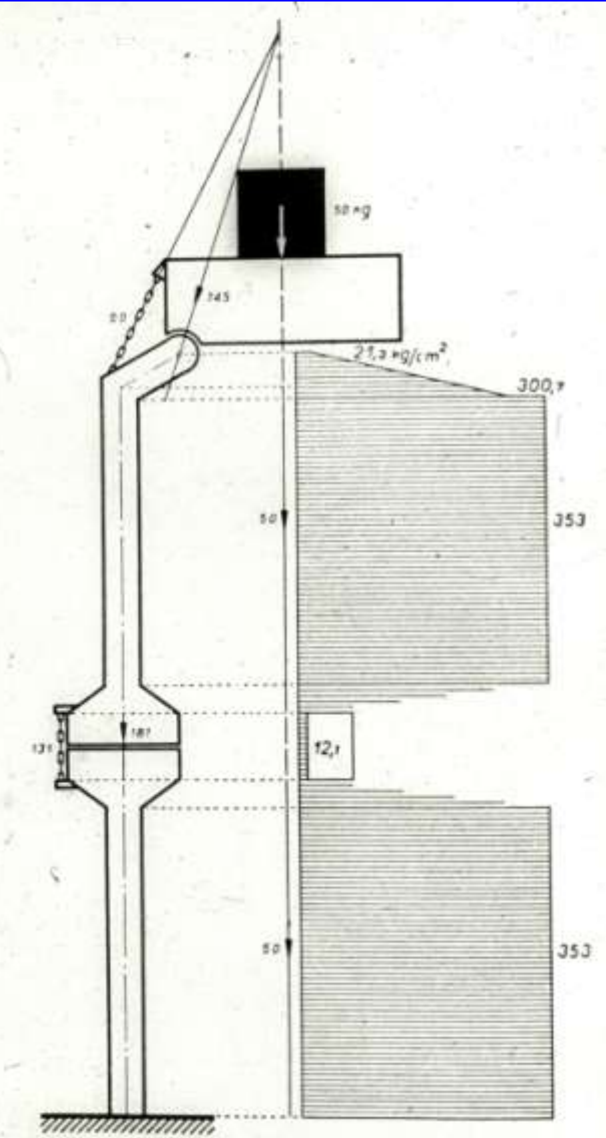


Fig. 6

Adding Lateral Tension Bands and Trochanter decreases the unit load in the column

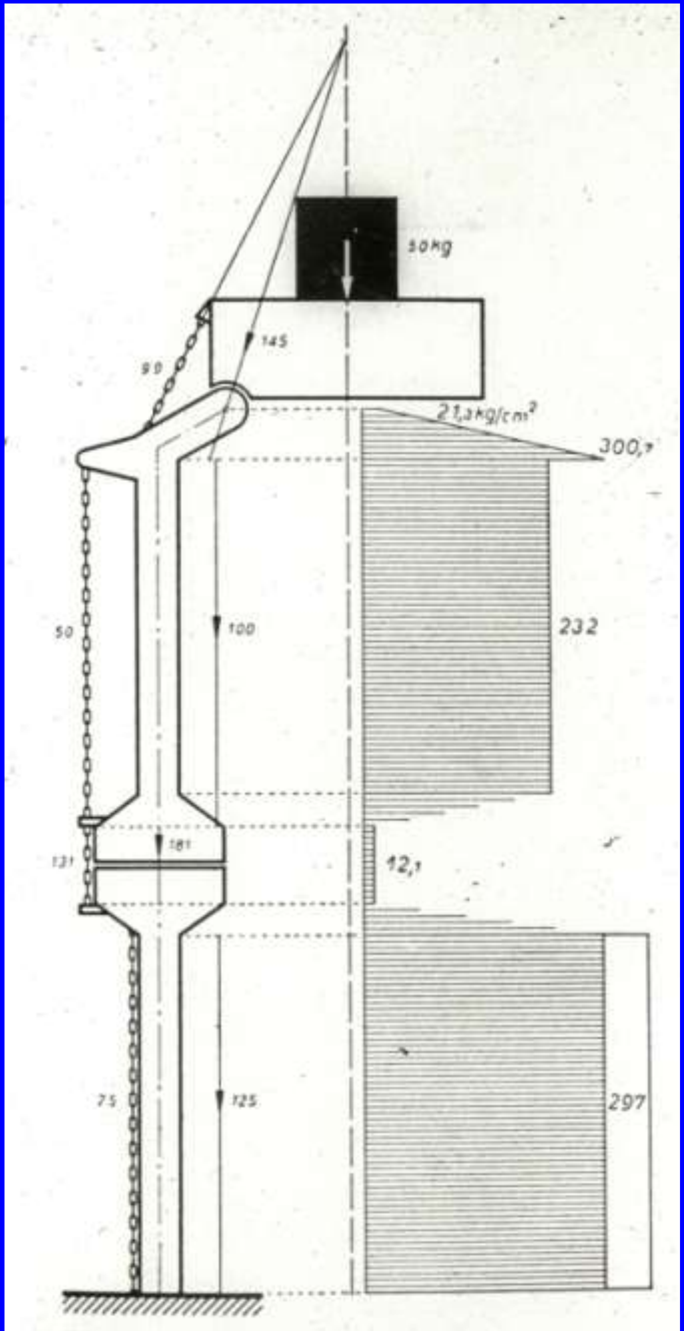


Fig. 7

Inclining the limb markedly decreases both unit loads and ligament tensions

(Need a subtalar joint)