Kantonsspital Aarau

Department of Orthopedic Foot Surgery

Gait Laboratory

Forces Acting in the Forefoot During Normal Gait – A Clinical Application

Wyss Ch., MD, Department of Orthopedic Surgery Kantonsspital Aarau

CH-5001 Aarau (Switzerland)

christian.wyss@ksa.ch

Für Christian

von Hilaire

Dez. 2003

BIOMECHANICS OF THE FOREFOOT

Thesis presented for the Degree of Doctor of Philosophy

by

Hilaire A.C. Jacob

Department of Orthopaedic Surgery, BALGRIST

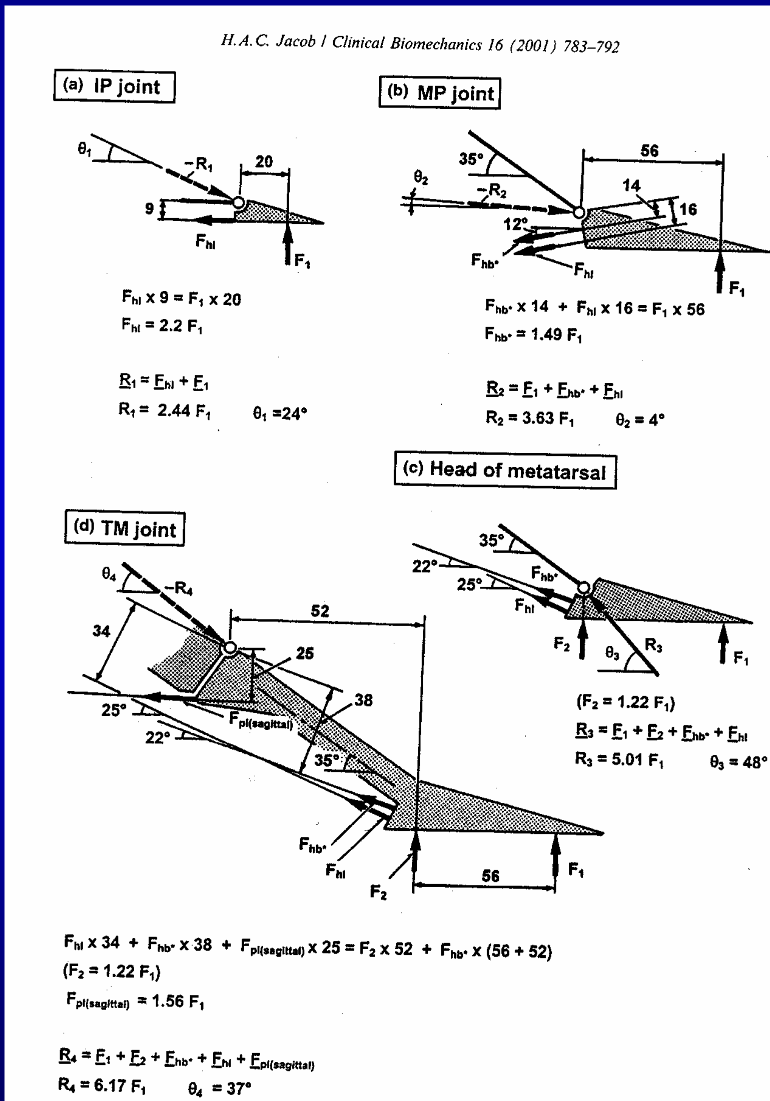
University of Zurich

Bioengineering Unit
University of Strathclyde
Glasgow

May 1989

Vol. I

A Basic Paper

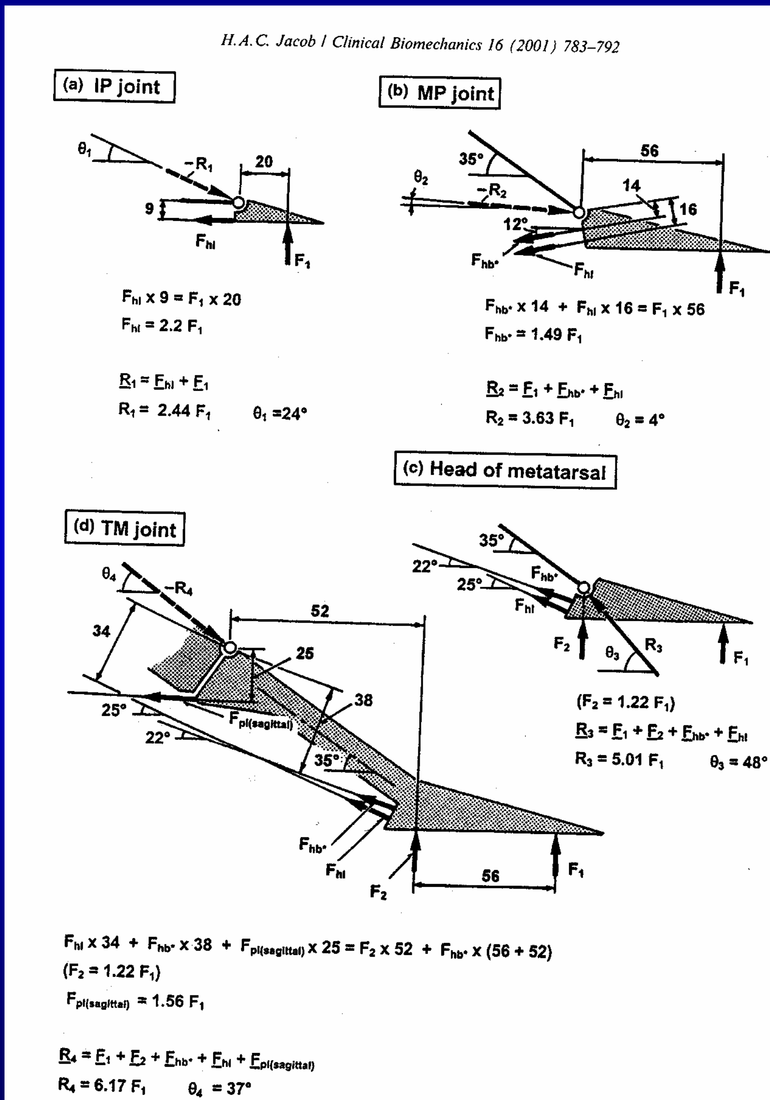


Jacob, H.A.C:

Forces acting in the forefoot during normal gait – an estimate

Clinical Biomechanics 16 (2001) 783 – 792

A Basic Paper



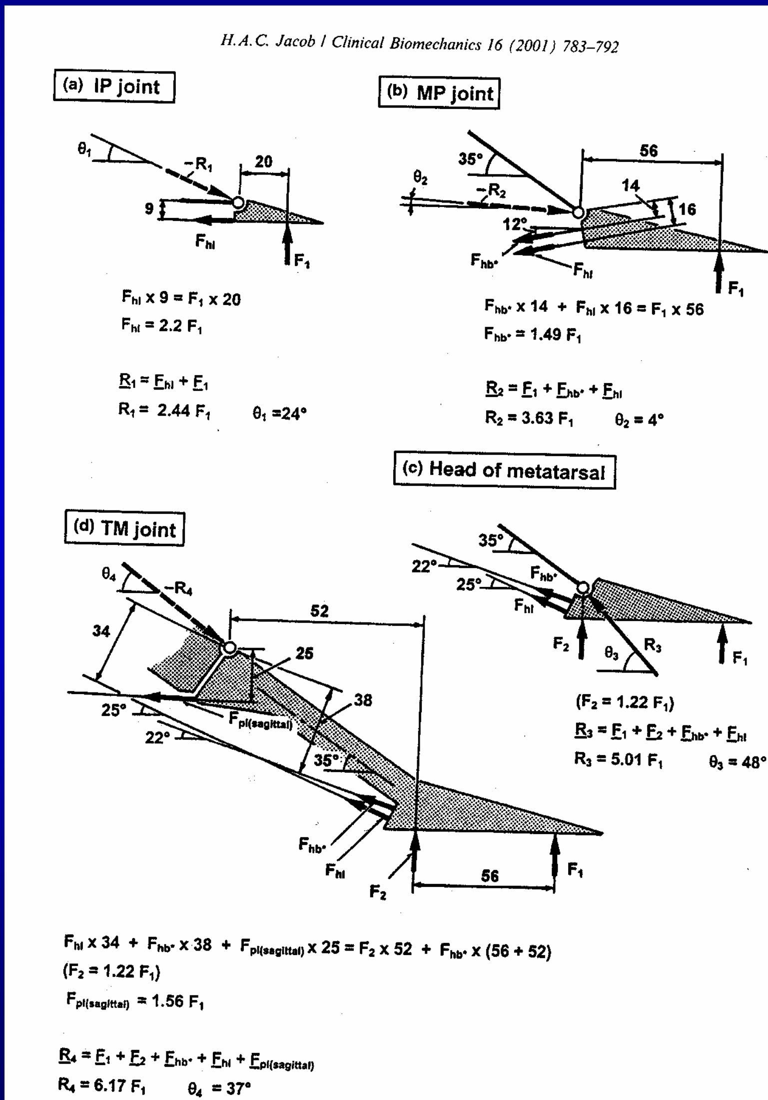
Jacob, H.A.C:

Forces acting in the forefoot during normal gait – an estimate

Clinical Biomechanics 16 (2001) 783 – 792

- static model of the 1st and 2nd ray

A Basic Paper



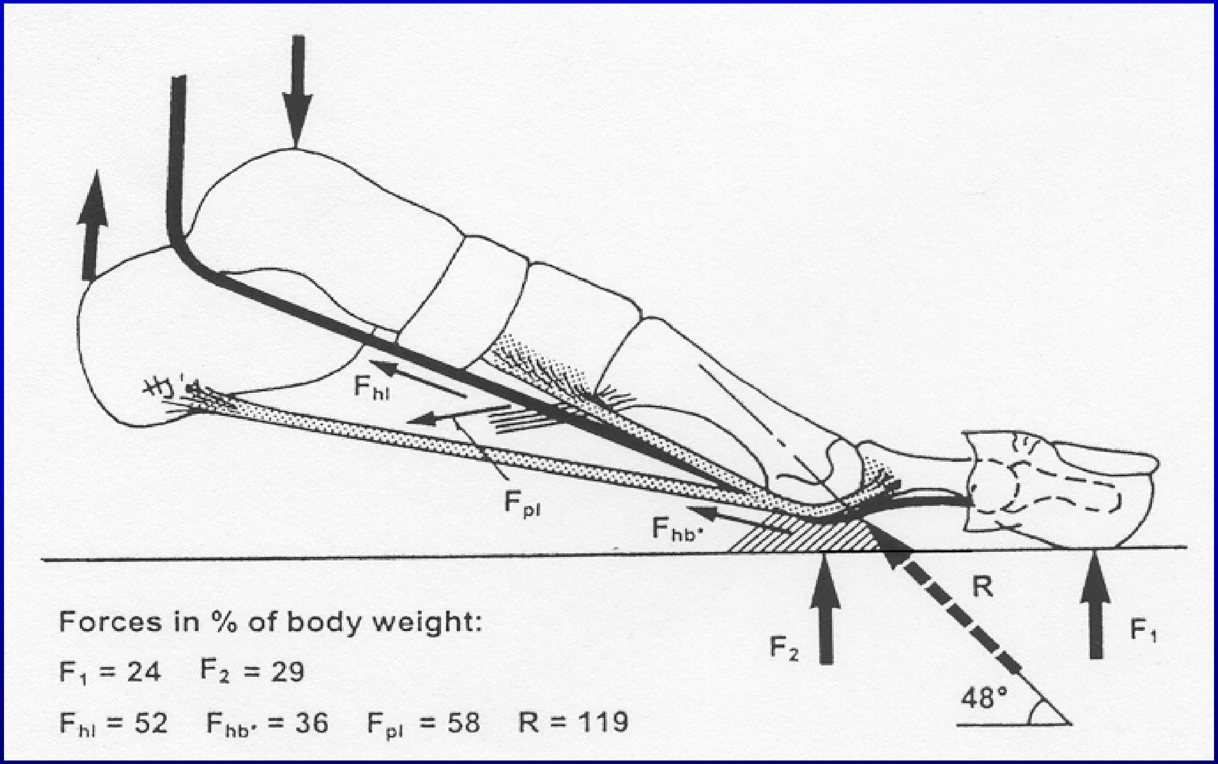
Jacob, H.A.C:

Forces acting in the forefoot during normal gait – an estimate

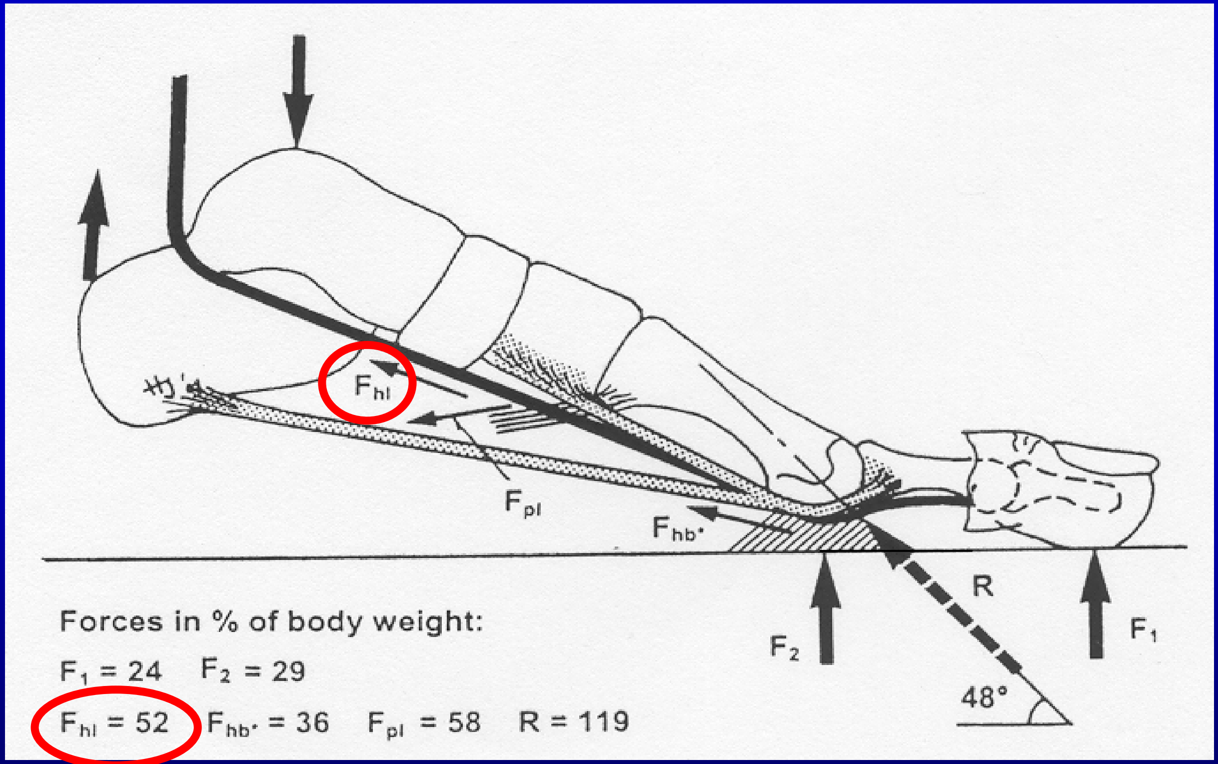
Clinical Biomechanics 16 (2001) 783 – 792

- static model of the 1st and 2nd ray
- only guilty for the push off

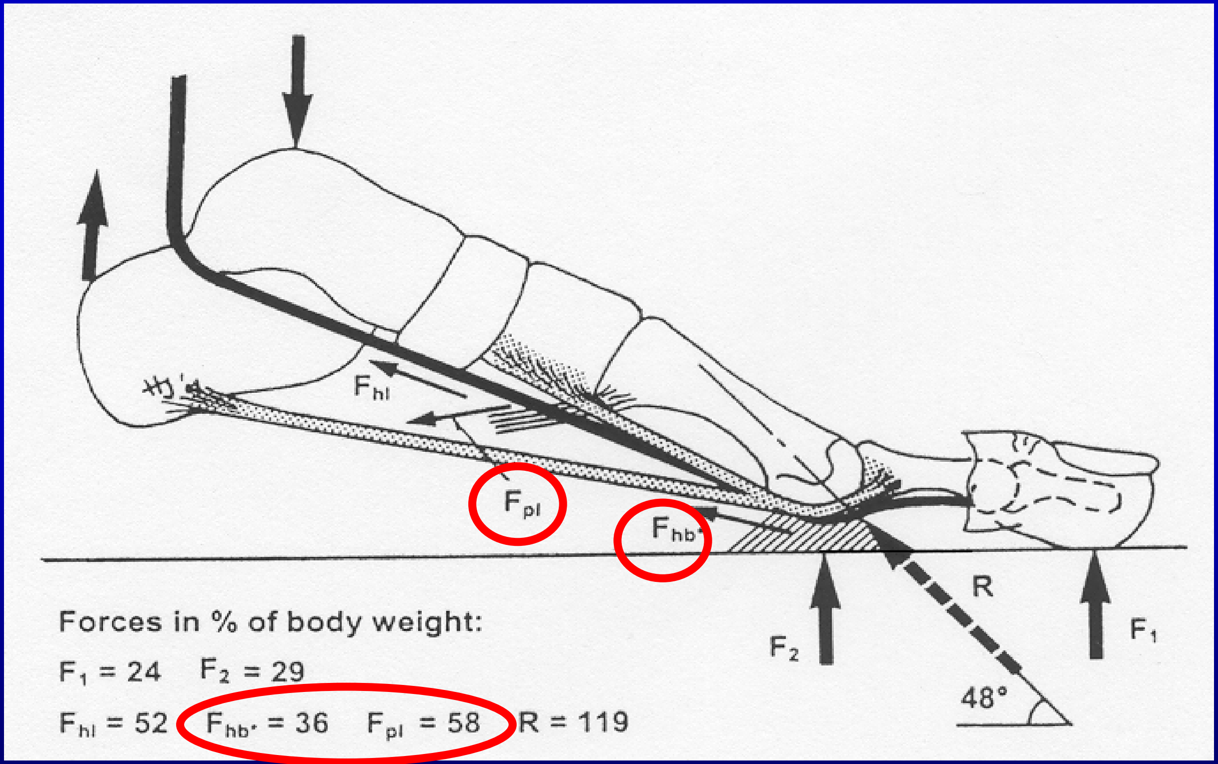
External forces, determined with dynamic pressure measurement, do not correspond to the forces which really act on the foot



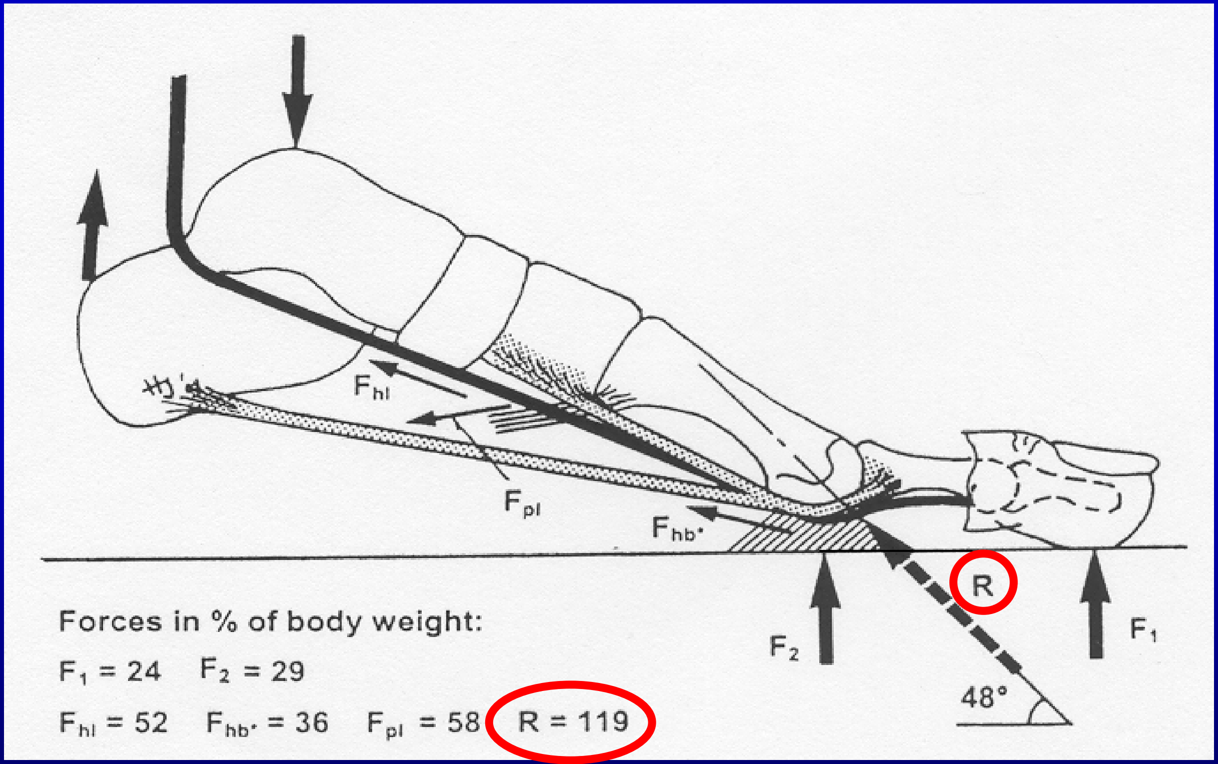
External forces, determined with dynamic pressure measurement, do not correspond to the forces which really act on the foot



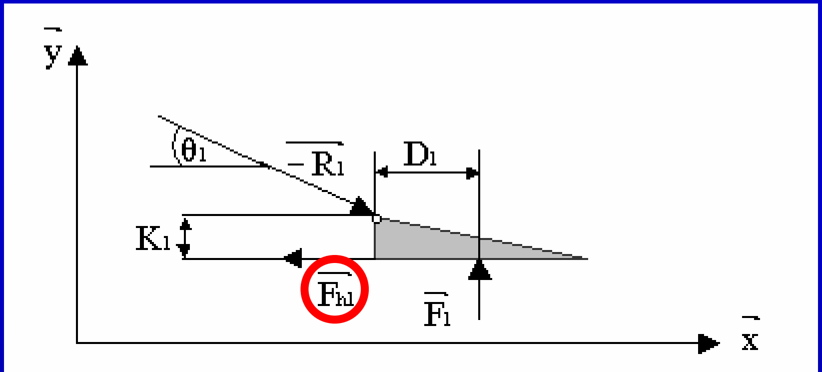
External forces, determined with dynamic pressure measurement, do not correspond to the forces which really act on the foot



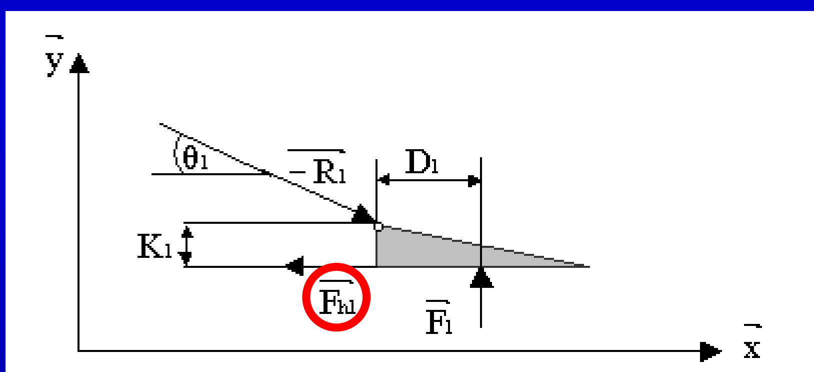
External forces, determined with dynamic pressure measurement, do not correspond to the forces which really act on the foot



Free Body Diagram for the IP Joint of the 1st Ray



Free Body Diagram for the IP Joint of the 1st Ray



Conditions of equilibrium in the IP joint:

1) $F_{h1} * K_1 = F_1 * D_1 \Rightarrow F_{h1} = \frac{F_1 * D_1}{K_1}$

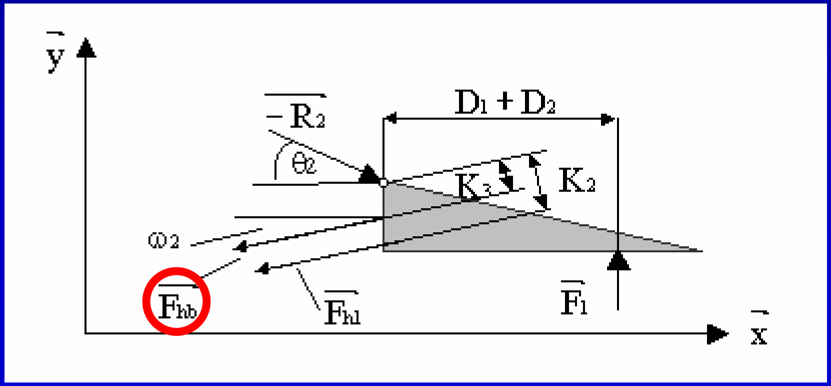
2) $\overline{R_1} = \overline{F_{h1}} + \overline{F_1}$

Thus leading to:

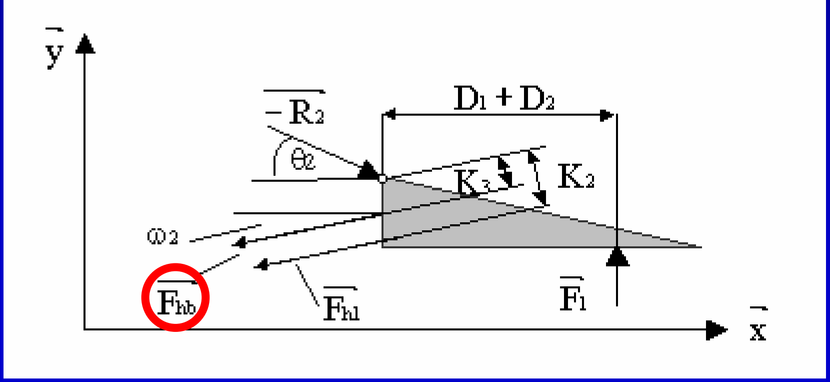
3) $R_1 = \sqrt{F_{h1}^2 + F_1^2}$

4) $\theta_1 = \arccos\left(\frac{F_{h1}}{R_1}\right)$

Free Body Diagram for the MP Joint of the 1st Ray



Free Body Diagram for the MP Joint of the 1st Ray



Conditions of equilibrium at the MP joint:

5) $$F_{hb} * K_3 + F_{hl} * K_2 = F_1 * (D_1 + D_2) \Rightarrow F_{hb} = \frac{F_1 * (D_1 + D_2) - F_{hl} * K_2}{K_3}$$

6) $$\overline{R_2} = \overline{F_1} + \overline{F_{hb}} + \overline{F_{hl}}$$

$$R_{2x} = (F_{hb} + F_{hl}) * \cos\omega_2$$

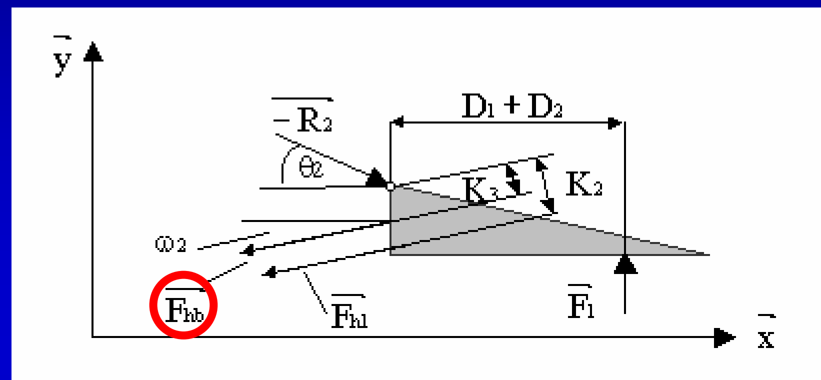
$$R_{2y} = F_1 - (F_{hb} + F_{hl}) * \sin\omega_2$$

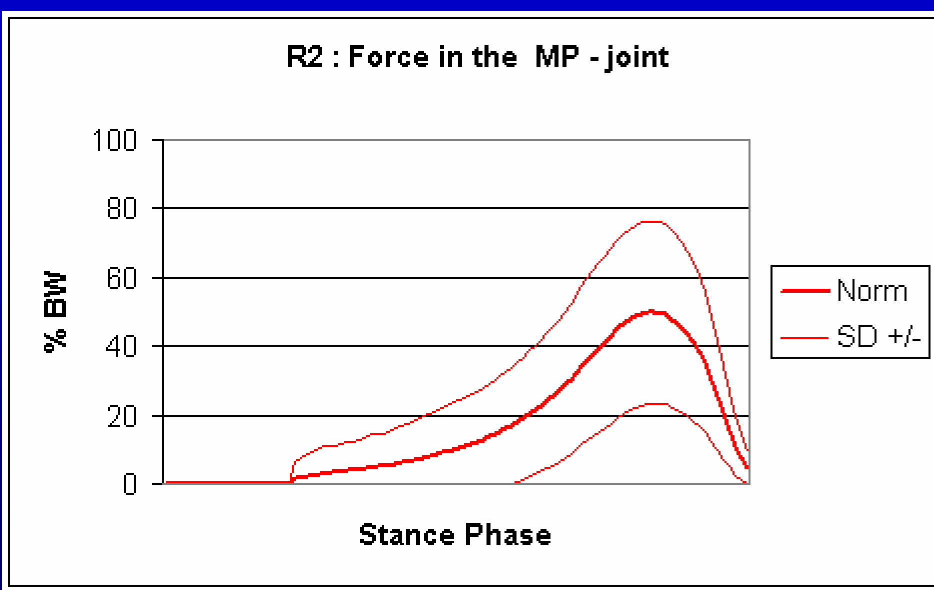
Thus leading to:

7) $$R_2 = \sqrt{R_{2x}^2 + R_{2y}^2}$$

8) $$\theta_2 = \arccos\left(\frac{R_{2x}}{R_2}\right)$$

Free Body Diagram for the MP Joint of the 1st Ray





Conditions of equilibrium at the MP joint:

5) $F_{hb} * K_3 + F_{hl} * K_2 = F_1 * (D_1 + D_2) \Rightarrow F_{hb} = \frac{F_1 * (D_1 + D_2) - F_{hl} * K_2}{K_3}$

6) $\vec{R_2} = \vec{F_1} + \vec{F_{hb}} + \vec{F_{hl}}$

$R_{2x} = (F_{hb} + F_{hl}) * \cos\omega_2$

$R_{2y} = F_1 - (F_{hb} + F_{hl}) * \sin\omega_2$

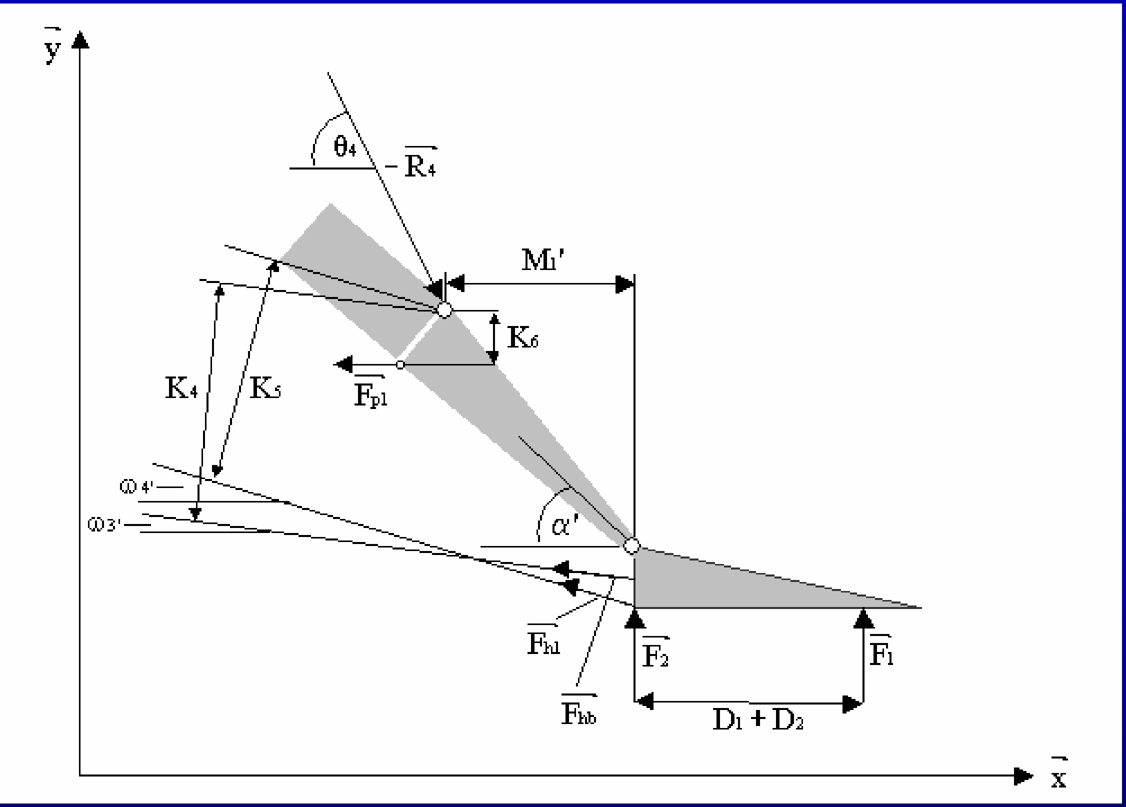
Thus leading to:

7) $R_2 = \sqrt{R_{2x}^2 + R_{2y}^2}$

8) $\theta_2 = \arccos\left(\frac{R_{2x}}{R_2}\right)$

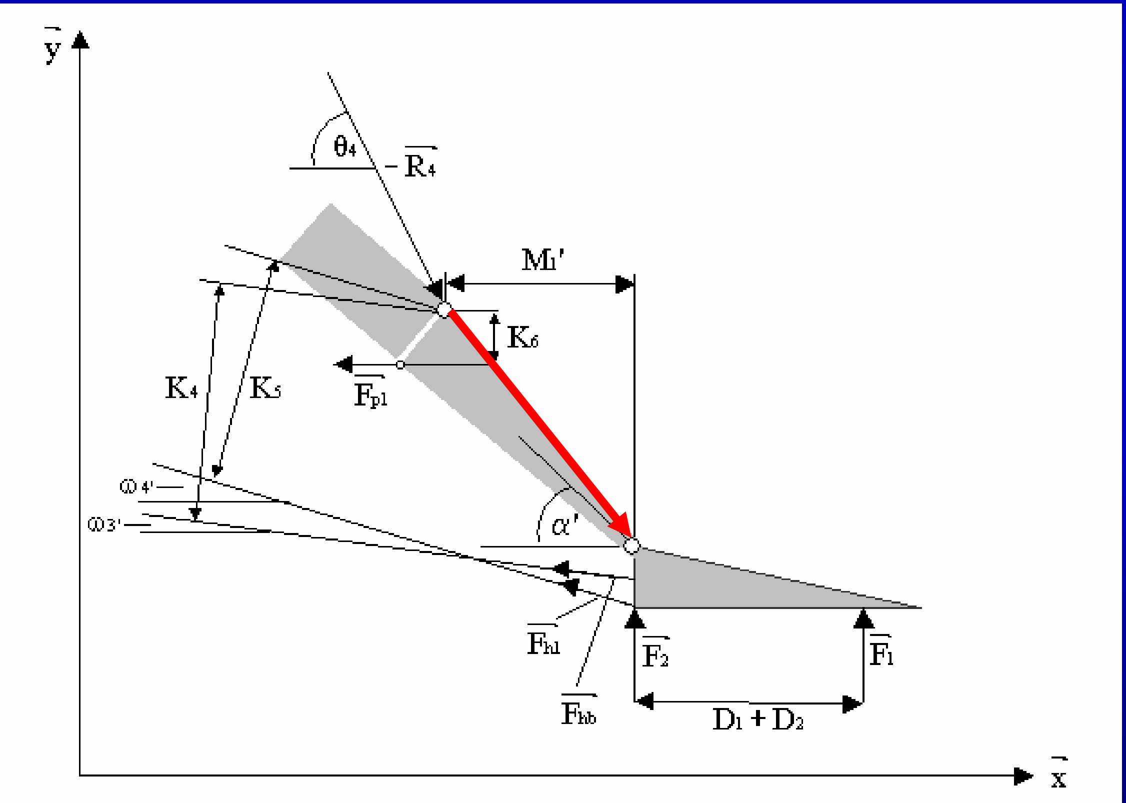
Clinical Application in the Daily Routine

Free Body Diagram of the TMT1 Joint



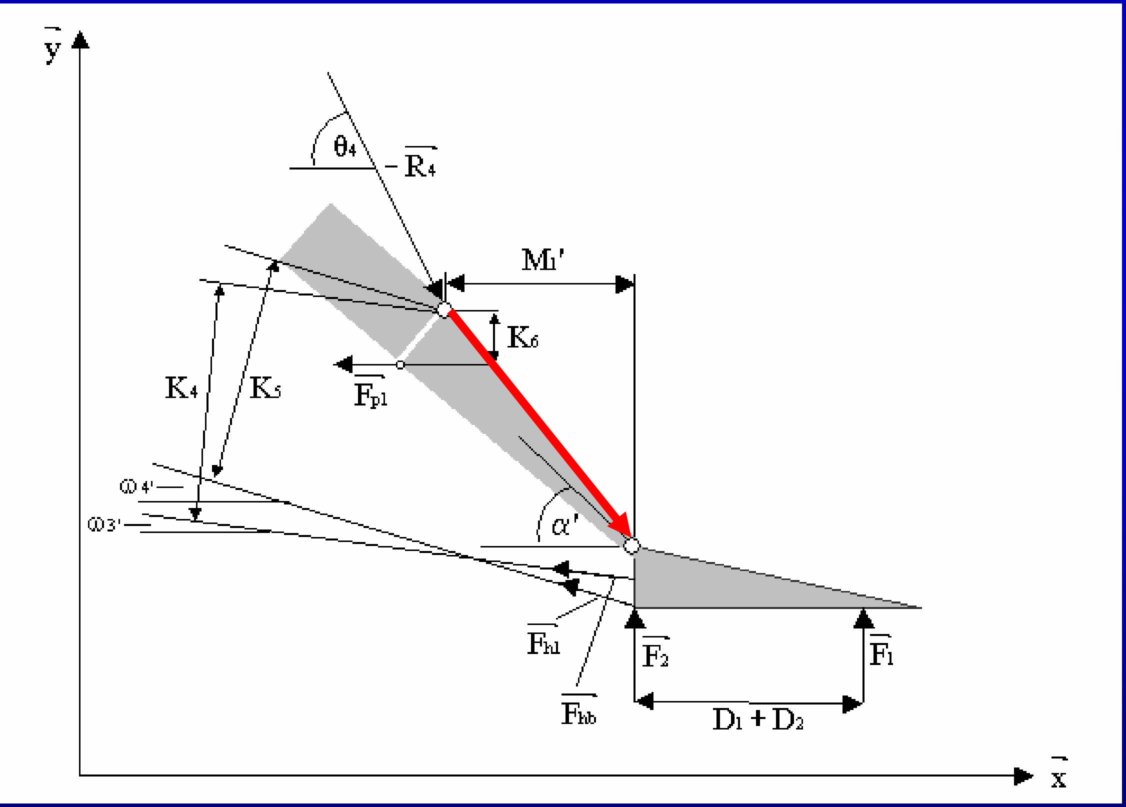
Clinical Application in the Daily Routine

Free Body Diagram of the TMT1 Joint

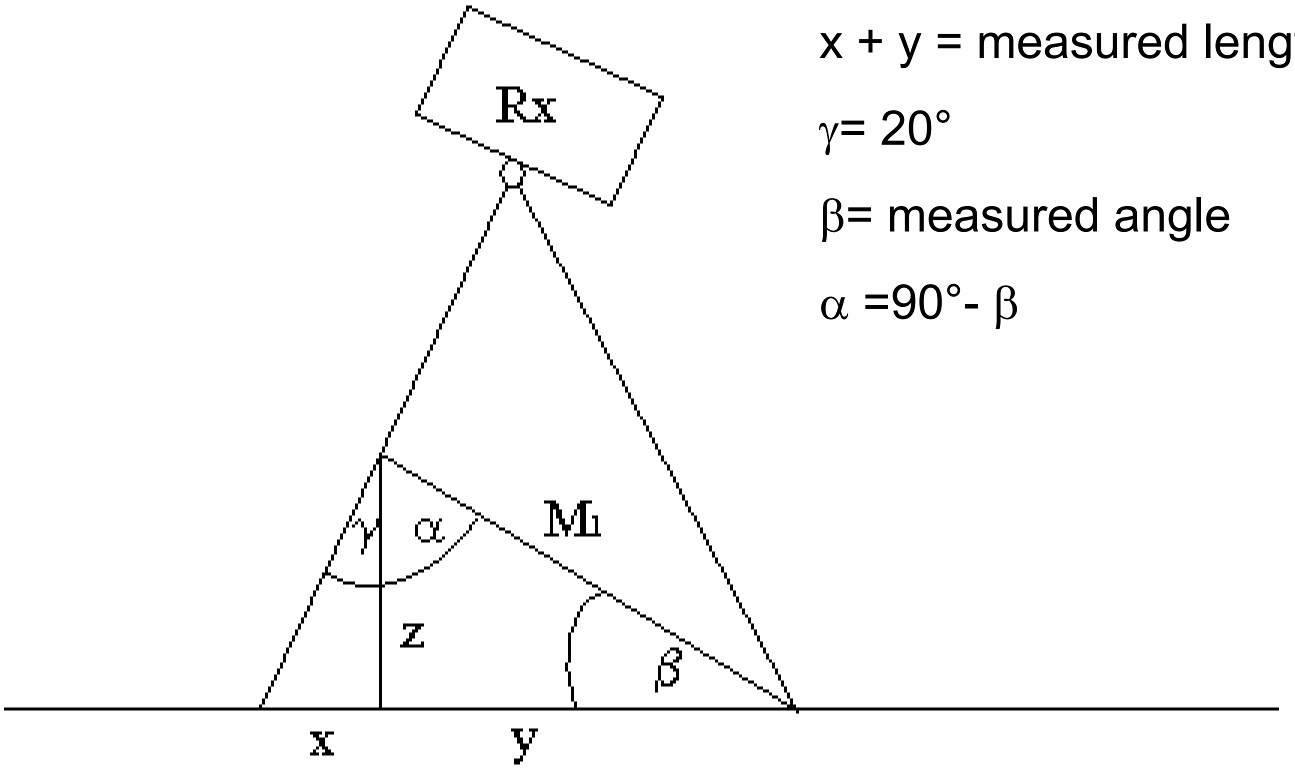


Clinical Application in the Daily Routine

Free Body Diagram of the TMT1 Joint



Correction of the Projection Error



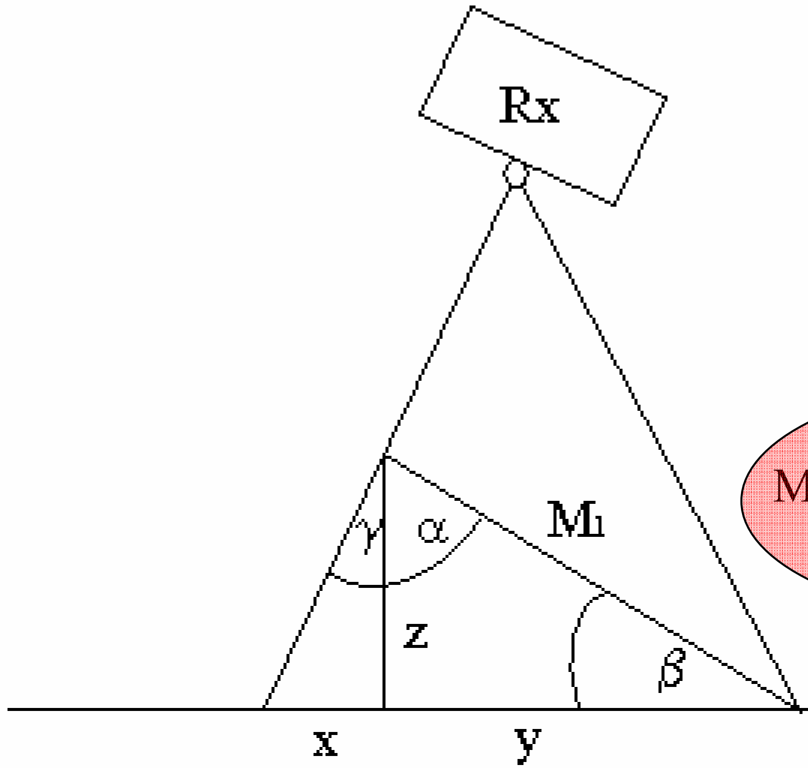
x + y = measured length

γ= 20°

β= measured angle

α =90°- β

Correction of the Projection Error



x + y = measured length

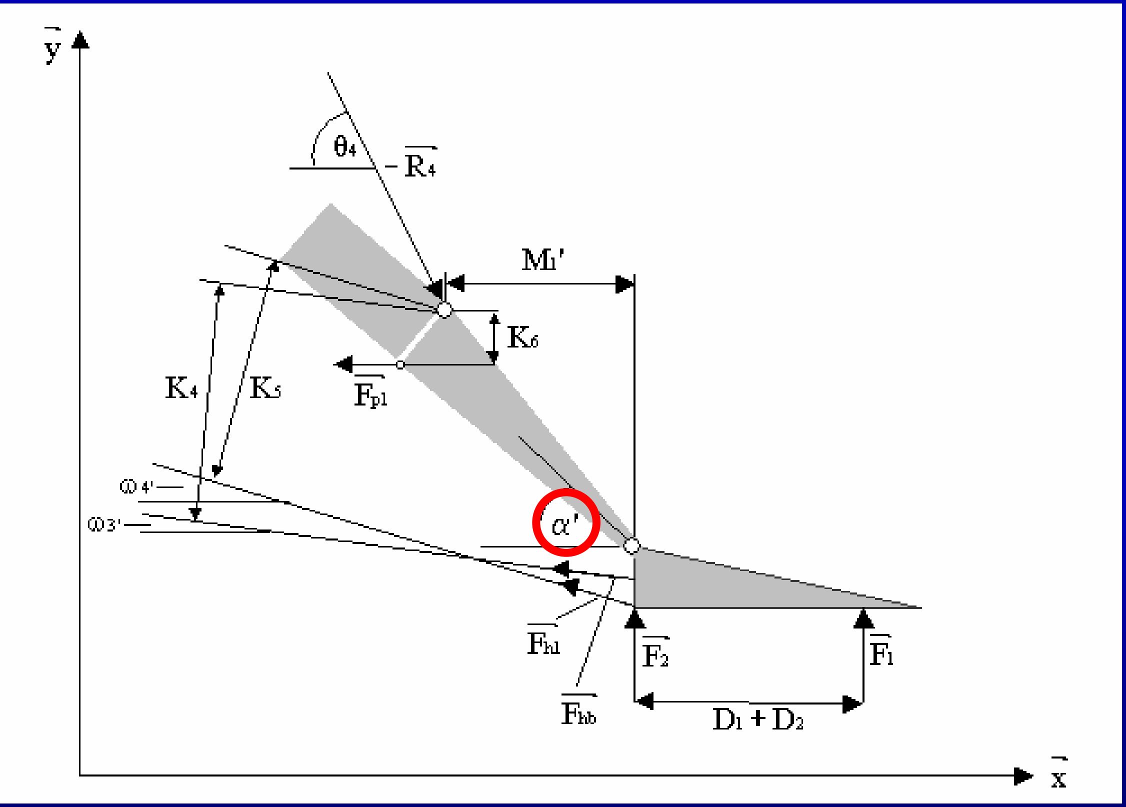
γ= 20°

β= measured angle

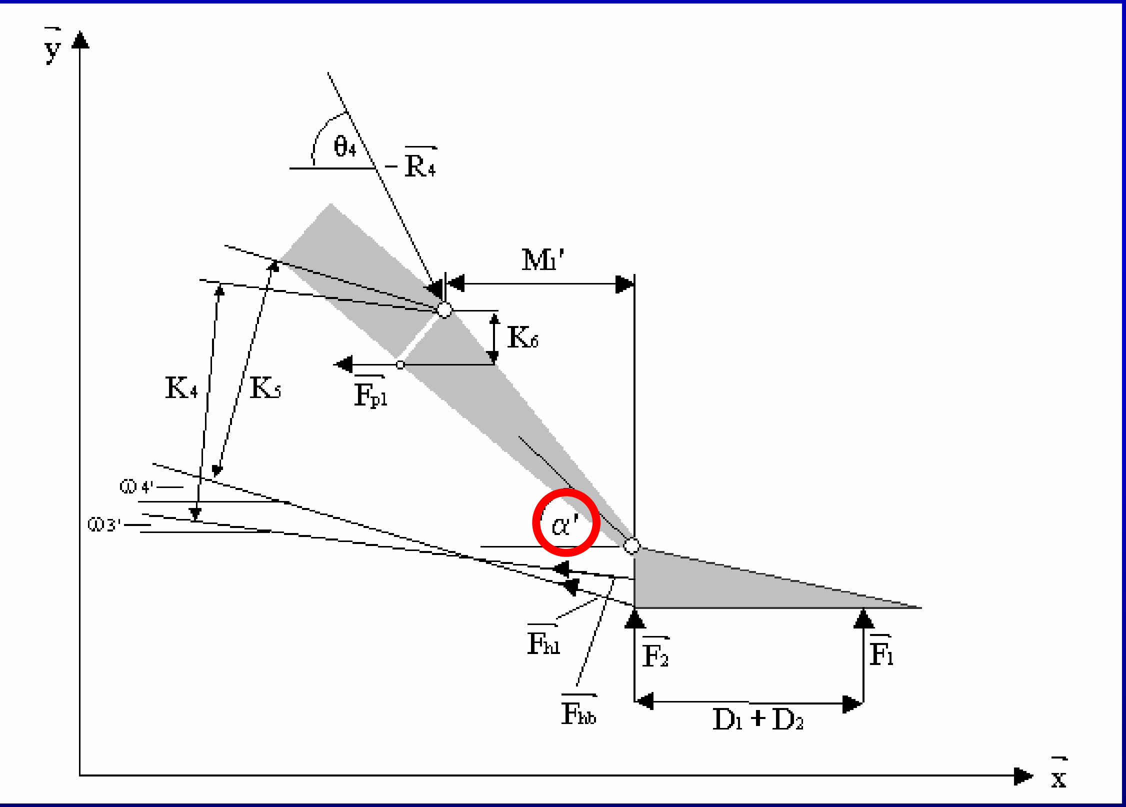
α =90°- β

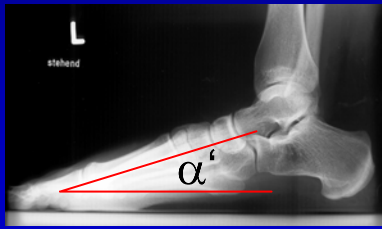
$$M_1 = \frac{x + y}{\cos\alpha * (\tan\alpha + \tan\gamma)}$$

Clinical Application in the Daily Routine

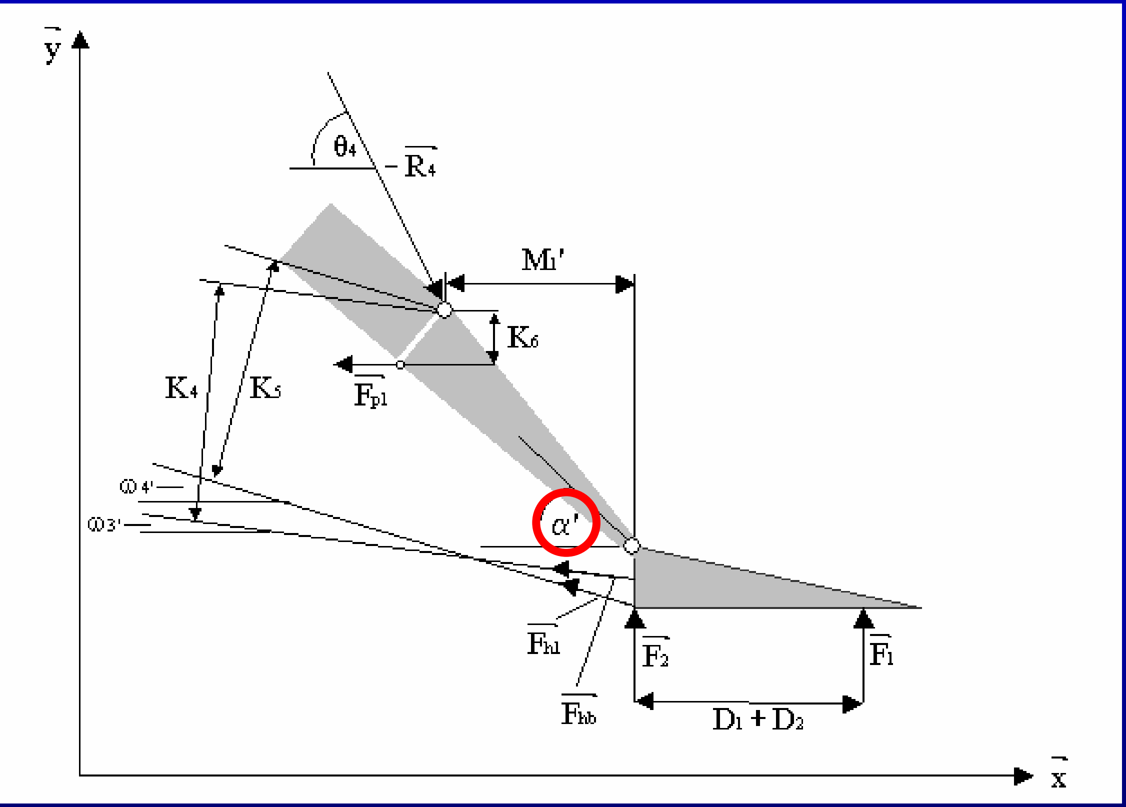


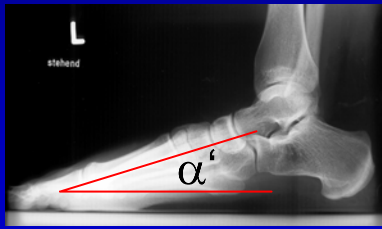
Clinical Application in the Daily Routine

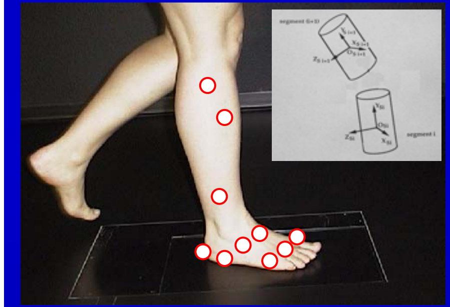


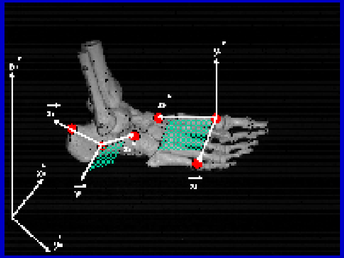


Clinical Application in the Daily Routine

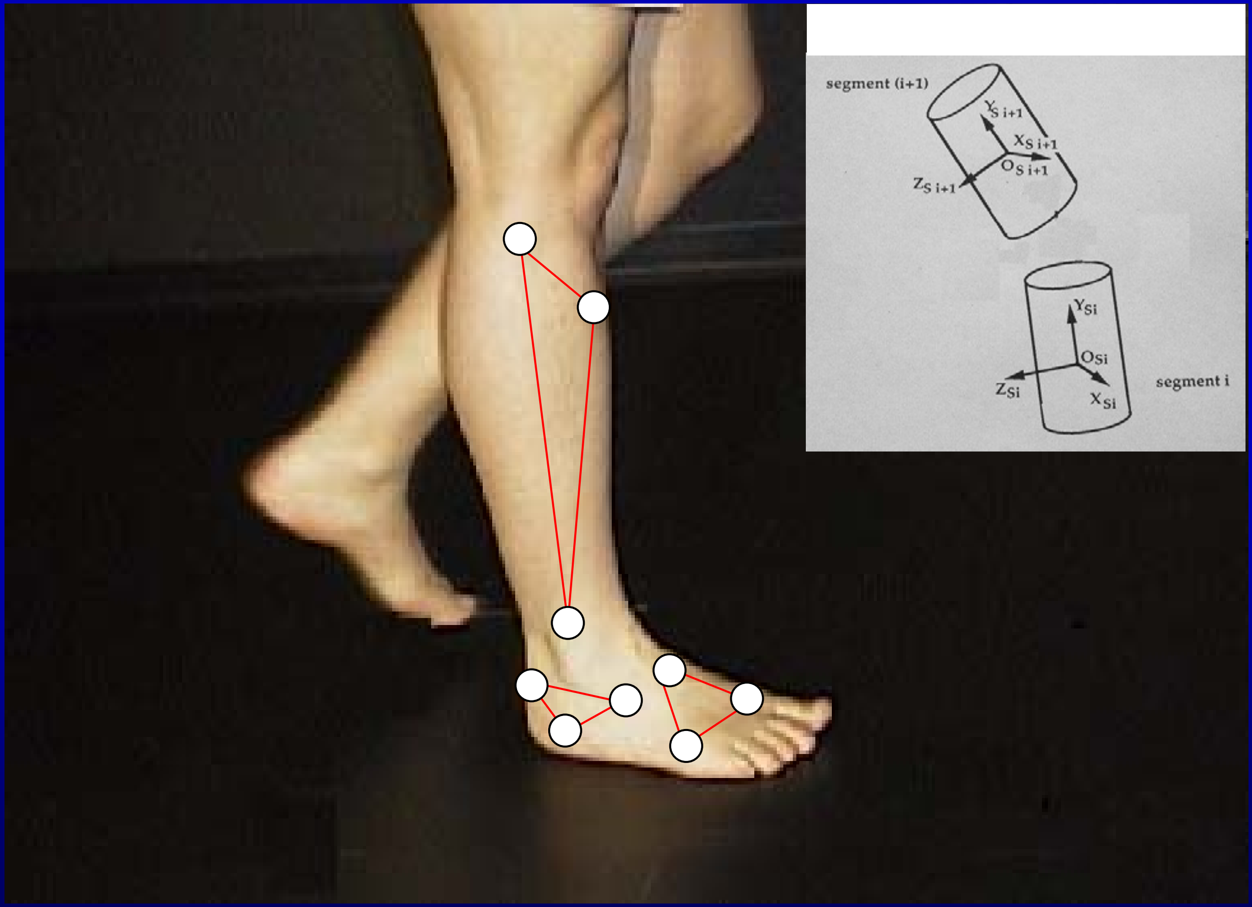




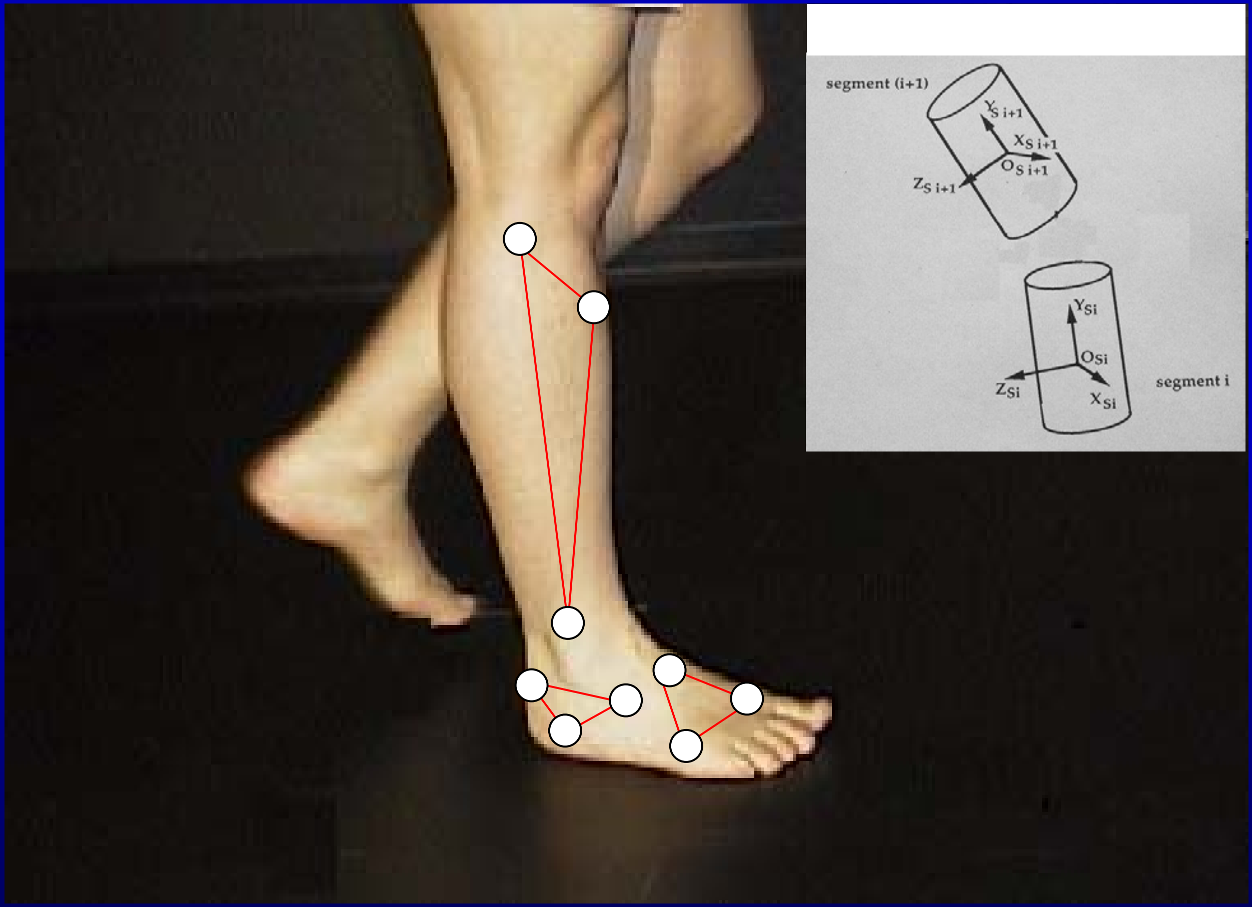




3D Motion Analysis

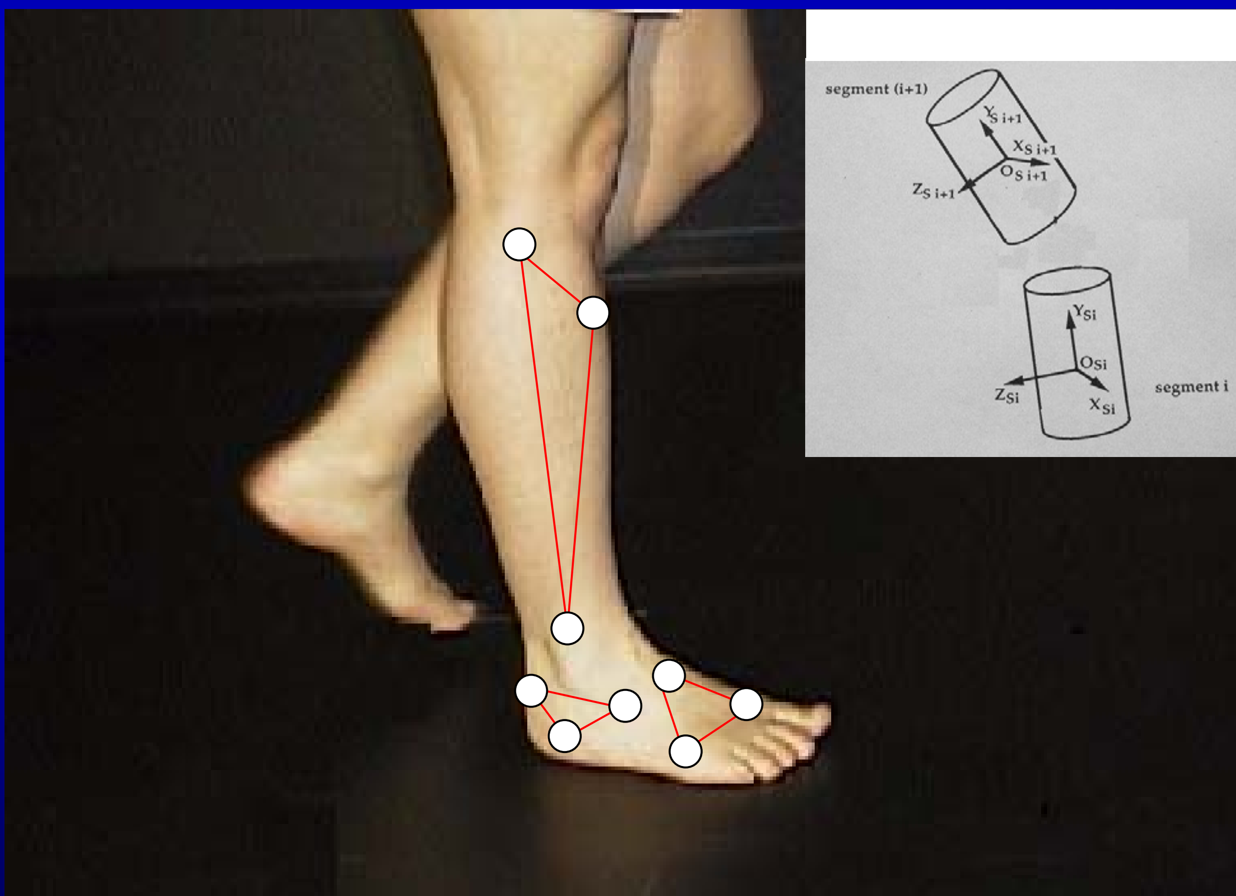


3D Motion Analysis



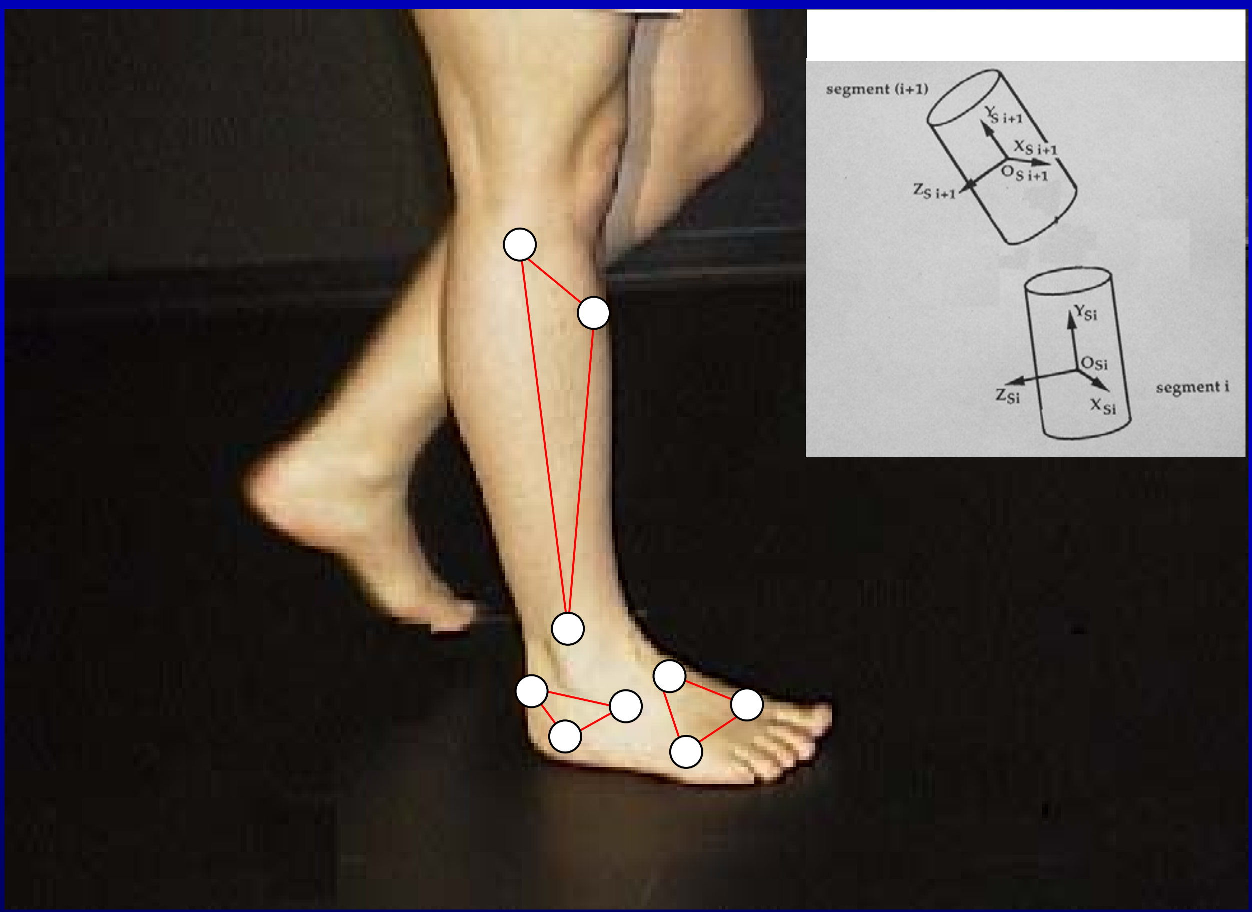
- Vicon 250 (50Hz)

3D Motion Analysis



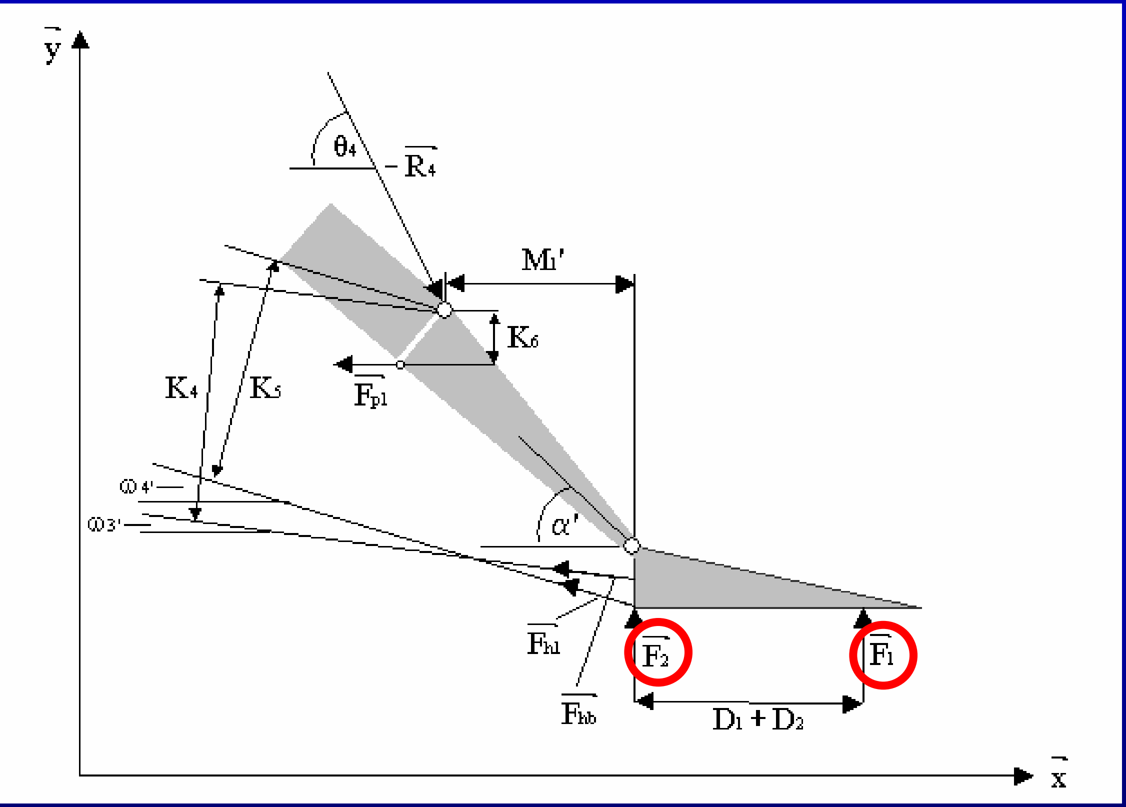
- Vicon 250 (50Hz)
- 5 Cameras

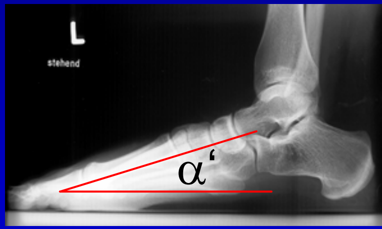
3D Motion Analysis

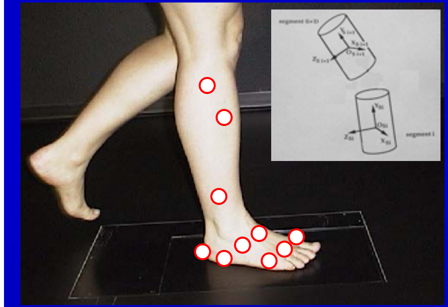


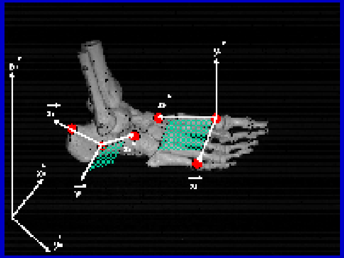
- Vicon 250 (50Hz)
- 5 Cameras
- unilateral

Clinical Application in the Daily Routine

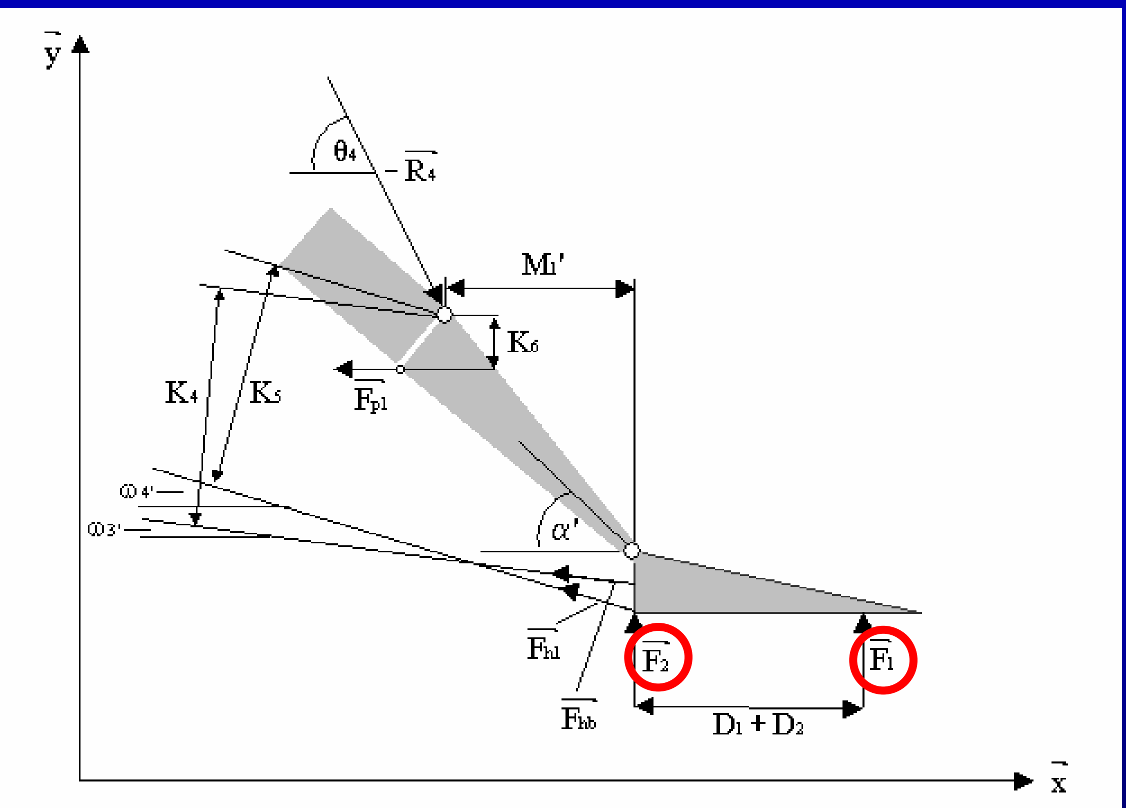


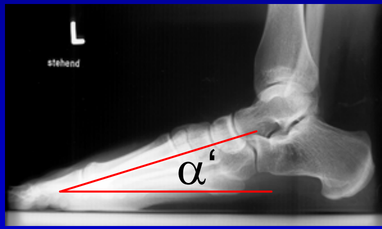


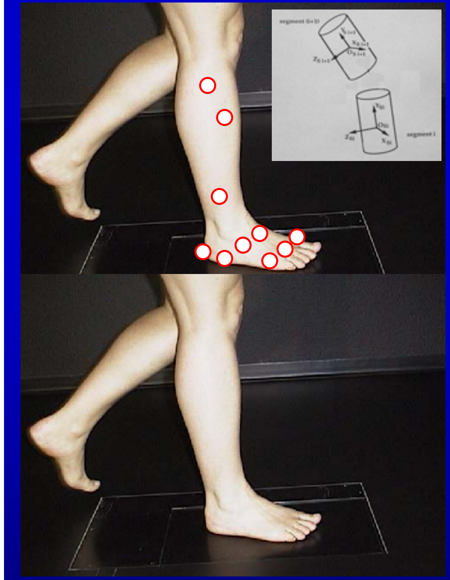


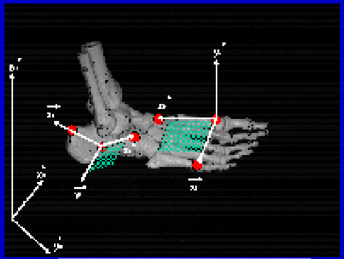


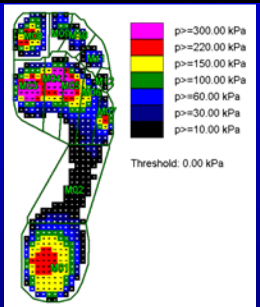
Clinical Application in the Daily Routine











Methods

Dynamic pressure measurement

Methods

Dynamic pressure measurement

- 4 Sensors per square cm

Methods

Dynamic pressure measurement

- 4 Sensors per square cm
- 50 Hz

Methods

Dynamic pressure measurement

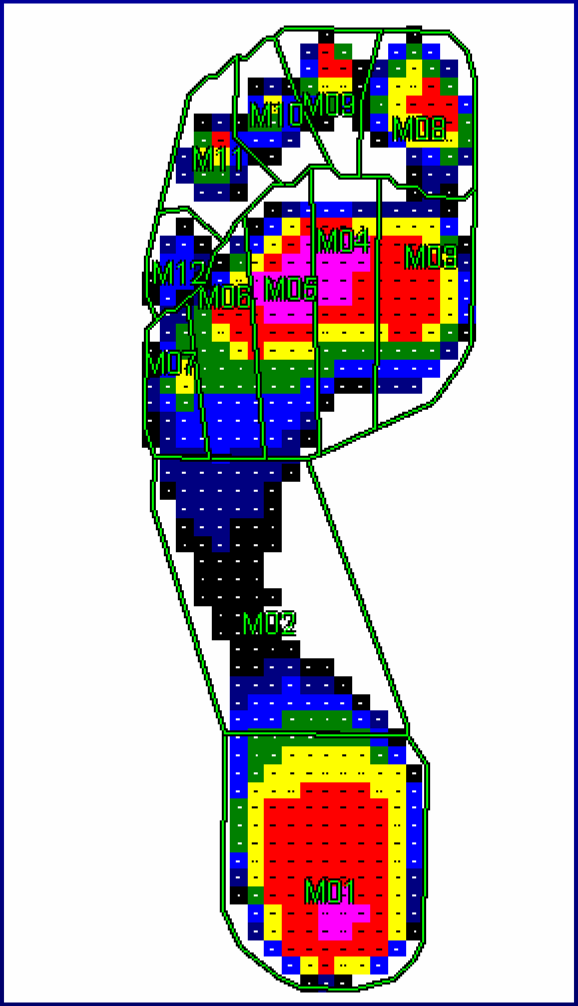
- 4 Sensors per square cm
- 50 Hz
- Second step method, 5 trials

Methods

Dynamic pressure measurement

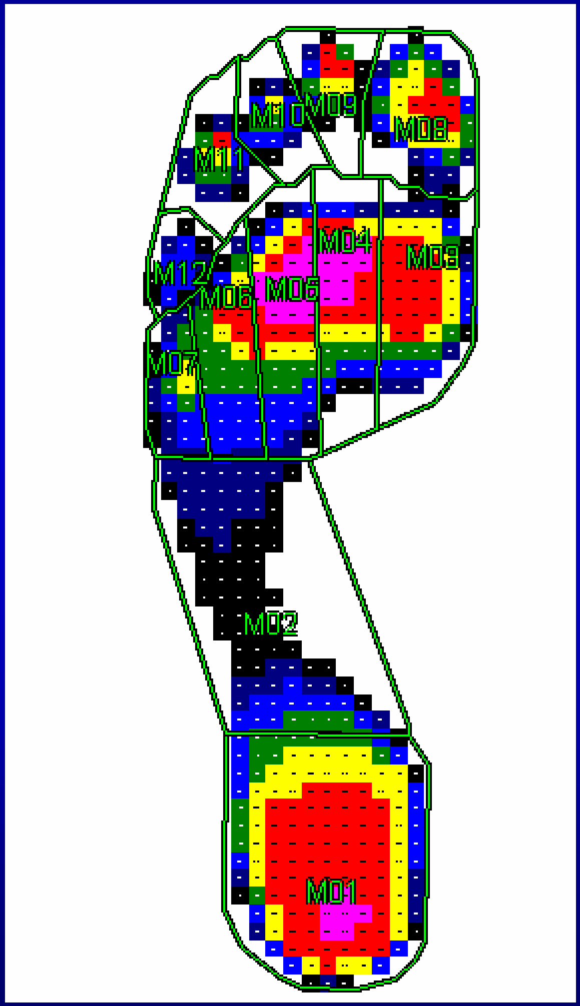
- 4 Sensors per square cm
- 50 Hz
- Second step method, 5 trials
- Gait velocity choosen freely

Dynamic Pressure Measurement



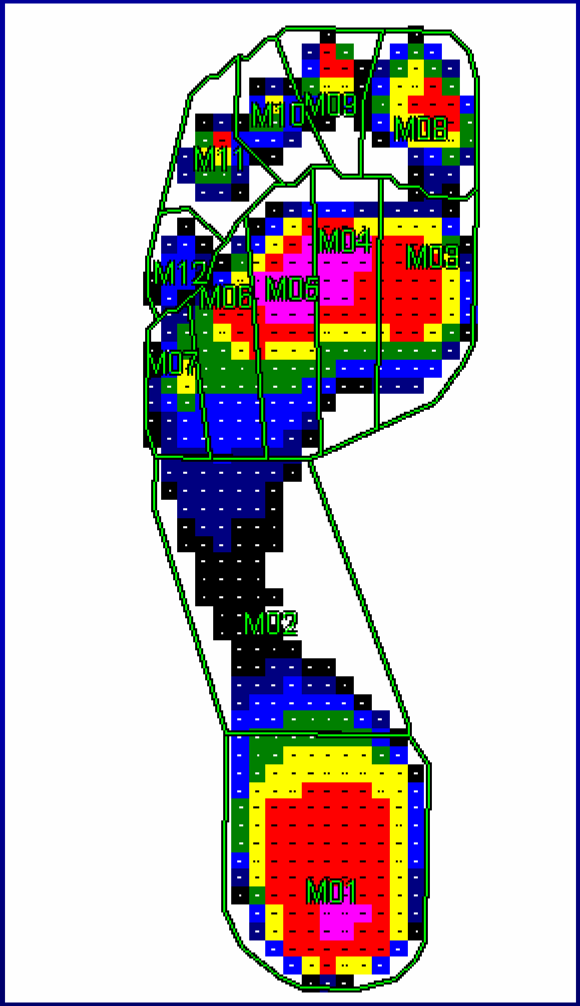
- Standardised mask with 12 areas

Dynamic Pressure Measurement



- **Standardised mask with 12 areas**
- **Forces were normalized to the body weight. Body weight = 100%**

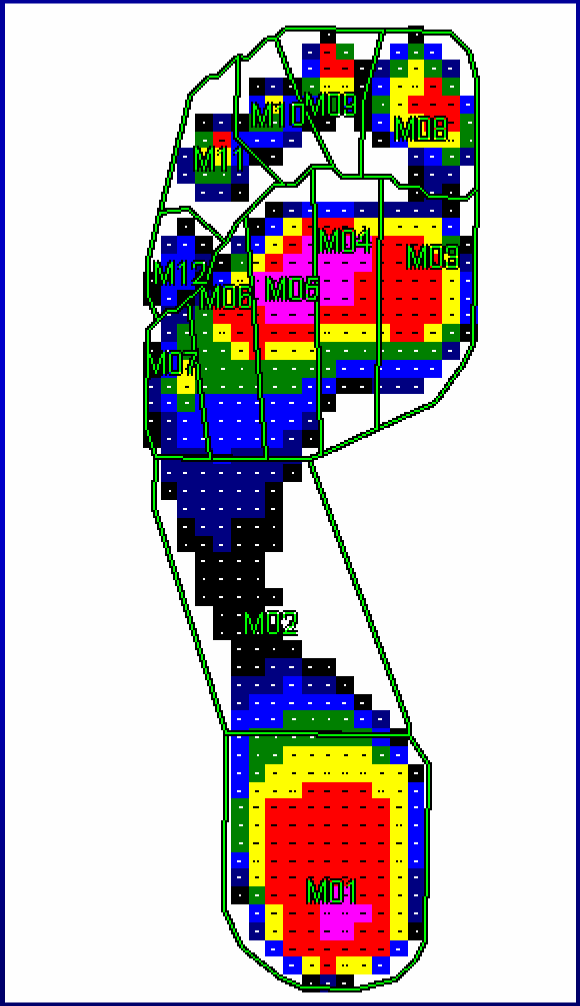
Dynamic Pressure Measurement



- Standardised mask with 12 areas
- Forces were normalized to the body weight. Body weight = 100%
- Time normalization

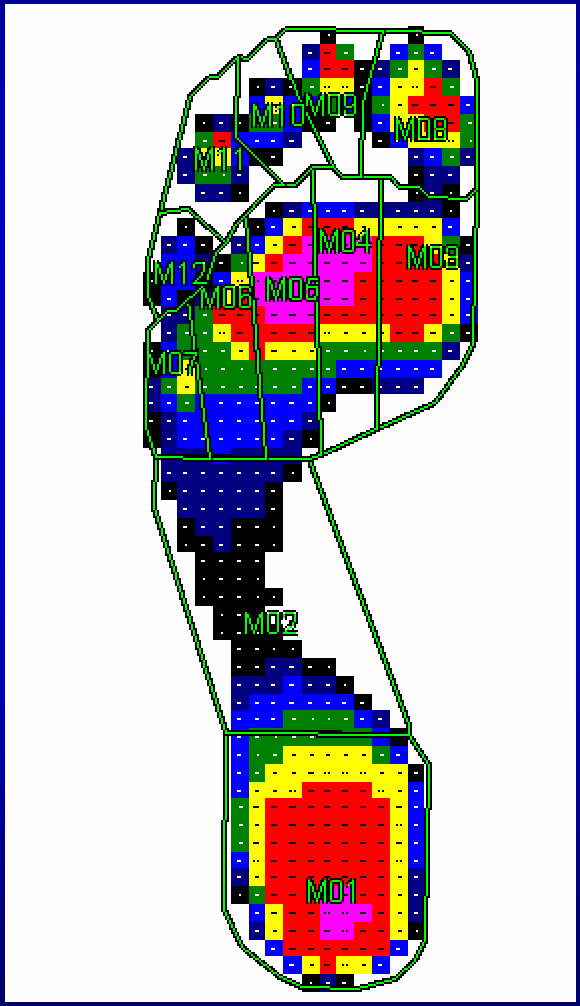
  > Each step is divided into 100 intervals

Dynamic Pressure Measurement



- Standardised mask with 12 areas
- Forces were normalized to the body weight. Body weight = 100%
- Time normalization
  - > Each step is divided into 100 intervals
  - > Linear interpolation

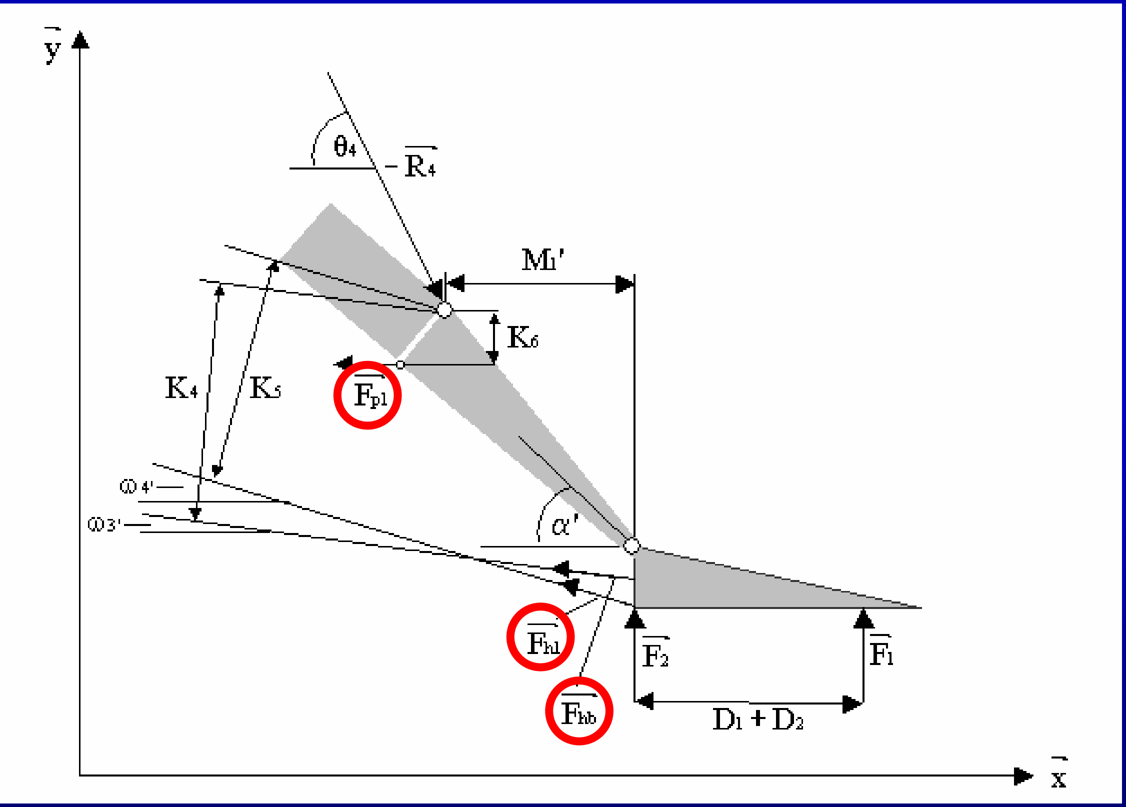
Dynamic Pressure Measurement

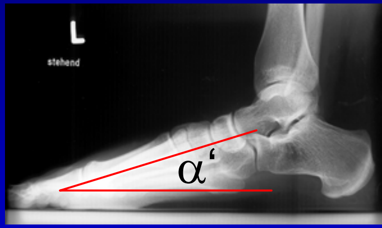


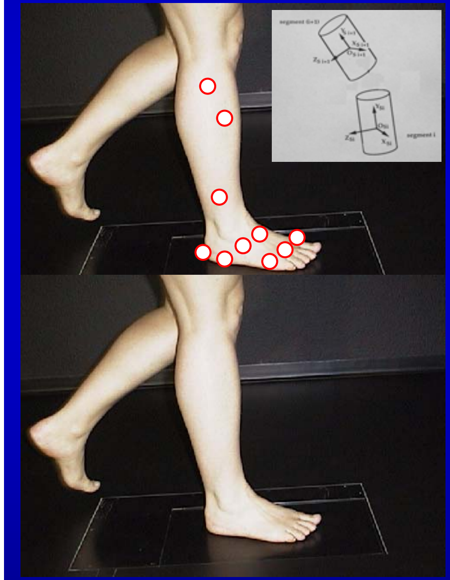
- Standardised mask with 12 areas
- Forces were normalized to the body weight. Body weight = 100%
- Time normalization
  - > Each step is divided into 100 intervals
  - > Linear interpolation
- 5 trials > in each interval > Median/StDv

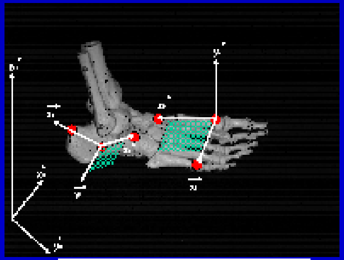
Muscle Forces

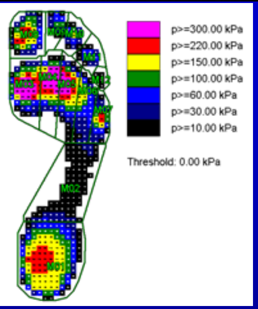
Inverse Dynamics





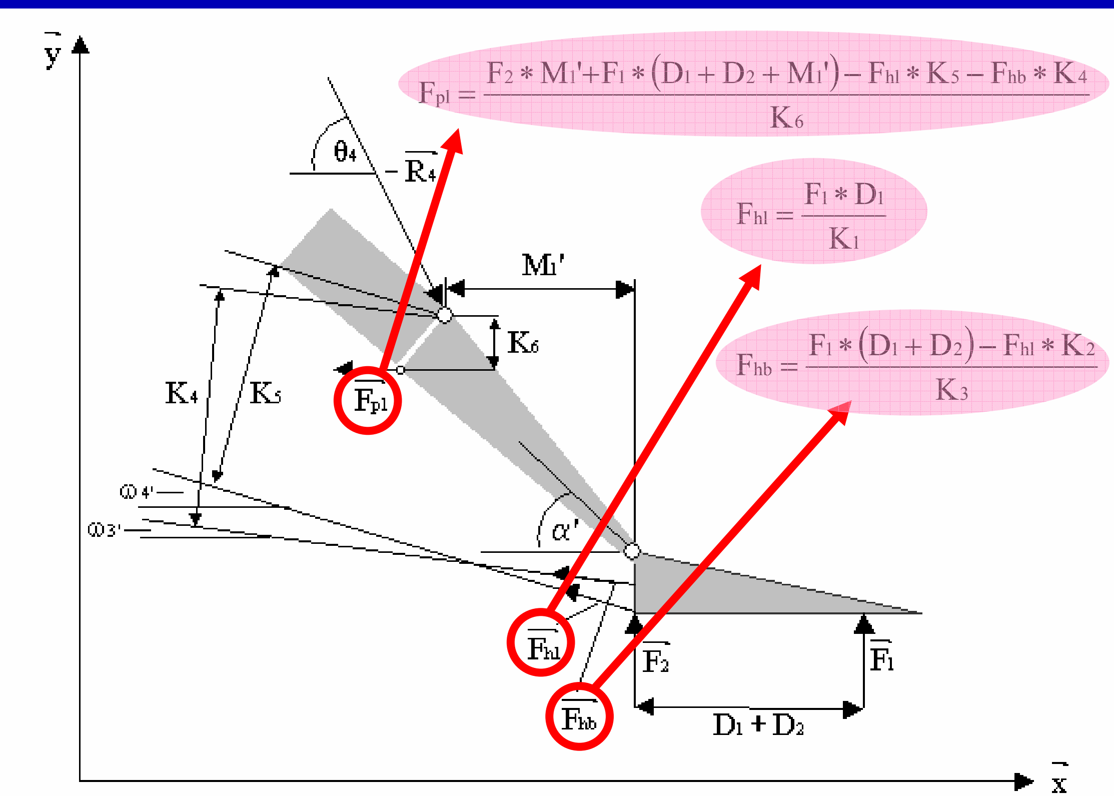


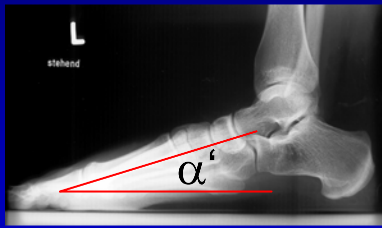


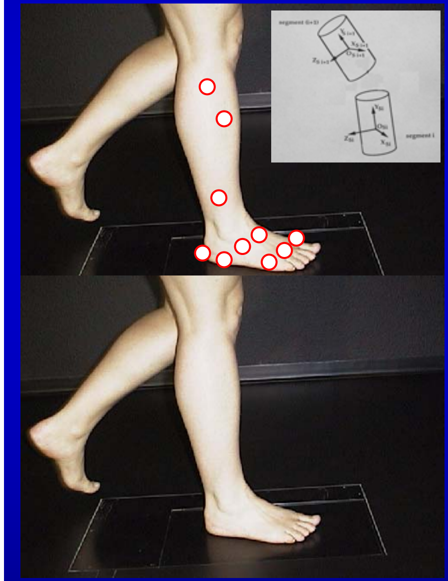


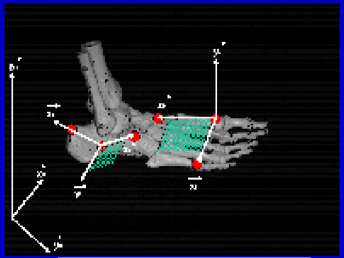
Muscle Forces

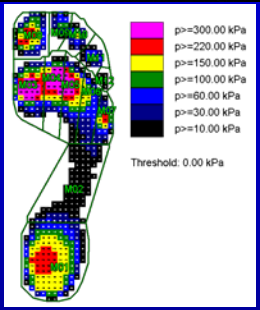
Inverse Dynamics using EMG





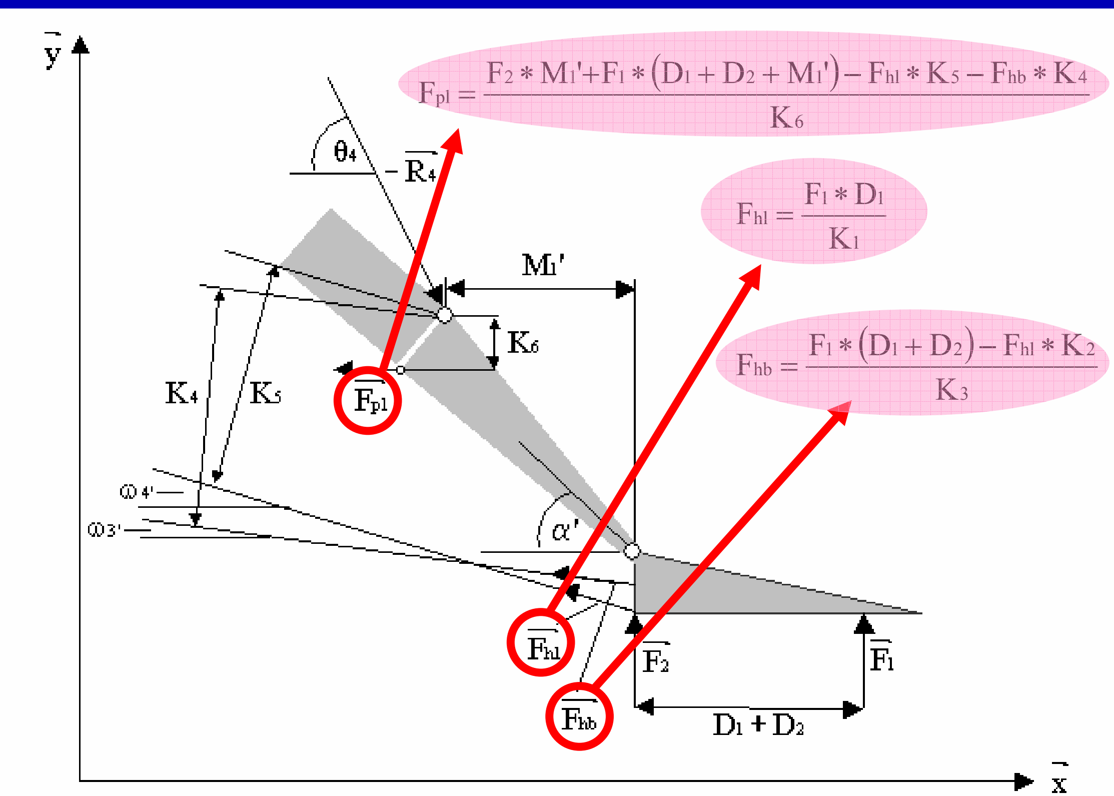


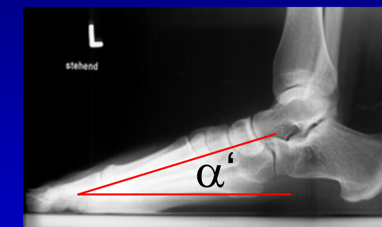


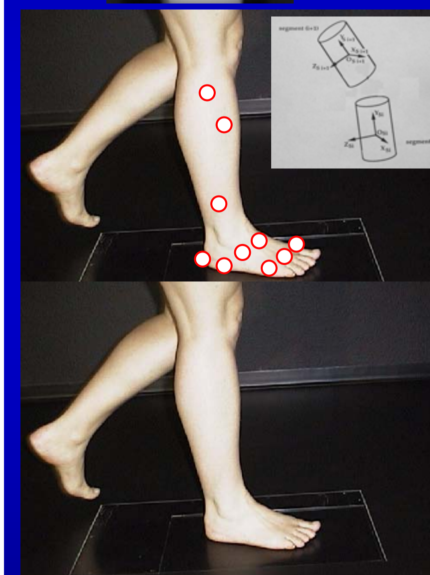


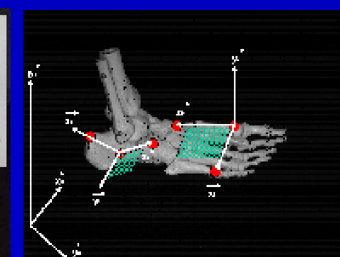
Muscle Forces

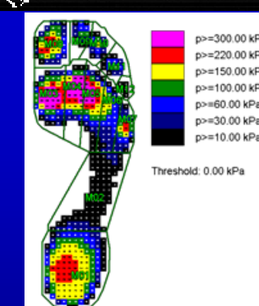
Inverse Dynamics using EMG

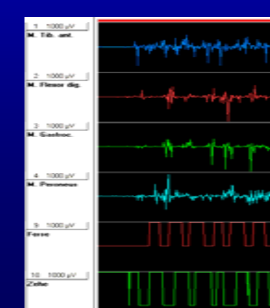




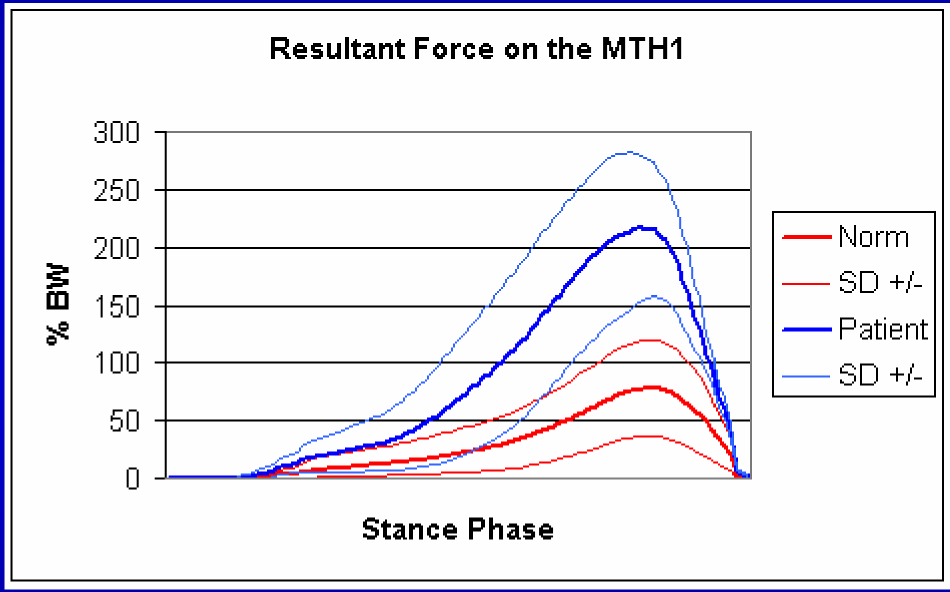






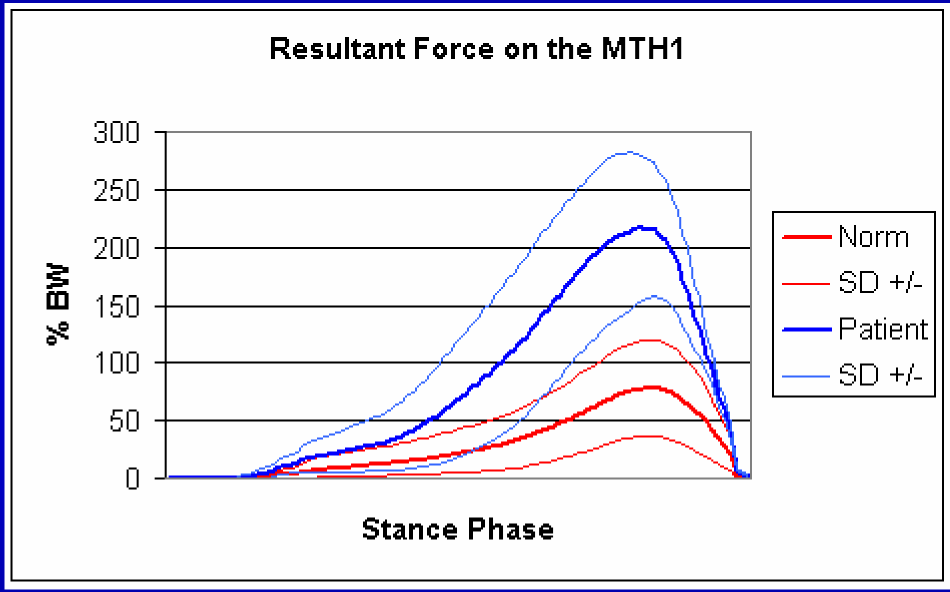


Clinical Approach



- 5 Trials
- Median
- Standard Deviation

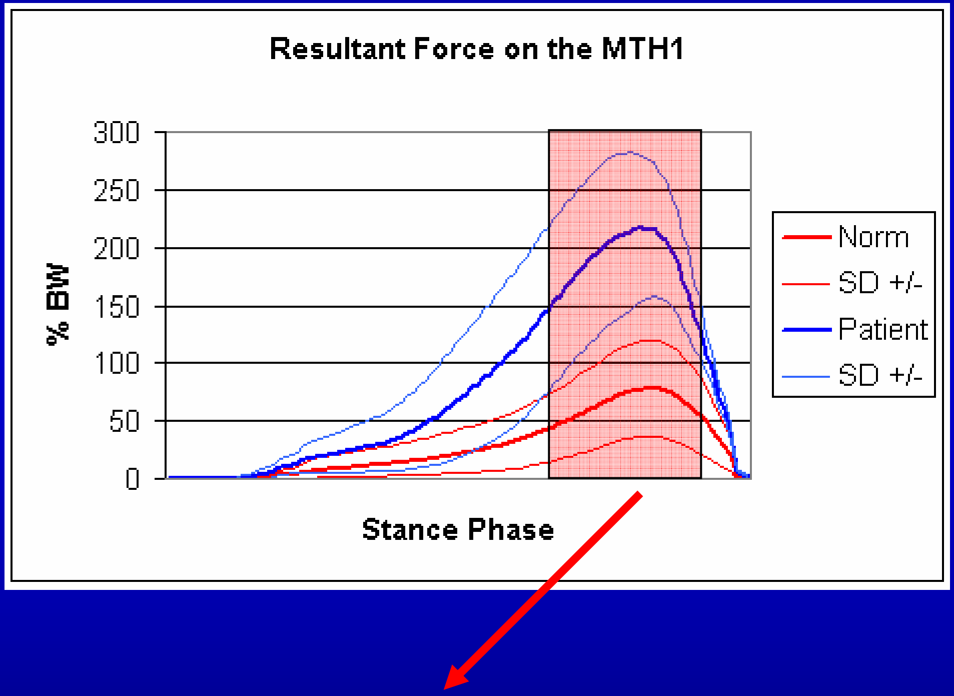
Clinical Approach



- 5 Trials
- Median
- Standard Deviation

more than 2 standard deviations >> pathologically

Clinical Approach



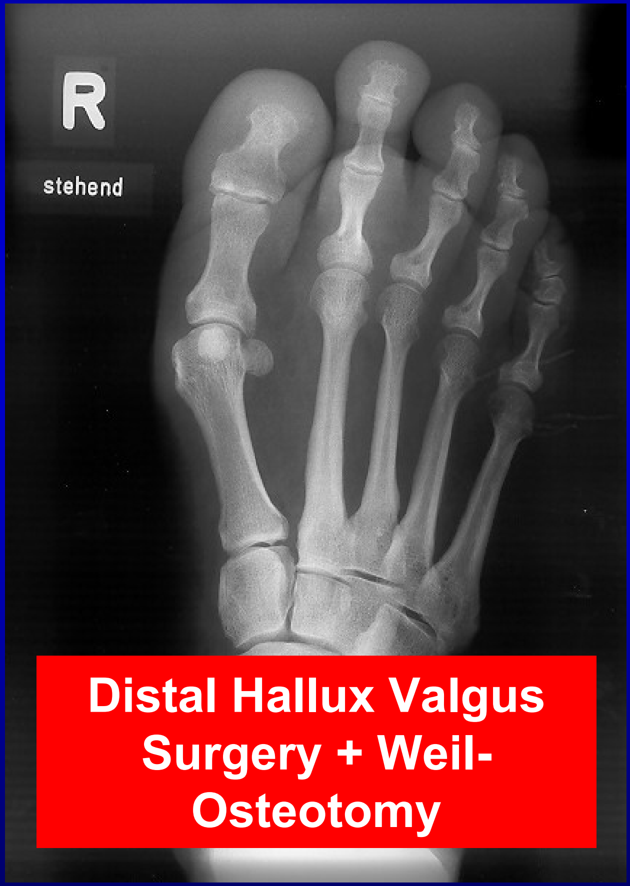
- 5 Trials
- Median
- Standard Deviation

more than 2 standard deviations >> pathologically

Clinical Example: Metatarsalgia, conservatively treated without succes

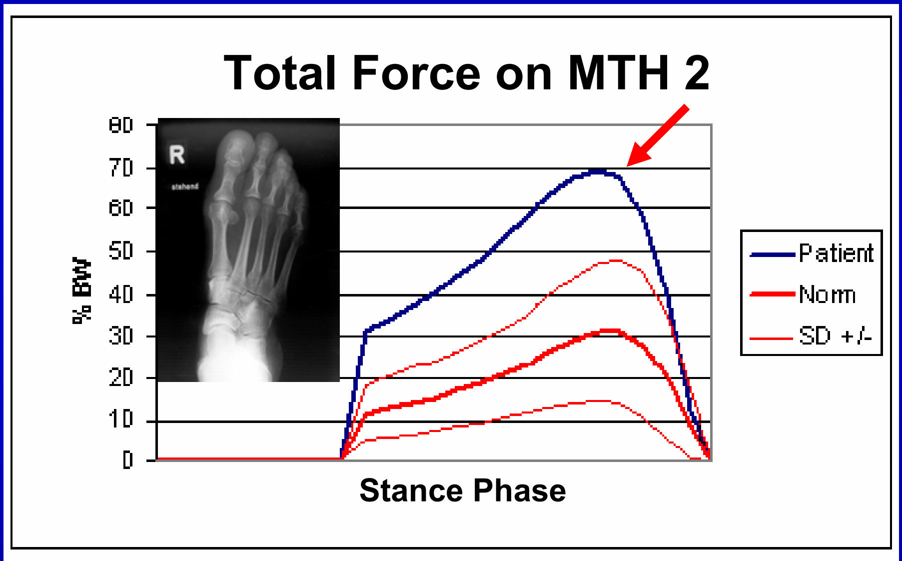
Case 1

Case 2

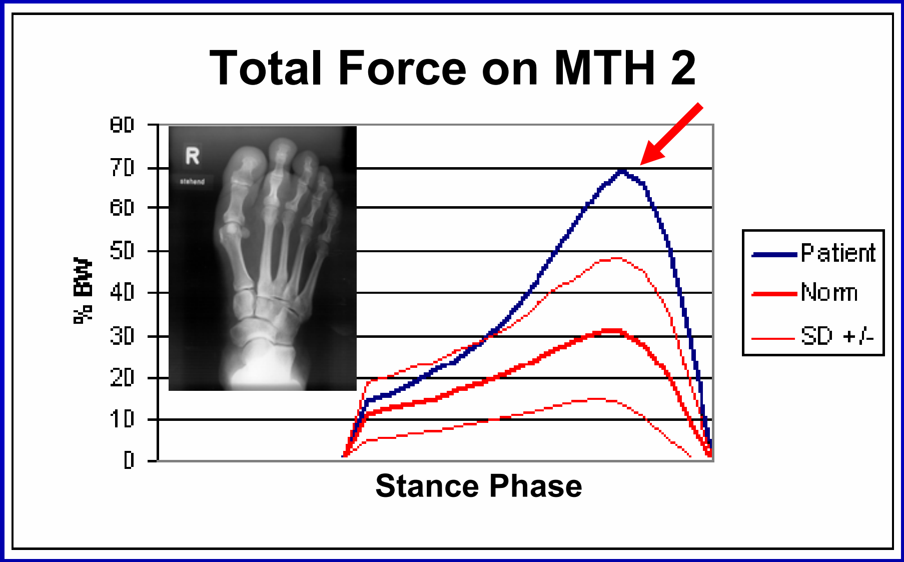


Gait Analysis Data: Increased Total Force on MTH 2

Case 1



Case 2



Aim of the computer simulation:

to decrease patients data (blue line) to the norm

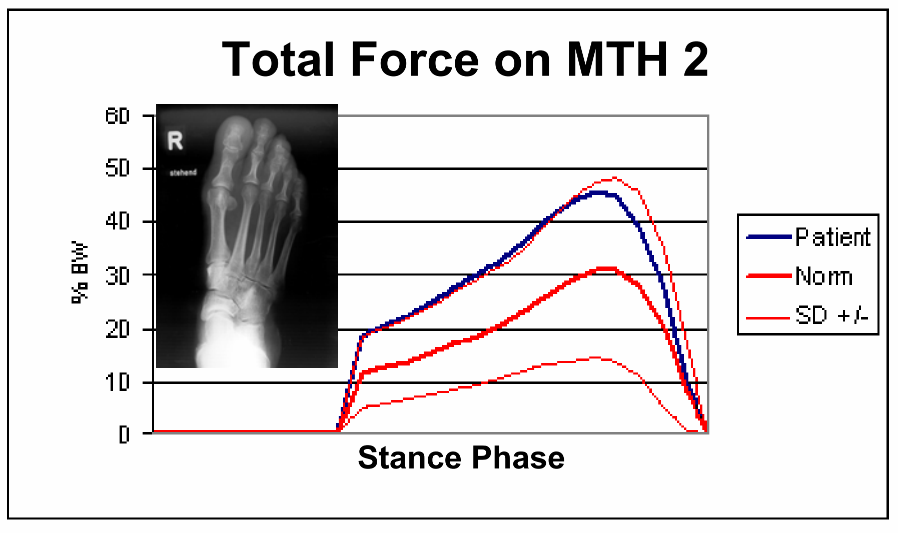
Computer simulated treatement with Insoles

Decrease of 40% of the external force

Computer simulated treatement with Insoles

Decrease of 40% of the external force

Case 1

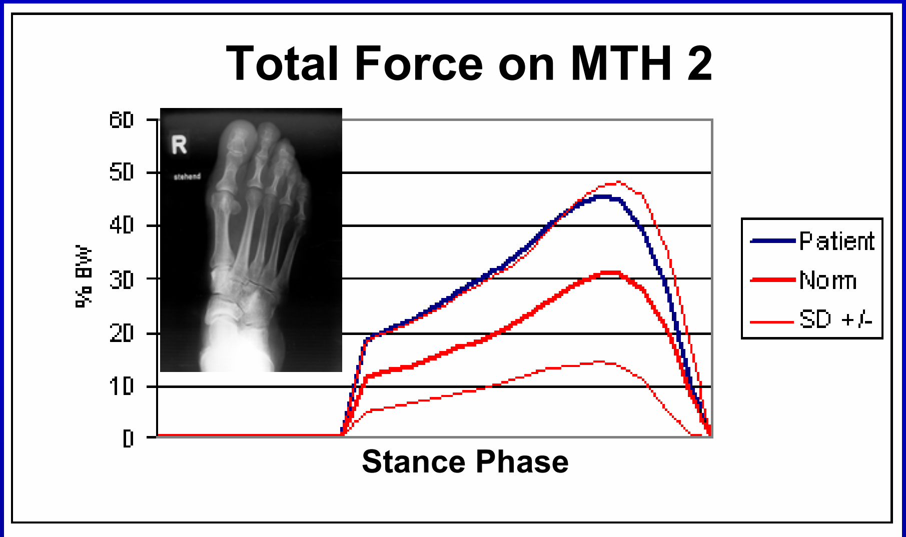


Insole = useful

Computer simulated treatement with Insoles

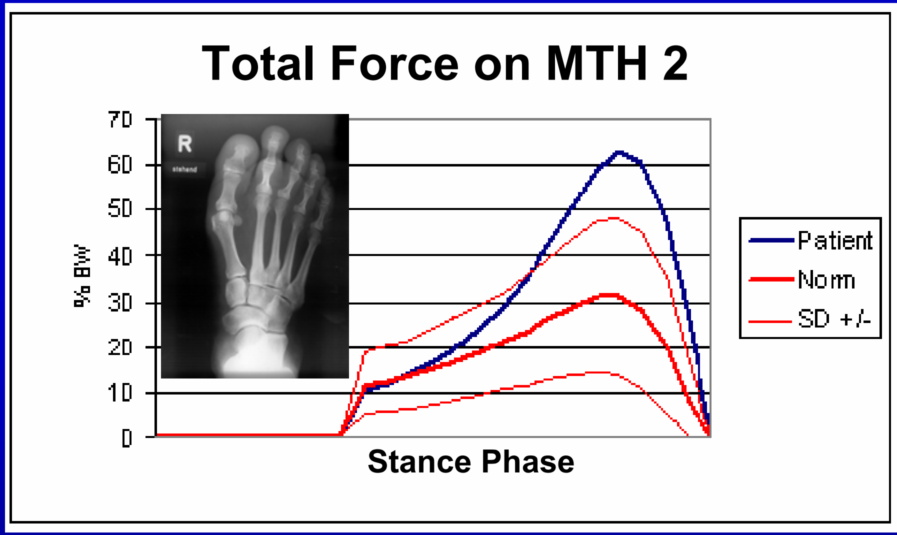
Decrease of 40% of the external force

Case 1



Insole = useful

Case 2



Insole not useful

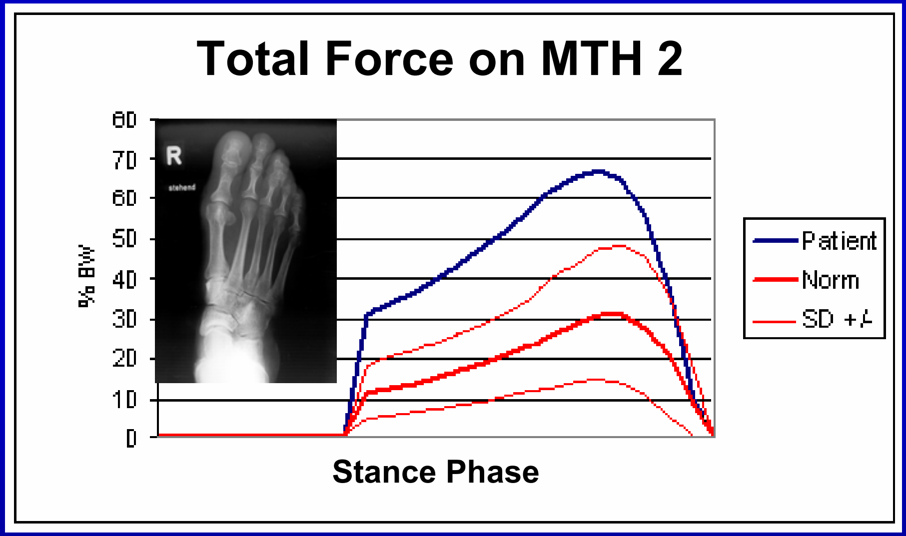
Computer simulated treatement with PIP arthrodesis

Shortening of the Phalanx of 1cm

Computer simulated treatement with PIP arthrodesis

Shortening of the Phalanx of 1cm

Case 1

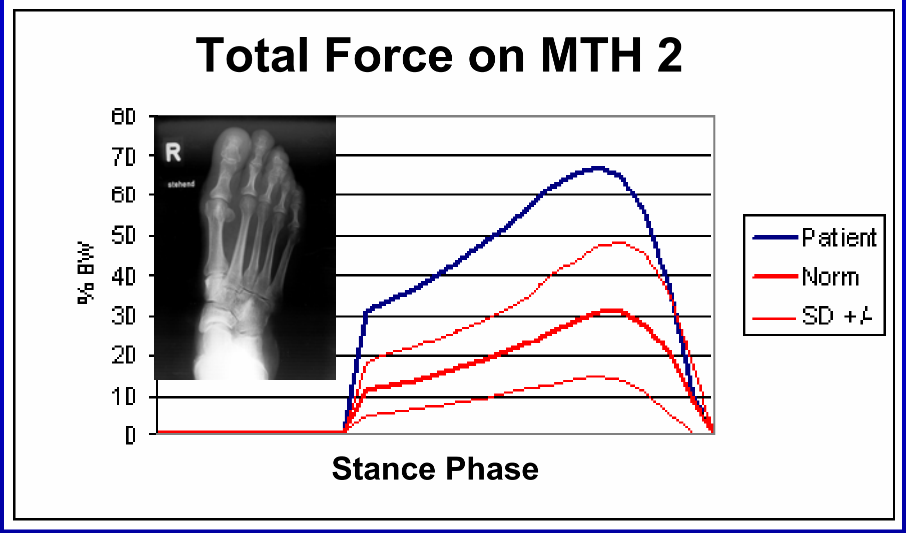


PIP resection not useful

Computer simulated treatement with PIP arthrodesis

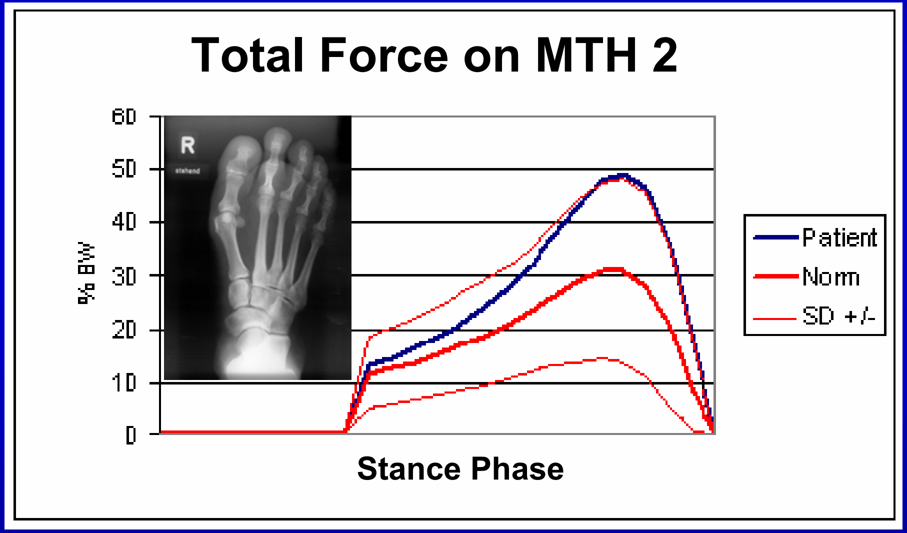
Shortening of the Phalanx of 1cm

Case 1



PIP resection not useful

Case 2

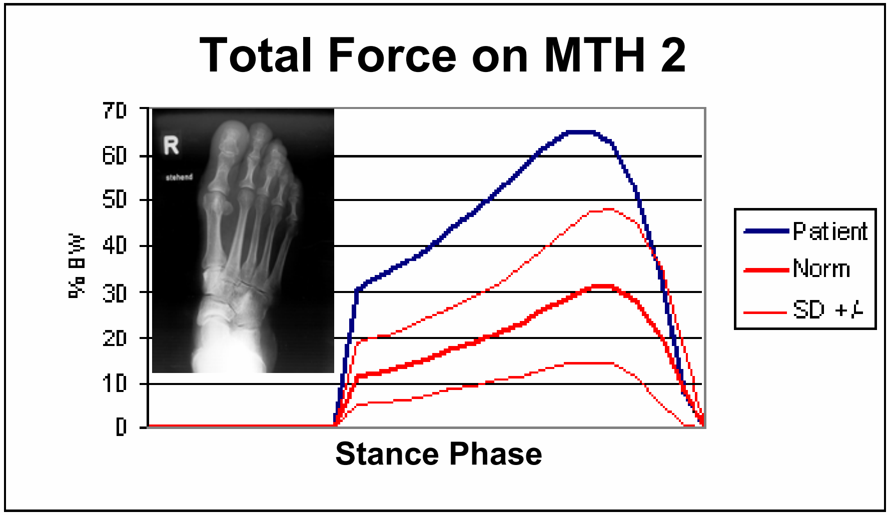


PIP resection probably useful

Computer simulated treatement with tenotomy of FDL

Computer simulated treatement with tenotomy of FDL

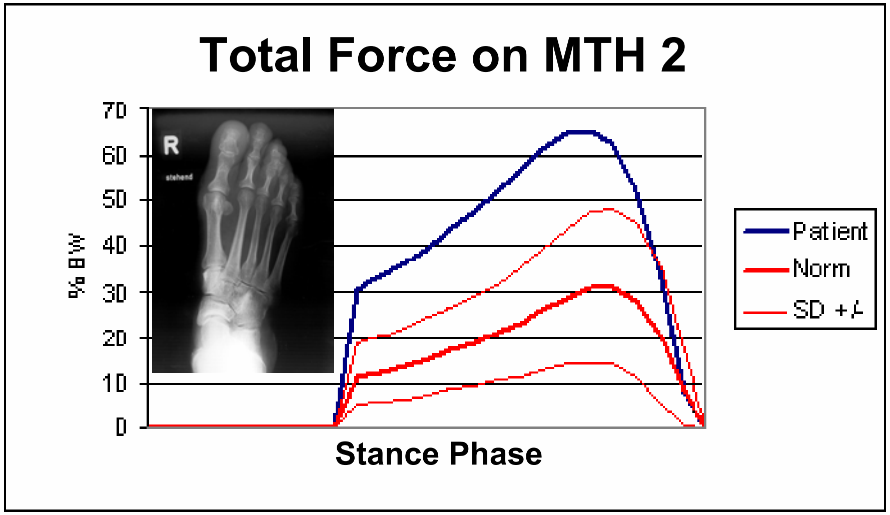
Case 1



Tenotomy not useful

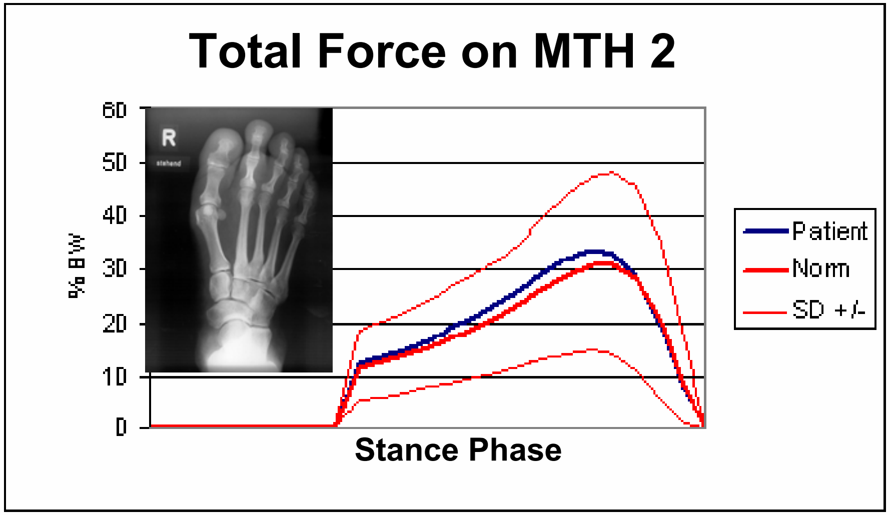
Computer simulated treatement with tenotomy of FDL

Case 1



Tenotomy not useful

Case 2



Tenotomy excellent

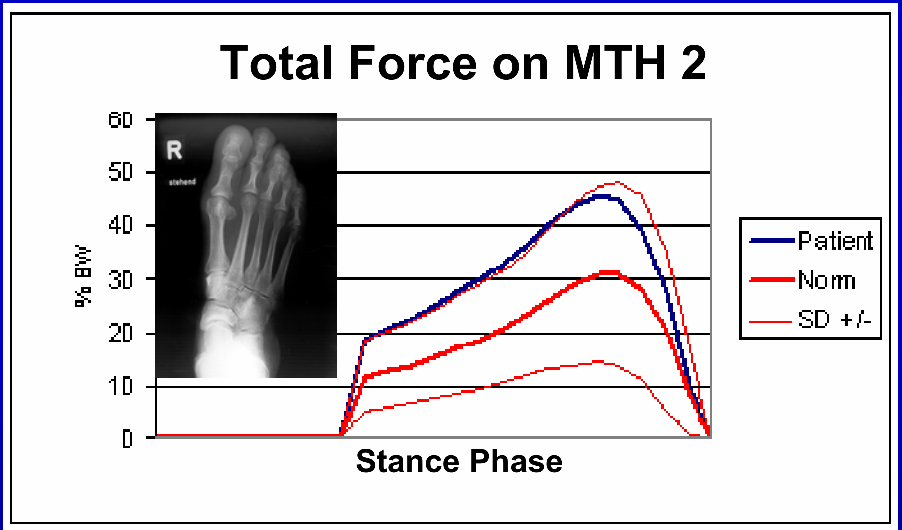
Computer simulated treatement with shortening of MT 2

Decrease of 40%, shortening of the metatarsal of 1cm

Computer simulated treatement with shortening of MT 2

Decrease of 40%, shortening of the metatarsal of 1cm

Case 1



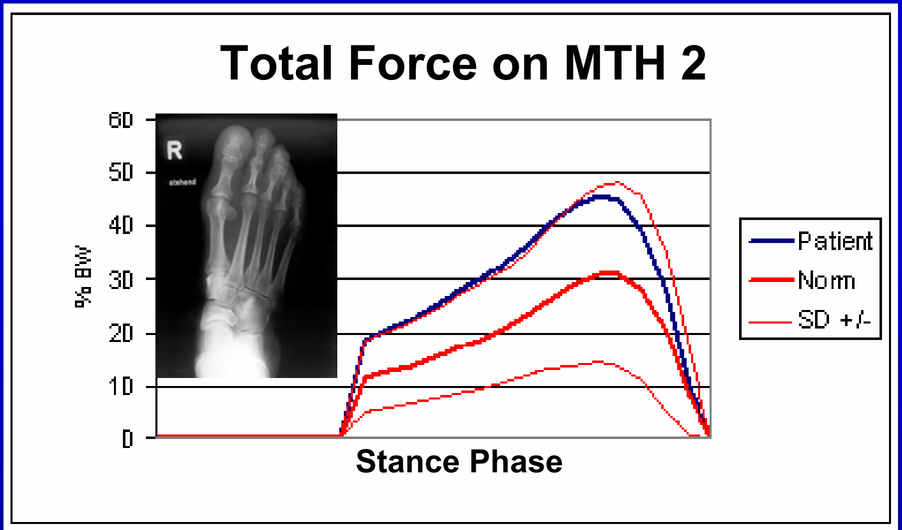
Osteotomy could be useful

not better than the insole

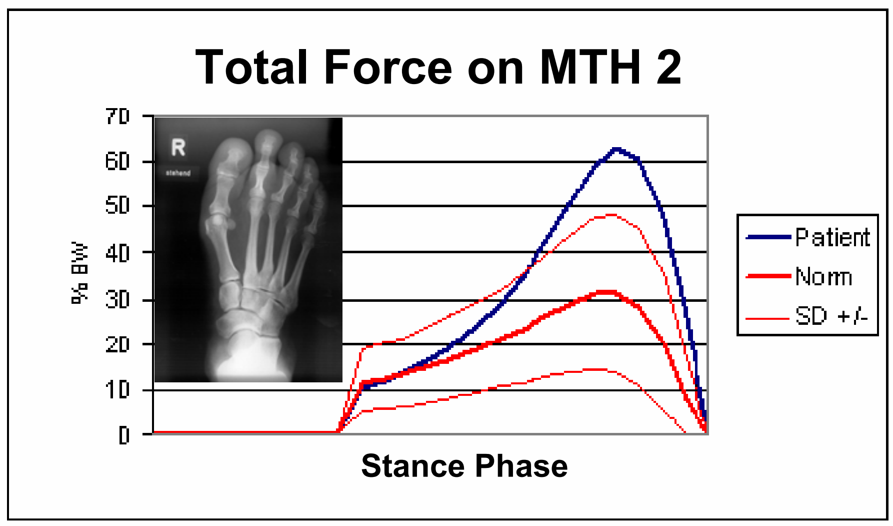
Computer simulated treatement with shortening of MT 2

Decrease of 40%, shortening of the metatarsal of 1cm

Case 1



Case 2



Osteotomy could be useful

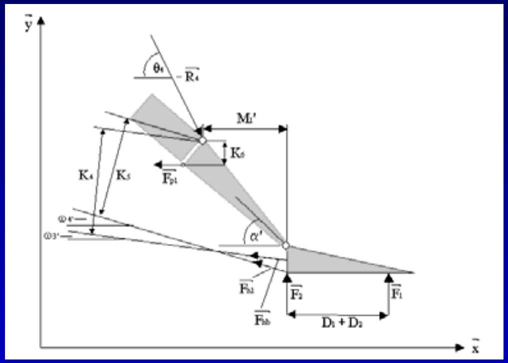
not better than the insole

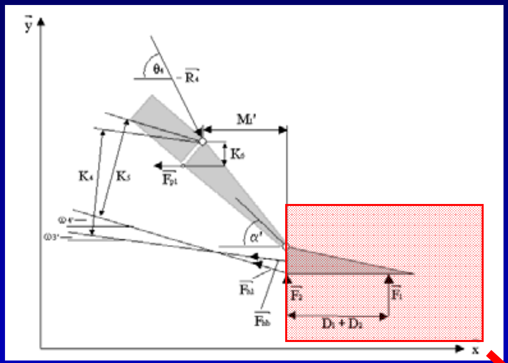
Osteotomy not useful

Shortening of the second metatarsal leads not to a significant reduced total force on the metatarsal head

1. Is there a correlation between the length of the metatarsals and increased forces at the metatarsal heads

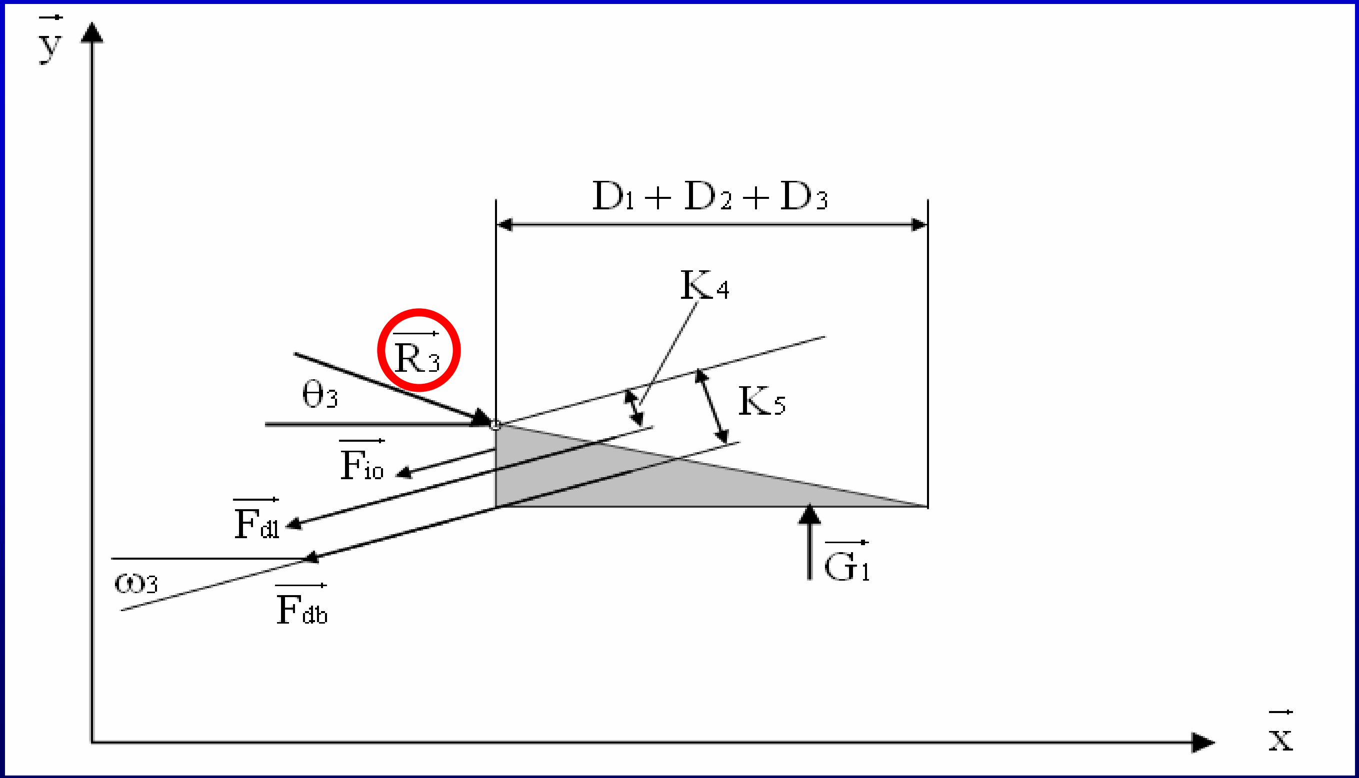
Theoretical Study

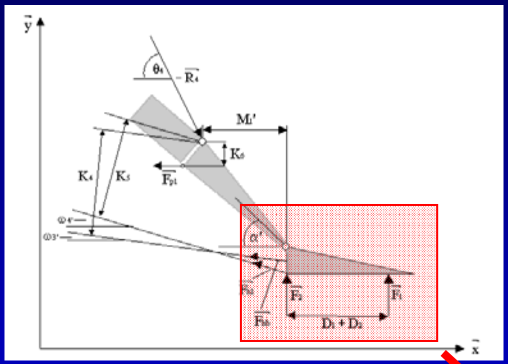




Theoretical Study

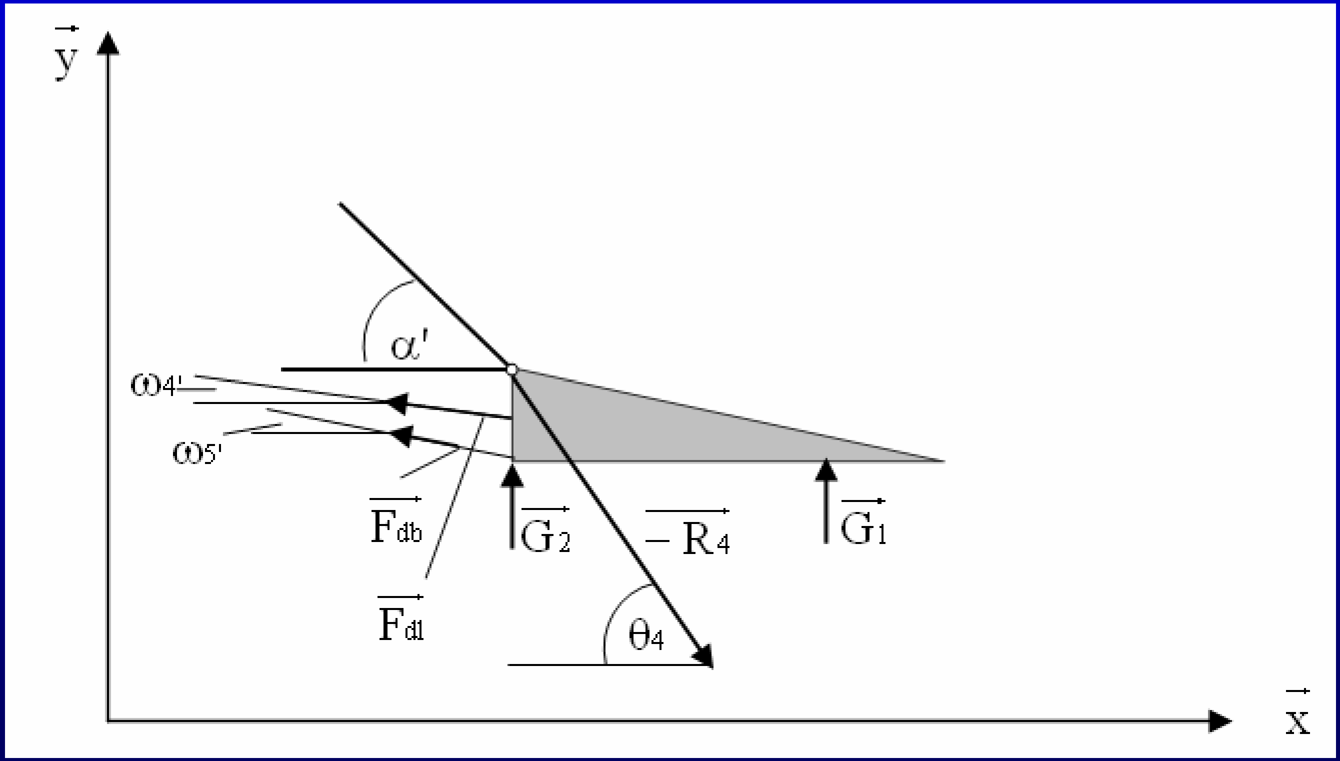
Determination of the Intraarticular Force





Theoretical Study

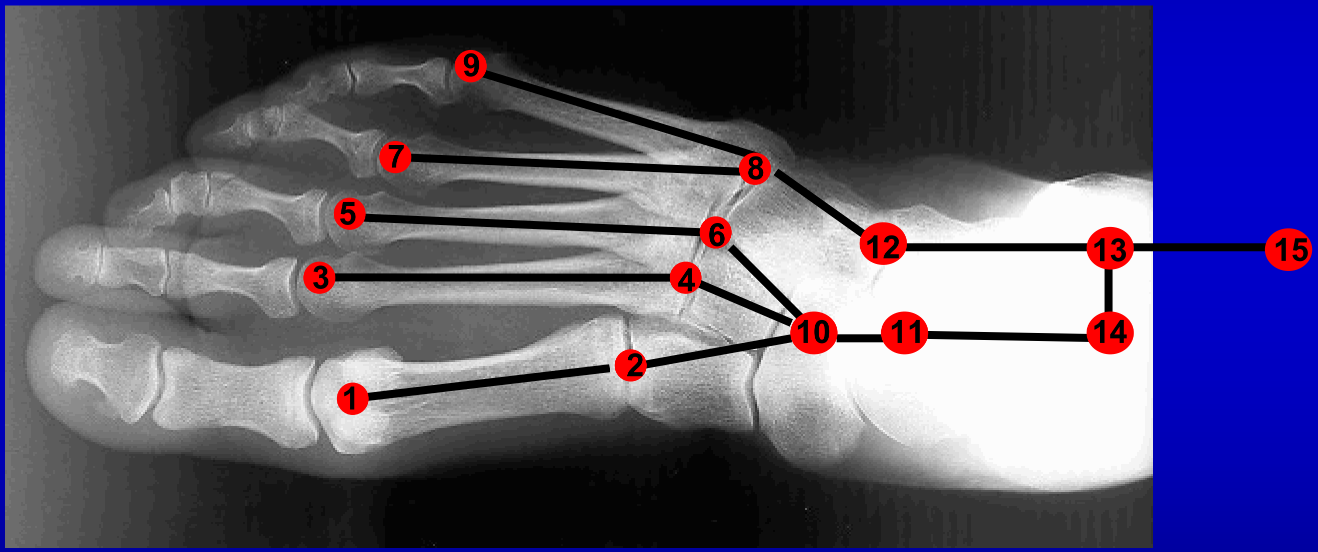
Determination of the Resultant Force



Experimental Study

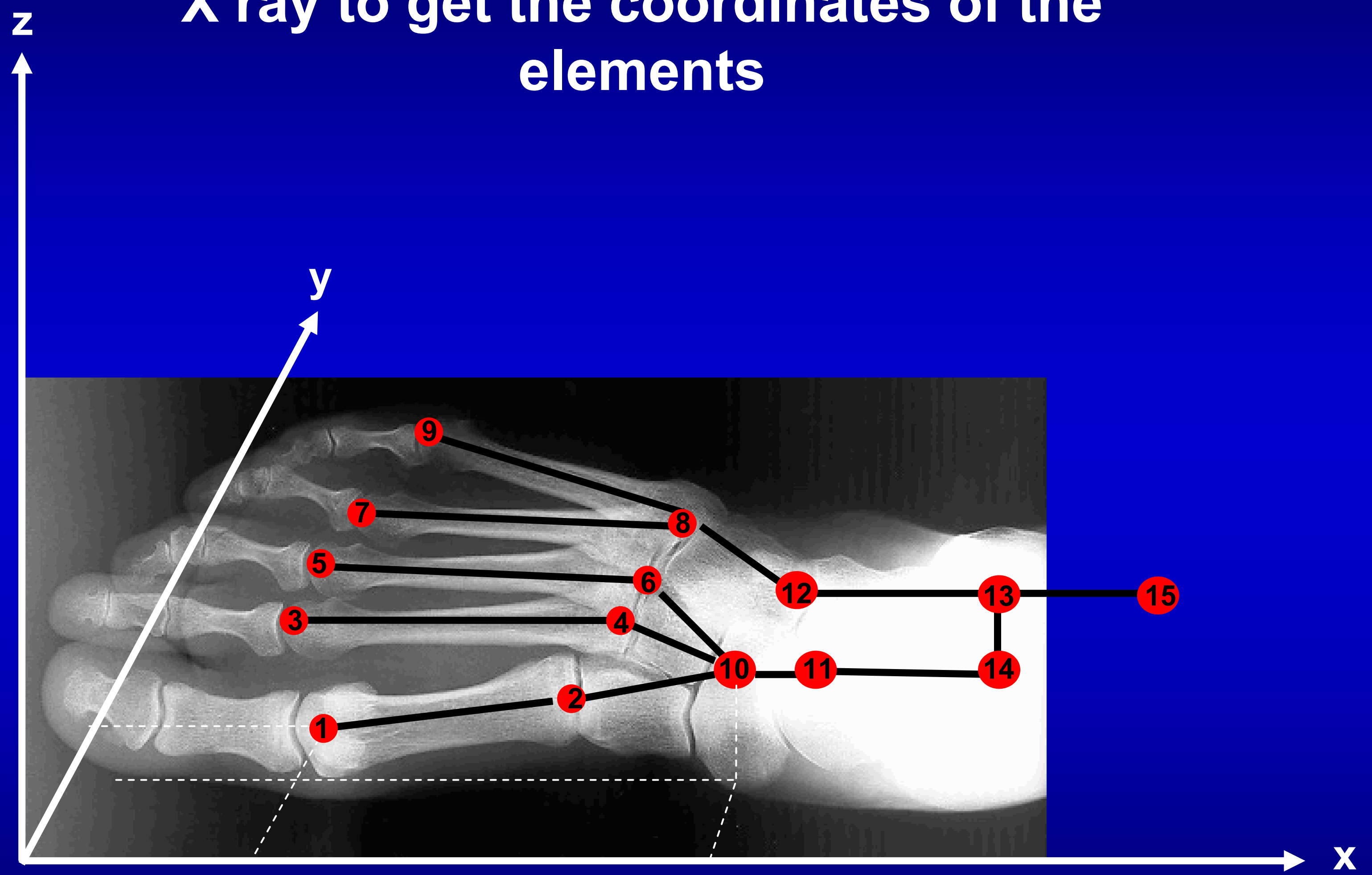
Finite Element Method
(Space Truss Elements)

element	node i	node j
1	1	2
2	3	4
3	5	6
4	7	8
5	9	8
6	2	10
7	4	10
8	6	10
9	8	12
10	10	11
11	12	13
12	14	13
13	13	15

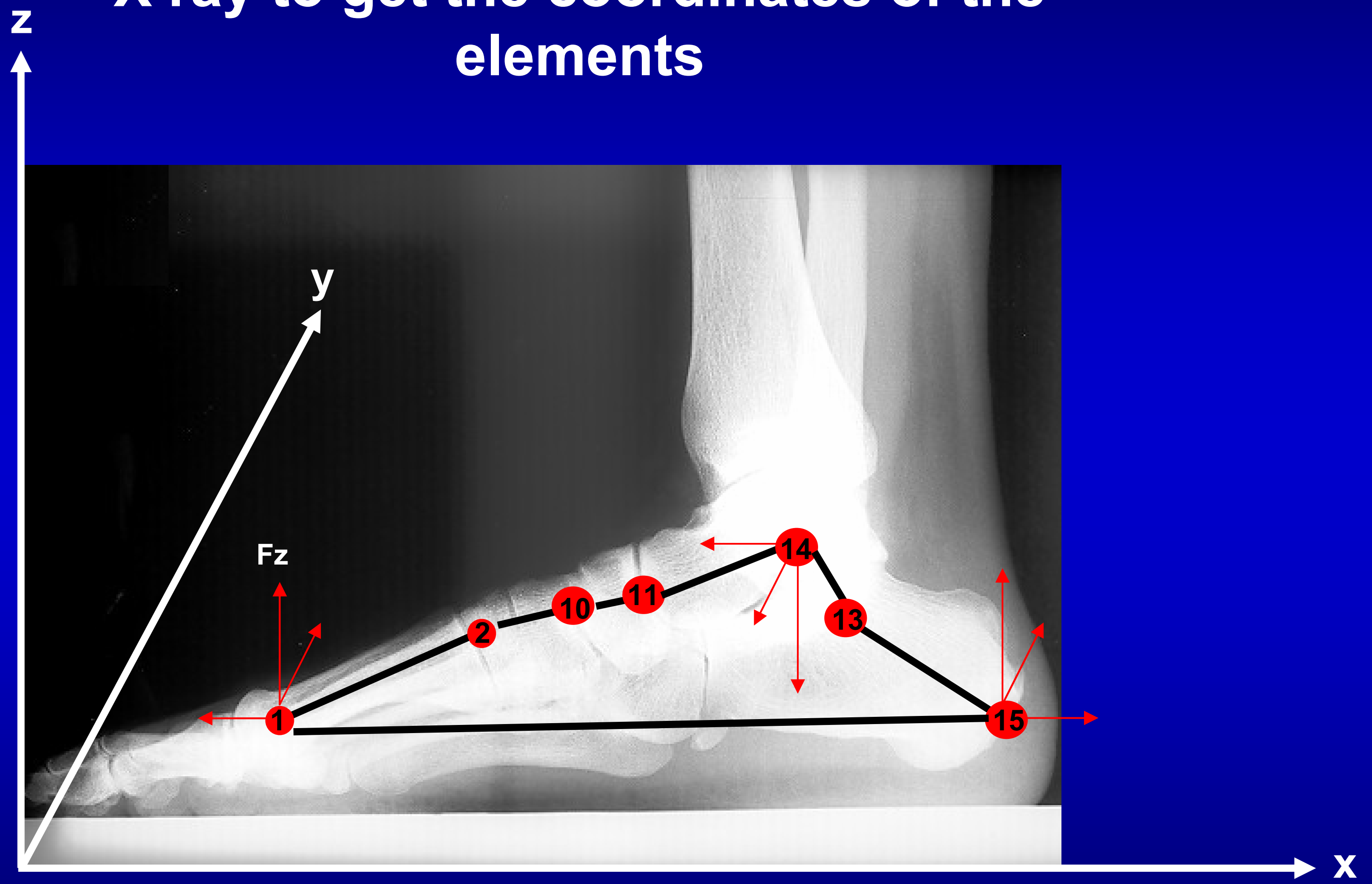


13 element model

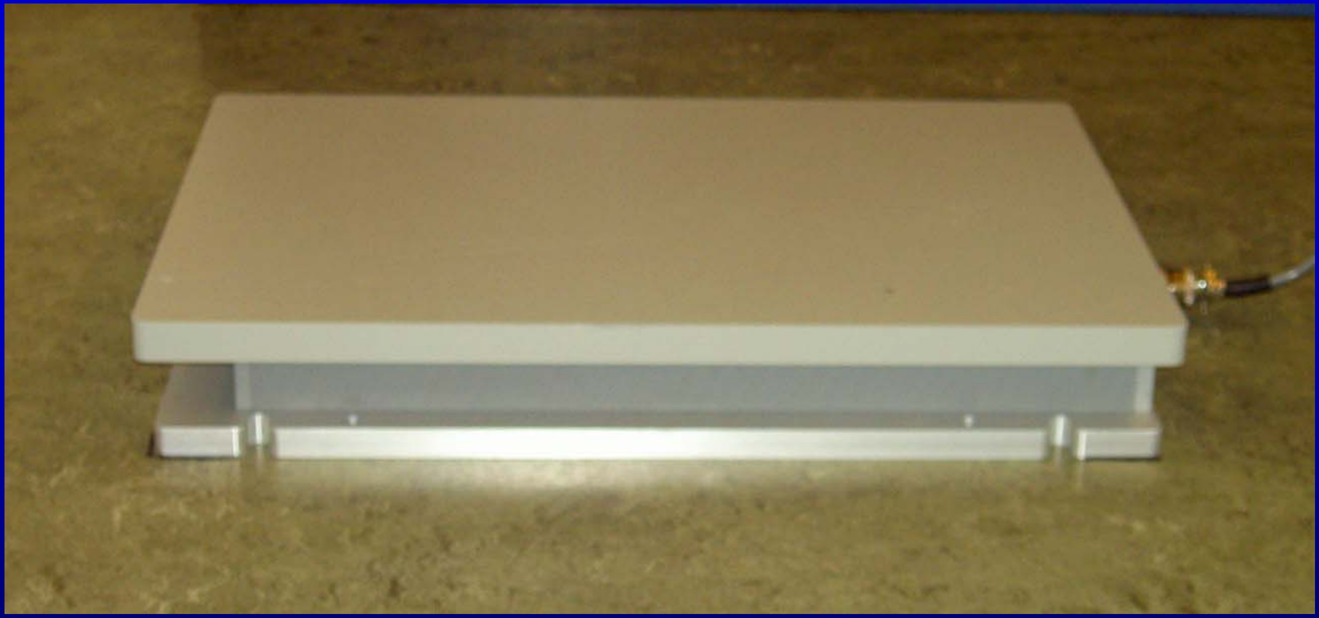
X ray to get the coordinates of the elements



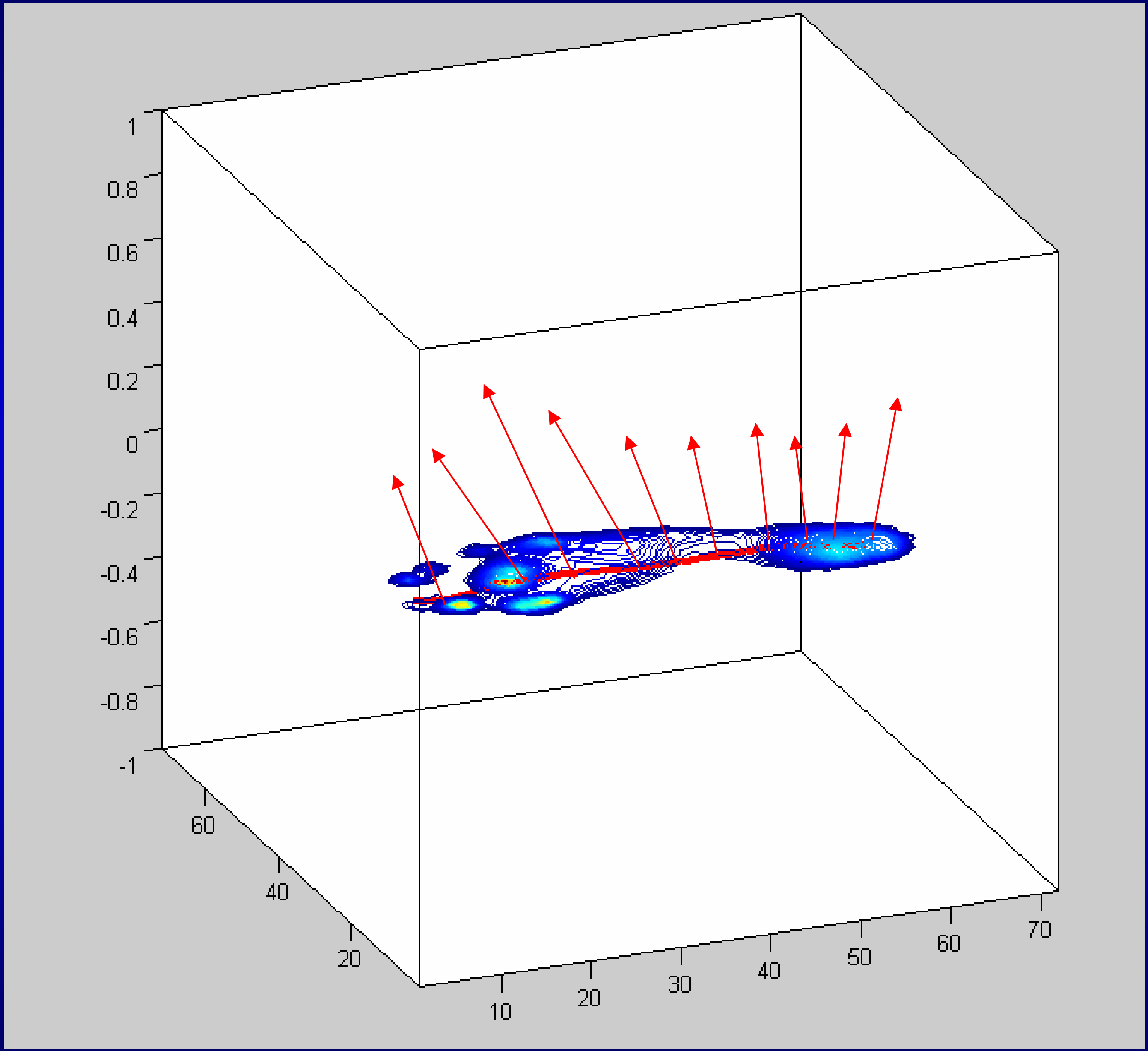
X ray to get the coordinates of the elements



AMTI 3 D Force Plate



AMTI 3 D Force Plate + EMED SF Pressure measurement



1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
60
40
20
10
20
30
40
50
60
70

ELSEVIER

Clinical Biomechanics 16 (2001) 446–454

CLINICAL BIOMECHANICS

www.elsevier.com/locate/clinbiomech

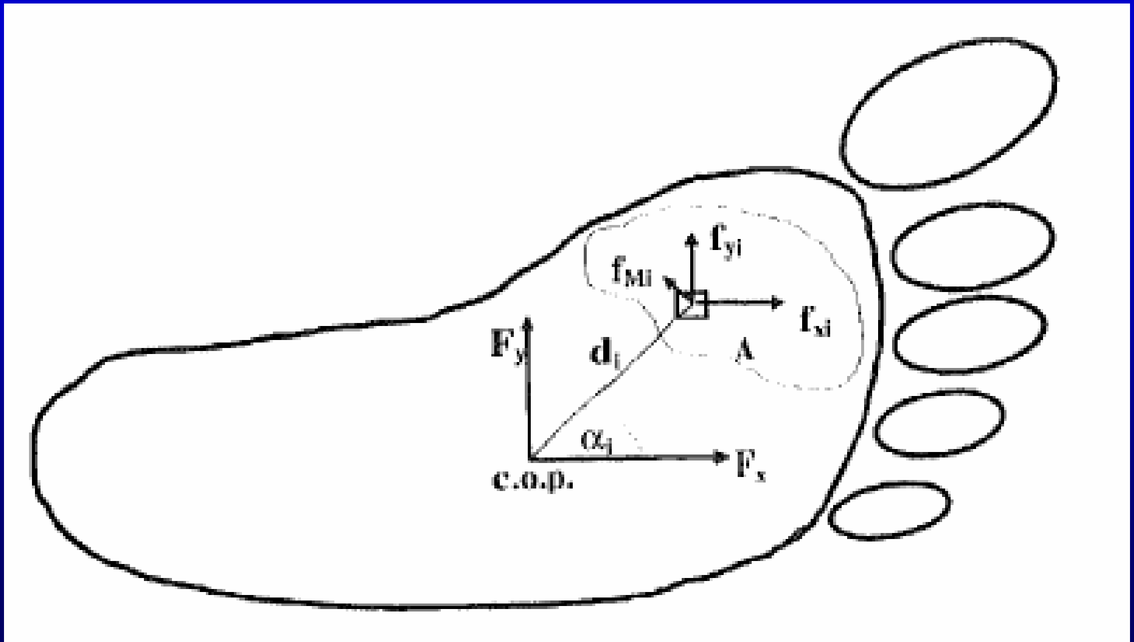
Pattern of abnormal tangential forces in the diabetic neuropathic foot

Luigi Uccioli [a], Antonella Caselli [a], Claudia Giacomozzi [b,*], Velio Macellari [b], Laura Giurato [a], Lina Lardieri [a], Guido Menzinger [a]

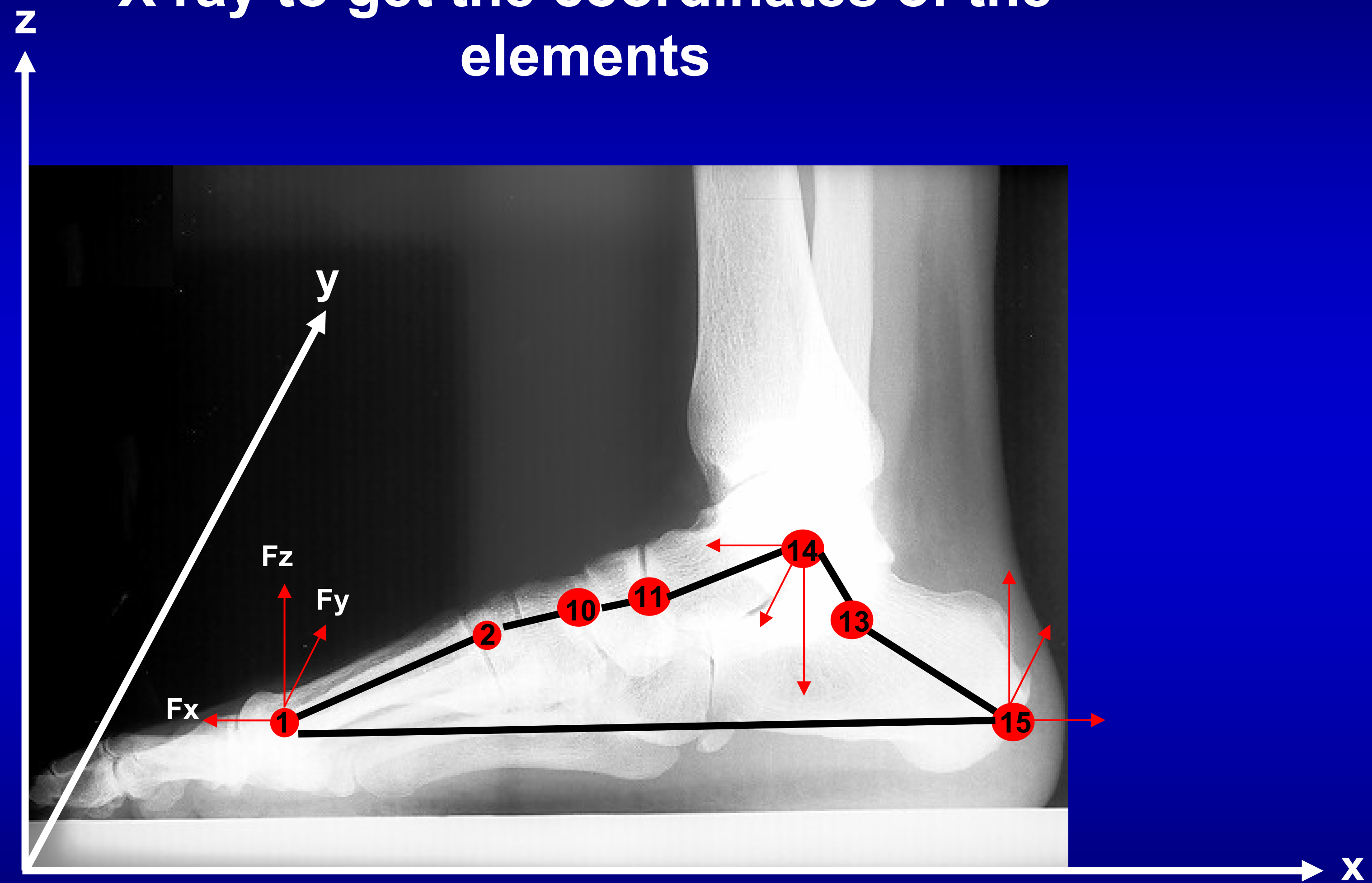
[a] *Department of Internal Medicine, University of Rome Tor Vergata, Rome, Italy*

[b] *Biomedical Engineering Laboratory, Istituto Superiore di Sanità, Viale Regina Elena 299, 00161 Rome, Italy*

Received 29 September 2000; accepted 7 February 2001



X ray to get the coordinates of the elements



Shortening of 1 cm of the metatarsal 2 leads to an increased force in the vertical direction of 4%

Shortening of 1 cm of the metatarsal 2 leads to an increased force in the vertical direction of 4%

~ 1% Body Weight (stdv = 7% BW)

The change of the resultant force at the second metatarsal head after a shortening is not significant and is not due to the shortening itself

It is due to the reduced force at the tip of the second toe because of loosening of toe function after the operation

Experimental Study

50 healthy / 50 metatarsalgia

Experimental Study

50 healthy / 50 metatarsalgia

No correlation between length of metatarsals and the resultant or intraarticular forces

2. Is there a correlation between metatarsalgia and increased forces at the metatarsal heads

Healthy (n=505) versus Metatarsalgia (n=342)

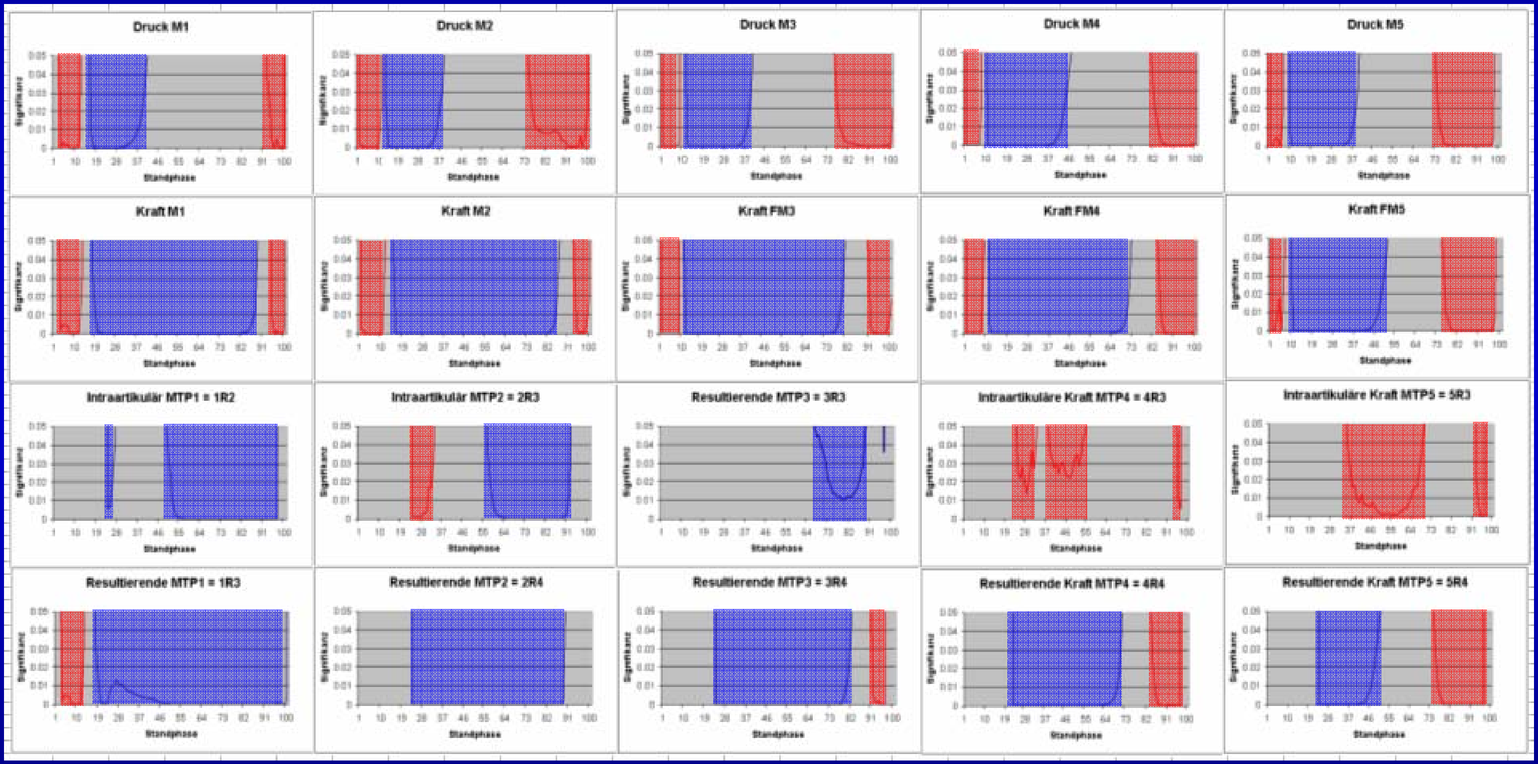
Ray 1 2 3 4 5

Max. Pressure

External Force

Intraart. Force

Resultant Force



signifcant decrease

signifcant increase

The Facts

- The resultant forces at the metatarsal heads do not correlate with the external forces

The Facts

- The resultant forces at the metatarsal heads do not correlate with the external forces
- The resultant forces are higher than external forces

The Facts

- The resultant forces at the metatarsal heads do not correlate with the external forces
- The resultant forces are higher than external forces
- Metatarsalgia correlates not with increased resultant forces

The Facts

- The resultant forces at the metatarsal heads do not correlate with the external forces
- The resultant forces are higher than external forces
- Metatarsalgia correlates not with increased resultant forces
- The length of metatarsals correlates not with increased forces

In Conclusion

We should not believe in orthopedic surgeons doctrin we should measure the problem

Thank you for your attention

Kantonsspital Aarau

Department of Orthopedic Foot Surgery

Gait Laboratory