Biomechanics: past, present and future

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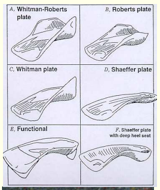
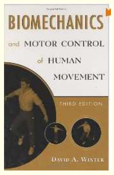
Biomechanical Research pre – 1980s

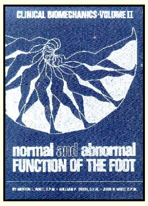
- 'Mainstream' biomechanics
  Basic modelling
- Winter, Elftman, Lapidus,
- Wright et al, Close, Isman, Inman





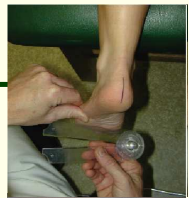
Clinical biomechanics pre 1980s

- Podiatric biomechanics - 1971 a vintage year
  - Root, Orien and Weed
  - Sgarlato, Compendium of podiatric biomechanics. CCPM San Francisco
  - Valmassy



Root derived orthoses

- Root /modified Root Device
- Blake's Inverted Device
- Kirby's Medially Skived Device
- Tri-plane wedge

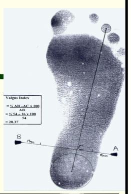


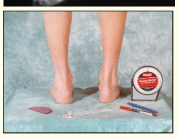
Biomechanics in the 90s

- Reliability studies
- Questioning the dogma
- Competing theories
- Emergence of evidence

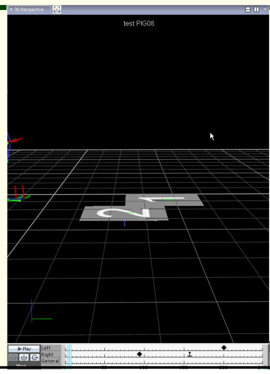
– Foot print indices
  • Valgus index (Rose 1991, Thompson 1994)
  • Arch index (Cavanagh 1987)
  • Misc other (Kouchi 1996, Freychat 1996)
  • Conflict (Kernozek 1990, Hawes 1992)
– Radiographic measures (Cavanagh 1997)
  • Individual angles
  • Composite angles

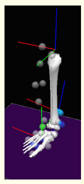
Open chain and closed chain measures
OKC and CKC states measurably different
Eg 9.4° at TNJ, 4.4° at STJ (Kitaoka 1995)
Foot functions around RCSP c/f NCSP (McPoil 1996)
OKC application based on theory
OKC frontal plane biased
Reliability of all clinical measures limited
(Ball 1993, Elveru 1988, McPoil 1995)



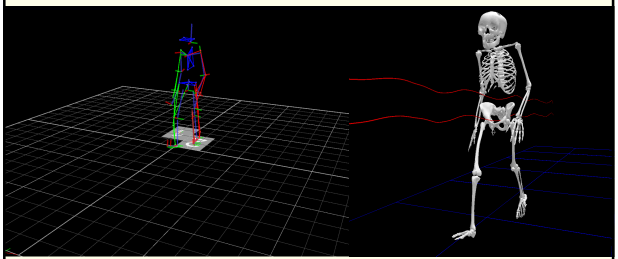


Modern day biomechanics



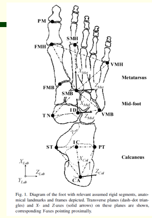


Complex modelling



Multisegment foot models

- Eg Oxford multi (3) segment foot model
- Heidelberg ‘functional segment’
- Used in conjunction with standard models for hip, knee and ankle
- Problems with shod
- Mainly kinematics only



Modelling – finite element and others

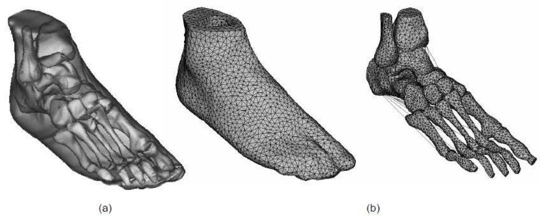
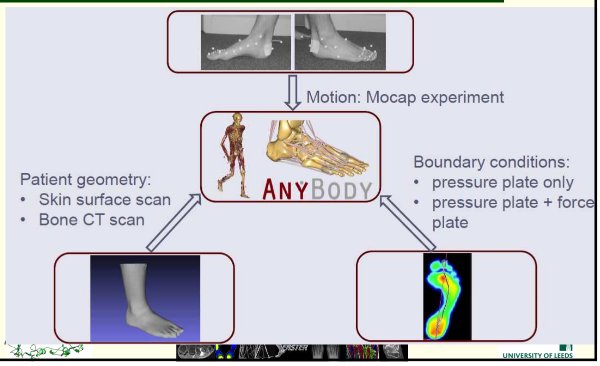
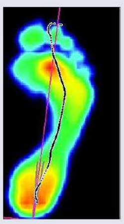


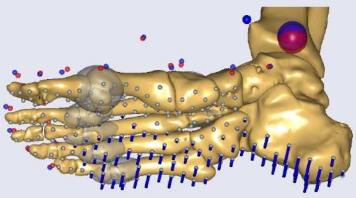
Figure 1. (a) Surface model and (b) FE meshes of the encapsulated soft tissue and bony structures.

AnyBody -Glasgow Maastricht



Use of the foot model – applying boundary conditions (ground reaction force)





Does Science help us to understand how foot orthoses work?

Change Foot Motion

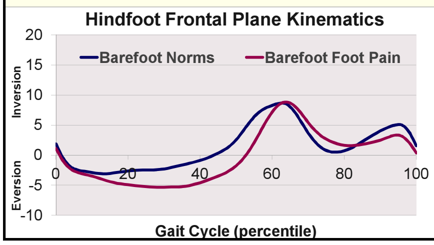
versus

Modifying Internal Foot Forces

Changing Foot Motion

- Biomechanical Theory and some gait studies suggest:

  Foot Pain - Relates - ↑ Rearfoot pronation.
- Supported by comparative studies between healthy pain free "normals" and foot pain groups.



PhD Results

Greater Rearfoot Eversion (pronation) In participants with **midfoot pain** (n=15). **Compared** to control group of **norms** (n=15)

Foot Orthoses Change Foot Motion

- Gait Studies in normal healthy and pathological groups.
  - Concentrated on rearfoot pronation
  - Show mixed results:
- **+ 3° to - 5° Change of rearfoot eversion (pronation)**

Author	Participants	Orthoses	Biomechanical Measure	Difference from shod
Branthwait et al. 2004	Healthy group n= 9	Semi custom	Max calcaneus eversion	- 2.1°
		Medial wedge	Max calcaneus eversion	- 3.1°
Brown et al. 1995	Health group n=24	Bespoke rigid cast	Max calcaneus eversion	- 0.4°
		Arch support	Max calcaneus eversion	- 0.2°
Davis et al. 2008	Healthy group n=19	Bespoke rigid cast	Max calcaneus eversion	- 0.8°
		Semi custom	Max calcaneus eversion	- 0.7°
Ferber et al. 2011	Healthy group n=20	Semi custom	Max calcaneus eversion Medial arch angle	- 0.3° - 0.1°
		Arch support	Max calcaneus eversion Medial arch angle	+ 0.2° + 0.2°
McPoil et al. 2000	Healthy group n=10	Semi custom	Max internal tibial rotation	- 2.9°
		Arch support	Max internal tibial rotation	- 3.3°
Nester et al. 2003	Healthy group n=15	10° Medial wedge	Max internal tibial rotation	- 3°
Pascual et al. 2009	Healthy group n=12	7° Medial wedge	Max internal tibial rotation Foot abduction	+ 0.7 -1.6
		7° Lateral wedge	Max internal tibial rotation Foot abduction	+ 0.2 - 0.4
Zifchock et al. 2008	Healthy group n=19 Pes Planus low arch	Bespoke rigid cast	Max calcaneus eversion Calcaneus eversion velocity	+1° - 20°/s
		Semi custom matched to arch height	Max calcaneus eversion Calcaneus eversion velocity	+0.2° - 20°/s
Ferber et al. 2005	Foot & leg pain n=11	Semi custom 4° wedge	Terminal stance coupling angle	+3.3°
		Semi custom 15° or 25° wedges	Terminal stance coupling angle	- 2.5
Genova et al. 2000	Symptomatic Pes planus n=13	Semi rigid n=10 & soft n=3	Max calcaneus eversion	- 2.2°
Scacroff et al. 2007	Symptomatic Pes planus n=8	Medial wedge	Max calcaneus eversion	+1.5°
		Semi custom	Max calcaneus eversion	- 1.8°
		Proprioceptive orthoses.	Max calcaneus eversion	+ 0.6°
Stell et al. 1994	Symptomatic n=60	Bespoke rigid cast	Max calcaneus eversion Calcaneus eversion velocity	- 2° - 40°/s
		Semi custom arch support & medial wedge	Max calcaneus eversion Calcaneus eversion velocity	- 5° - 100°/s
McCulloch et al. 1993	Symptomatic n=10	Rigid Cast n=7 & Semi-Rigid Cast n=3	Inversion at heel strike Max calcaneus eversion	- 3.3° - 3.3°

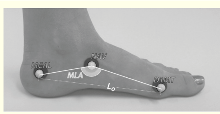
Changing foot motion

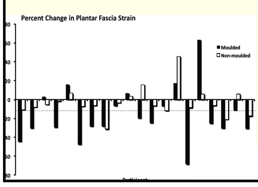
- Selection of Gait Studies:
- The results are variable in rearfoot eversion (pronation):
  - **2° to 5° Reductions - 10 studies**
  - **0 to 1° Reductions - 5 studies**
  - **0 to 3° Increases - 8 studies**
- **+ 3° to - 5° Change of rearfoot eversion (pronation)**

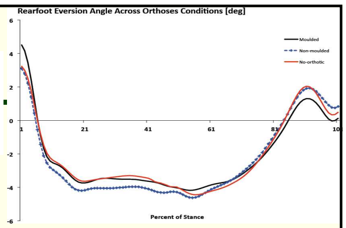
EG Ferber & Benson 2011

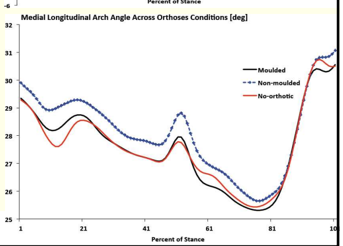
Changes in multi-segment foot biomechanics with a heat-mouldable semi-custom foot orthotic device

Journal of Foot and Ankle Research 2011, 4:18









How do Foot Orthoses Work?

Changing Foot Motion

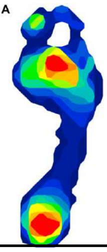
versus

Modifying Internal Foot Forces

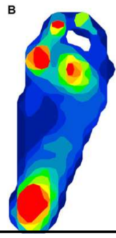
Internal Foot Forces
Difficult to measure

- **Common Surrogate Measures - Foot Pressure**
- **Abnormal Foot Pressure patterns with Foot Pathology**
- **E.G. Midfoot OA and Healthy Groups** ***Rao et al. 2011, Menz et al. 2010***
  Relationship between foot pressure & symptom severity

A
Healthy

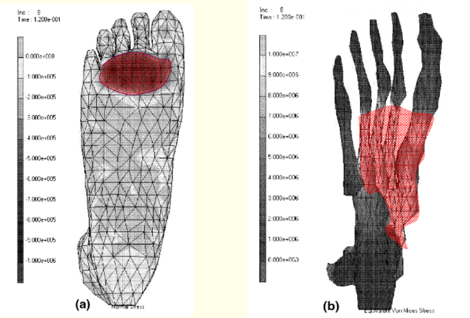


B
Midfoot
OA



Finite Element Models

Normal External Foot Pressure compared to Internal Foot Forces



Chen 2001, Clinical Biomechanics :16 , p614-620

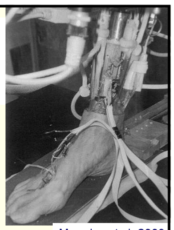
Direct Bone Stress Measurement

Strain Gauges - Highly Invasive

Used mainly in cadavers & some (brave) humans

- Foot Orthoses Can Alter Bone Forces
- Reductions Compression ,Tension & Shear Strain
  – Metatarsal and Tibia Bones

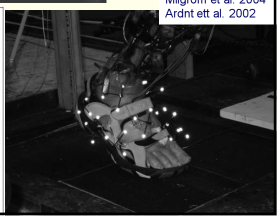
Meardon et al. 2009, Ekenman et al.2002



Meardon et al. 2009
Milgrom et al. 2004
Ardnt ett al. 2002

Table 2: Key Variables with Condition Means, 95% Confidence Levels, Effect Sizes, and *p* Values

Variable	Condition	Mean	95% Confidence Levels Lower Bound	95% Confidence Levels Upper Bound	Effect Size	*p* value
Compression Strain ($\mu\varepsilon$)	No orthotic	−775.5	−417.9	−1135.9	referent	referent
	Custom	−697.5	−325.0	−1044.9	0.17	0.04
	Semi-custom	−758.6	−396.6	−1115.5	0.04	0.98
Tension Strain ($\mu\varepsilon$)	No orthotic	353.9	191.2	518.8	referent	referent
	Custom	290.1	118.0	445.9	0.31	<0.01
	Semi-custom	305.2	143.3	471.0	0.24	0.05
Shear Strain ($\mu\varepsilon$)	No orthotic	1097.9	564.1	1635.4	referent	referent
	Custom	963.7	407.6	1479.1	0.20	<0.01
	Semi-custom	1035.1	498.6	1570.0	0.09	0.13
Compression Strain Rate ($\mu\varepsilon$/s)	No orthotic	−5713.6	−4371.8	−7069.4	referent	referent
	Custom	−4869.5	−3391.8	−6117.0	0.63	0.01
	Semi-custom	−5316.1	−3939.7	−6640.1	0.30	0.13
Tension Strain Rate ($\mu\varepsilon$/s)	No orthotic	5034.9	3790.6	6313.2	referent	referent
	Custom	4268.4	2742.3	5298.1	0.34	0.15
	Semi-custom	4252.7	3003.6	5530.1	0.35	0.13
Shear Strain Rate ($\mu\varepsilon$/s)	No orthotic	8539.3	7005.1	10029.3	referent	referent
	Custom	7134.5	5408.3	8468.0	0.69	<0.01
	Semi-custom	7504.4	5977.5	9001.7	0.51	0.03



Modern clinical practice – what do we know?

- Weak evidence for foot orthoses in managing a range of MSK conditions.
- Some effects on patient reported outcomes – but equivocal in different conditions
- Effects on kinematics more limited than expected ...
  and vary between patients!
- Reasonable data in some specific conditions

Clinical knowledge - summary

<u>The effects of orthoses on the mechanical function of the foot</u>

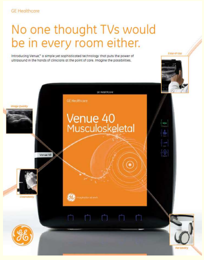
- Cushioning reduces pressure – indicated for callus and ulcers
- U's and wings reduce force and pressure – as above plus internal stresses.
- New viscoelastic materials also reduce high frequency force
- Contoured devices are good at redistributing force (and pressure)
- Large changes in internal distribution of forces within the foot are likely brought about by FFO therapy

- FFOs change foot kinematics in a predictable manner but foot kinetics are too difficult to measure as yet.
- The effect of altered foot mechanics on kinematics and kinetics of proximal structures is small
- Locally the effects are large
- Contoured devices are probably not interchangeable with other approaches such as flat FFOs and taping.

A few predictions...

Imaging in biomechanical research

- Standalone – ultrasound, MRI
- Combination techniques



Imaging in biomechanical research

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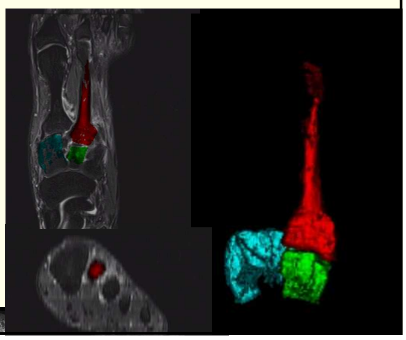
Imaging in biomechanical research

3D Bone volumes segmented using Analyze v10

- 3D bone volumes
- 3D volume abnormal bone marrow lesions



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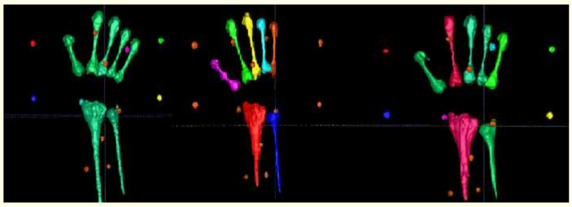
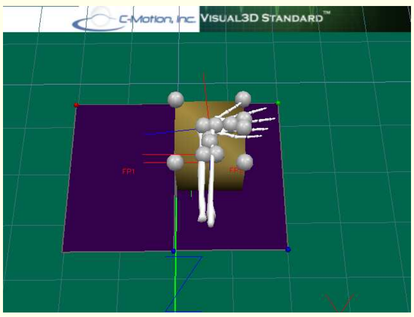
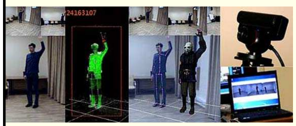


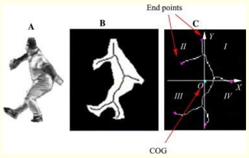
Imaging in biomechanical research



Markerless technologies

Markerless (ish) technologies





Likely clinical developments

The future:

- Instrumented stocking, scanner room or stereography?
  - Joint motions and forces
  - Pressures (triplanar)
  - Temporal and spatial measures
  - Real time
  - Less than £5 per assessment
- Clinical – PROMS in practice, systematic datasets, affordable dynamic quantification, internal imaging

Thank you

NHS National Institute for Health Research

Arthritis Research UK Providing answers today and tomorrow

EPSRC Engineering and Physical Sciences Research Council

iMBE Engineering '50 active years after 50' through multi-disciplinary research, innovation, knowledge creation and translation.

NHS National Institute for Health Research Leeds Musculoskeletal Biomedical Research Unit