Biomechanical aspects of orthopedic footwear constructions

– details for the treatment of forefoot problems –

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The roots of orthopedic footwear

≈ 1000 - 750 B.C.

50 year old woman
• right great toe disarticulation
• wooden prosthesis, fixed with a sleeve

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The roots of orthopedic footwear - Europe

1917
foundation of the first association in Germany:

“Registered Federation of German orthopedic shoemakers”
Orthopedic products
- Classification and description of devices

- orthopedic footwear
  - customized
  - prefabricated
  - modifications
- foot orthoses (FO)
  - “classical” biomechanical
  - motor-sensory stimulating
- orthoses
- soft Orthoses
- foot prostheses
- ...

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"Biomechanics is the science that examines forces acting upon and within a biological structure and effects produced by such forces."

(Nigg et al. 1994)

\[ GRF = m \times a \quad [N] = \left[ \frac{kg \times m}{s^2} \right] \]
Types of mechanical stress

Load detection during orthopedic treatment conditions

Why?
- to know about the physiological situation,
  Cavanagh et al. 1994, Cheng et al. 2010
- the differences at several foot pathologies like:
  - Diabetic Foot Syndrome,
    Cavanagh et al. 1994, Wrobel et al. 2010
  - or results of overloading like stress fractures
    Arndt et al. 2002, Milgrom et al. 2002
- and to control the effects
  of the orthopedic treatments
  Brown et al. 2004, Hutchins et al. 2007
Plantar pressure

\[ p = \frac{F}{A} \quad \text{[Pa} = \frac{N}{m^2} \text{]} \quad \text{[N/cm}^2\text{]} \]

Measuring systems
- platforms
- insoles

http://www.novel.de/novelcontent/emed
http://gebiom.de/index.php?comp=0&lang=de&dyn=1&link_gr=druckmessung&link_id=3
http://h‐p‐cosmos.com/de/anwendungen/laufanalyse/index.htm

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Detection of other forms of loading during orthopedic treatment conditions

**Why and how?**

- **plantar pressure measurements** with insoles  
  → stress analysis with **one-dimensional parameters**  
  *Davis et al. 1998, Cheng et al. 2010*

- **multiaxial stress analysis**  
  in general with **invasive procedures!**  
  *Arndt et al. 2002, Milgrom et al. 2002*

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**Bending load and resulting stress at the foot**

\[
M_b = F_b \times d = \sigma_{b_{\text{max}}} \times W_{ax} [Nm]
\]

- **Mid stance phase of gait**
  - \(M_b, \text{Nm}\)
  - \(\sigma_b, \text{N/mm}^2\)

- **Terminal stance phase of gait**
  - \(M_b, \text{Nm}\)
  - \(\sigma_b, \text{N/mm}^2\)

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Bending load and resulting stress at the foot

\[ M_b = F_b \times d = \sigma_{b_{\text{max}}} \times W_{ax} \ [Nm] \]

<table>
<thead>
<tr>
<th>Mid stance phase of gait</th>
<th>Terminal stance phase of gait</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_b [\text{Nm}] )</td>
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... increasing bending moments resulting in higher bending stress!

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Stief, T.: PAC Symposium 2016, Quebec

Bending load detection

vebito\text{SCIENCE}

\( \rightarrow \text{insole system} \)

- data frequency
  - 125 Hz
- A/D-Conversion
  - 16 bit
- data transfer protocol
  - wifi

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Stief, T.: PAC Symposium 2016, Quebec
Bending load detection

vebitoSCIENCE - results of Mb calibration at MTH I

\[ y = 1.00x + 0.26 \quad R^2 > 0.999 \]

× MTH I
× CT_MTH V

→ high measuring accuracy!

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Bending stress during walking

Arndt et al. 2002

vebitoScience
Bending stress during walking

mod. nach: Arndt et al. 2002

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Biomechanical aspects of orthopedic products

- orthopedic footwear
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- foot orthoses (FO)
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- foot prostheses
- ...

Customized Foot Orthoses - Diabetic Foot Syndrome

- patient:
  - m, 67 yrs., 95 kg, 1.81 m
  - Diabetic Foot Syndrome, no ulcers

- customized foot orthoses
  - individual last
  - sandwich design

  - plantar stress reduction
    - combined with a prefabricated
      in-depth shoes for the Diabetic Foot Syndrome

- plantar pressure measurements
  (with insoles / with customized Foot Orthoses (FO))
Customized Foot Orthoses - Diabetic Foot Syndrome

**with insole**

**with FO**

**biomechanical results:**

- **left big toe (DP)**: 24 N/cm² → -47%
- **left big toe (ball)**: 22 N/cm² → -41%
- **left heel**: 21 N/cm² → -44%

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Customized Foot Orthoses - Diabetic Foot Syndrome

evidence - Diabetic Foot Syndrome
- customized FOs are more efficient to relieve the MTP I and MTP V area, but there are big individual differences depending on the treatment concepts (El-Hilaly et al. 2013, Bus et al. 2004)

→ treatment standards for practice necessary to prevent the emergence of plantar ulcers and the recurrence (Paton et al. 2011, Cavanagh et al. 2010, Bus et al. 2015)

- low evidence of good quality supports the use of therapeutic footwear and foot orthoses with demonstrated pressure relief to prevent plantar foot ulcer recurrence

→ further work: high-quality controlled studies are needed (Bus et al. 2016, Nagel et al. 2009)

Orthopedic footwear modifications - Forefoot (toe only) rocker soles

- indications
  - hallux limitus and hallux rigidus
  - hallux valgus
  - rheumatoid arthritis at MTP I

- treatment objectives
  - facilitation the rollover of the foot during gait
  - reduction of forefoot stress during toe-off
  - protection of the metatarsal heads
  - reduction of bending stress at the metatarsophalangeal joints
Orthopedic footwear modifications
- Forefoot (toe only) rocker soles

evidence

Forefoot bending load at the human foot during walking using different shoe sole modifications

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Method

Shoe conditions

- **without modification (woR)**
  Samba, adidas group®

- **with control condition (wCR)**
  nora® Lunasoft AL, 10 mm, SH 52A

- **with forefoot rocker (wR)**
  nora® Lunasoft AL, 10 mm, SH 52A
  **apex:** 10 mm proximal MTP I and MTP V

**randomized, controlled design**
 Method

- **subjects**
  - 24 (11 m / 13 f)
  - 28 ± 6 years
  - shoe sizes US 10
  - no pathologies

- **measurements**
  - vebitoSCIENCE insole system
  - treadmill, velocity: subjects preferred

- **data preparation**
  - 30 continuing gait cycles
  - standardized to 100 % gait cycle

parameters

1. dorsiflexion moments (DFM)
2. plantarflexion moments (PFM)
3. range = DFM – PFM

- **data analysis**
  - Gaussian distribution:
    Kolmogorov-Smirnov-test
  - single factor repeated ANOVA, post-hoc Bonferroni correction
  - significance level:
    - \( \alpha < 0.05 \), *
    - \( \alpha < 0.001 \), **
Results - MTP I

- with forefoot rocker soles:  
  - significant decreased dorsiflexion moments at MTP I
- with forefoot rocker soles:  
  - significant decreased plantarflexion moments at MTP I
- with forefoot rocker soles:  
  - significant decreased range at MTP I

Discussion

- **the treatment objective of forefoot rocker soles is to relieve the forefoot**
  - this proof has not yet been unequivocally provided by plantar pressure distribution measurements in the shoe (Hutchins et al. 2009; Spencer 2000)
  - forefoot rocker soles are used to rock the foot during stance phase without bending (Janisse 1995)
  - the statistical decreased moments during walking show these effects of forefoot rocker soles
  - the shape of the forefoot rocker soles results in the reduction of the alternating loads and not only by stiffening the sole with an additional material
Prefabricated orthopedic footwear - Forefoot offloading shoes and walkers

- **forefoot offloading shoes - treatment objectives**
  - immobilization of the toes and offloading the forefoot, e.g. after surgery
  - widely used to reduce plantar pressure in the forefoot region in case of ulcers as a simple and cost-effective device

- **walkers - treatment objectives**
  - immobilization of the foot and ankle
  - reduction of high local pressures
  - are claimed to provide similar pressure relief to total contact casts
  - wound control, adaptation to foot/wound status and improved hygiene of the patient, because of the removable construction

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**Prefabricated orthopedic footwear - Forefoot offloading shoes and walkers**

**Evidence**

Influences of walkers and forefoot offloading shoes on bending and plantar pressure

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Footwear conditions

- **walkers**
  - DJO 'Aircast® AirSelectTM Short'
  - Otto Bock 'Malleo Immobil Air Walker low'
- **forefoot offloading shoes**
  - Darco 'OrthoWedge Light'
  - Fior & Gentz 'Hannover'
- **control condition**
  - adidas 'Samba'

Method

- 22 healthy subjects (9 f, 13 m); aged 18 – 52 years (30.5 ± 9.8 y)
- 40 m walkway, self-selected speed, 30 gait cycles analyzed
- relatively constant walking speed in all trials (±10%, controlled by light barriers)
- **measurement systems**
  - vebitoSCIENCE insole system
  - plantar pressure insole system
    - (medilogic, Germany)
- **randomized testing order**
- **statistics**
  - Single factor ANOVA with repeated measures,
    post-hoc Bonferroni correction,
  - $\alpha = 0.05$ (*)
Results
- Plantar pressure

• **colours**
  - forefoot offloading shoes (FOS), walkers, control condition

• **forefoot**
  - sig. reduction for FOS and walkers compared to control condition,
  - sig. differences between types of shoe

• **rearfoot**
  - sig. higher values for FOS,
  - sig. reduction for one walker

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Results
- Plantar pressure

• **forefoot**
  - sig. reduction for FOS and one walker compared to control condition,
  - sig. differences between FOS and walkers

• **rearfoot**
  - sig. higher values for FOS

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Results - Bending moments

Bending moment at MTP I

- Colours: FOS, walkers, control condition
- Sig. reduction of max DFM of all test shoes compared to the control condition
- Sig. difference between types of shoes
- Sig. difference between the FOS and between the walkers

Bending moment at D I

Reduction of mean values for all test shoes compared to neutral condition
Results
- Bending moments D I

- sig. reduction of max DFM of all test shoes compared to the control condition
- sig. difference between FOS and walkers

Forefoot offloading shoes and walkers
- Discussion

- plantar pressure
  - forefoot offloading shoes demonstrate a slightly more pressure-relieving efficacy at the forefoot
  - walkers relieving the rearfoot region
  - the pressure load transfer from the forefoot to the rearfoot using forefoot offloading shoes shows, that they should only be used to treat patient’s forefoot problems (Caravaggi et al. 2015, Nagel et al. 2009)

- bending
  - although the shoe types have a different design / construction, both reduce bending stress acting on MTP I
  - forefoot offloading shoes reduce bending at the interphalangeal joint of the big toe more than the walkers
  - the offloading effects during walking measured by bending parameters were attributable to demonstrate differences between the two forefoot offloading shoe conditions
Forefoot offloading shoes and walkers
- Conclusion

- using forefoot offloading shoes significantly benefit the roll-over process during walking by
  - redistribution of forefoot plantar pressure
  - and reduction of forefoot bending loading

- limitations
  clinical significance of the pressure- and bending-relieving efficacy could not be confirmed in this investigation and has to be addressed in further studies

General conclusion

- The right orthopedic devices / treatment or their combination constitutes an efficient individual treatment of forefoot problems!

- law of the instruments:
  “I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail.”  Malsow, 1966

→ Proper consideration and the corresponding parameters constitute the targeted review of orthopedic supplies in practice.
Thank you for attention & for supporting: www.bifo-ost.de!
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