

**Deutsche Sporthochschule Köln**  
 German Sport University Cologne

## Trainierbarkeit von Fußmuskeln bei Diabetischer PNP

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**Minimal footwear research at the IBO 2003-2010**



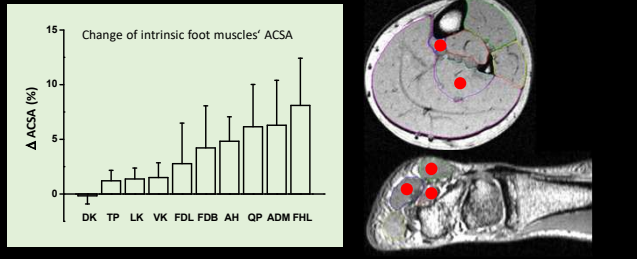
1. Six month training study (moderate intensity) with Free 5.0 (Goldmann 2005, Diplomarbeit; Potthast et al. 2005)
2. Sprint and cutting study with minimal footwear (unpublished)
3. Effects of flex grooves on toe flexor muscle strength after a fatiguing running protocol (unpublished)
4. Wire EMG of flexor hallucis longus muscle during barefoot and shod running on a treadmill (Goldmann et al. 2006, ISBS Salzburg)
5. The potential of human toe flexor muscles to produce force (Goldmann et al. 2012, J Anatomy)
6. The potential of toe flexor muscles to enhance performance (Goldmann et al. 2013, J Sports Science)
7. Athletic training with minimal footwear strengthens toe flexor muscles (Goldmann et al. 2013, Footwear Science)



– Six month training intervention with minimal footwear  
 – Experimental shoe group n = 50 (25 MRI)  
 – Control shoe group n = 50

(Goldmann 2005)

After six month moderate training with minimal footwear >> 20% increase in toe flexor strength...



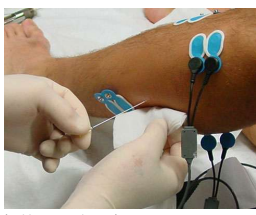
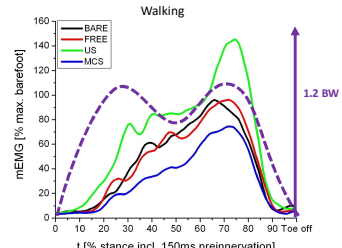
Muscle	Δ ACSA (%)
DK	0
TP	~1.5
LK	~1.5
VK	~1.5
FDL	~3.5
FDB	~4.5
AH	~5.5
OP	~6.5
ADM	~6.5
FHL	~8.5

(Goldmann 2005, Braunstein et al. 2008)

**WIRE EMG OF FLEXOR HALLUCIS LONGUS DURING BAREFOOT AND SHOD RUNNING ON A TREADMILL: A PILOT STUDY**

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Walking

Legend: BARE (black), FREE (red), US (green), MCS (blue)

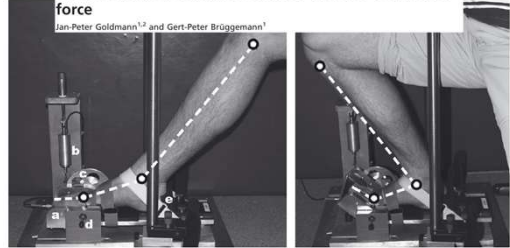
1.2 BW

(Goldmann et al. 2006)

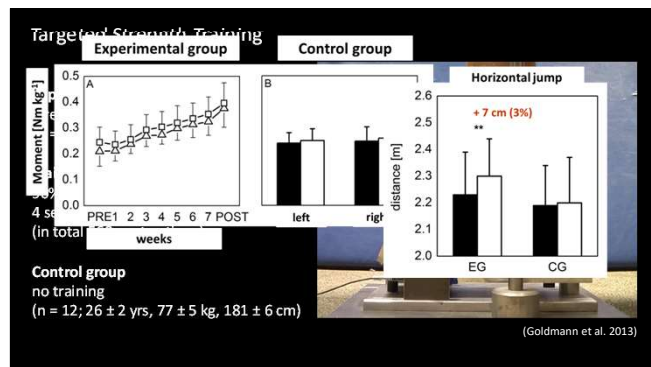
*Journal of Anatomy*

The potential of human toe flexor muscles to produce force

Jan-Peter Goldmann<sup>1,2</sup> and Gert-Peter Brüggemann<sup>1</sup>



doi: 10.1111/j.1469-7580.2012.01524.x



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## Strength training of extrinsic and intrinsic toe flexor muscles in diabetic patients with distal PNP

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### Purpose

Effect of targeted strength training intervention on

- 1) muscle strength & volume and
- 2) plantar pressure distribution during walking in diabetic patients with DPNP

**PRE Test**

MVC, MRI, Pressure distribution

**Training**

Dynamometer, Live feedback, 8 weeks, 3 sessions/week, 24 sessions total

**POST Test**

MVC, MRI, Pressure distribution

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### Patients

- 14 patients (female/male: 6/8),
- diabetes type 1/2: 6/8,
- duration of diabetes: 16.6 ± 9.7 years,
- age: 56 ± 7.2 years, height: 1.76 ± 0.09 m, mass: 94.8 ± 14.5 kg,
- body-mass-index: 30.7 ± 4.7 kg/m<sup>2</sup>,
- without an acute ulceration or foot and toe deformities,
- one patient had a fifth toe amputation at the left foot,
- one patient had a fully healed plantar ulcer.

(Höhne et al. 2013)

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### Assessment DPNP

- *Neuropathy disability score*
  - including Achilles tendon reflexes (0-2 points), perception of vibration (tuning fork, 0-1 points), temperature (tip therm°, 0-1 points) and pain (pinprick, 0-1 points);
- Six *Semmes-Weinstein filaments* (North Coast Medical, Inc., Morgan Hill, USA, filament-size: 2.83 to 6.65) (Pham et al. 2000);
- *Classification*: mild (3-5 points), medium (6-8 points) and severe (9-10 points) (Young et al. 1993);
- *DPNP*: Inability to feel filament 5.07 (≈ 10 g) at the minimum of two sites on the plantar surface (Frykberg et al. 1998)

(Höhne et al. 2013)

### Degree of Muscle Atrophy

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- MRI at fifth Metatarsal Head
- Five-Point Atrophy-Score (Bus et al. 2006)

Atrophy-Score:  
 0 - no atrophy  
 1 - mild atrophy  
 2 - moderate atrophy  
 3 - severe atrophy  
 4 - almost or no muscle tissue

(Höhne et al. 2013)

### Strength Training Intervention

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70% of MVC, 8 weeks, 3 sessions per week, 4 sets, 12 rep.  
with 3 s loading/3 s relaxation, 90 s rest (1152 contractions)

(Höhne et al. 2013)

### Results

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**strength + 49-62%**

**volume + 6.4%**

(Höhne et al. 2013)

	Contact time (%ROP)		Peak pressure (kPa)	
	PRE	POST	PRE	POST
Lateral heel	61.4 ± 7.6	60.5 ± 9.8	384.5 ± 104.3	330.2 ± 61.2 **
Medial heel	62.1 ± 7.1	61.1 ± 9.8	444.7 ± 216.3	384.1 ± 160.4 *
Lateral midfoot	65.6 ± 10.1	63.7 ± 10.5 *	152.8 ± 99.1	145.6 ± 84.2
Medial midfoot	50.4 ± 9.4	48.6 ± 10.8	118.4 ± 49.2	113.0 ± 40.6
Metatarsal 1	81.7 ± 5.0	80.6 ± 5.9	420.8 ± 201.5	403.0 ± 165.0
Metatarsal 2	85.1 ± 3.4	84.6 ± 3.6	632.3 ± 261.2	561.5 ± 258.7 ***
Metatarsal 3, 4, 5	86.9 ± 3.9	85.9 ± 3.4	471.2 ± 151.6	419.3 ± 121.7 **
Hallux	64.1 ± 14.8	66.9 ± 14.1	468.6 ± 234.8	452.7 ± 255.1
Second toe	54.3 ± 13.2	55.9 ± 14.6	199.0 ± 94.5	199.3 ± 104.6
Toes 3, 4, 5	57.0 ± 17.4	57.0 ± 18.6	138.6 ± 83.7	136.4 ± 89.0

\* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001

(Höhne et al. 2013)

### Results

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11% reduction of plantar peak pressure in walking

\*\*\* p < 0.001  
 \*\* p < 0.01  
 \* p < 0.05

(Höhne et al. 2013)

### Strength training of toe flexor muscles in the diabetic foot significantly...

...increases strength by 49-62%...

...and volume by 6.4% and...

...reduces plantar peak pressure by 11% (p < 0.05) during walking.

(Höhne et al. 2013)

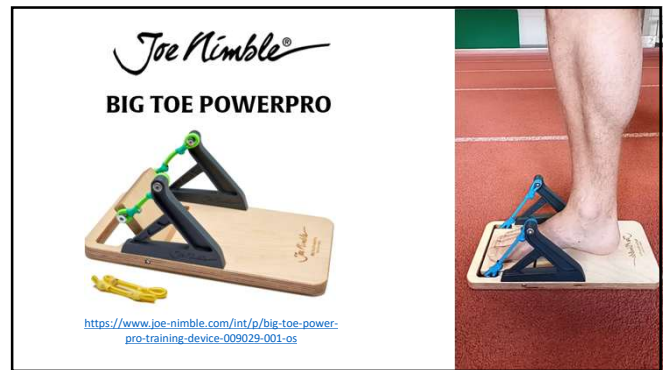
**Conclusion**



- Muscle function and tissue loss in diabetic feet can be counteracted by strength training of short and long toe flexor muscles.
- Although strength was severely compromised in the diabetic patients, strength improvements continuously increased during the intervention and were associated with a significant muscle volume gain.
- Strength and volume gains were associated with reductions of plantar peak pressure at common ulceration sites.

**Outlook**

- Quantitative assessment of foot muscle strength allows clinicians to detect early onset of muscle function loss in diabetic patients.
- We recommend the inclusion of targeted foot muscle strength training into diabetic patient education as a preventative and rehabilitative measure for ulcer prevention and mechanical stability of the foot.



**Outlook**

- Measurements of diabetic foot stiffness based on the findings of previous studies that reported increased stiffness in diabetic feet.



**Plantar soft tissues stiffen in people with diabetic foot syndrome**  
(Klaesner et al. 2002, D'Ambrogi et al. 2005, Chao et al. 2011, Kwak et al. 2020)

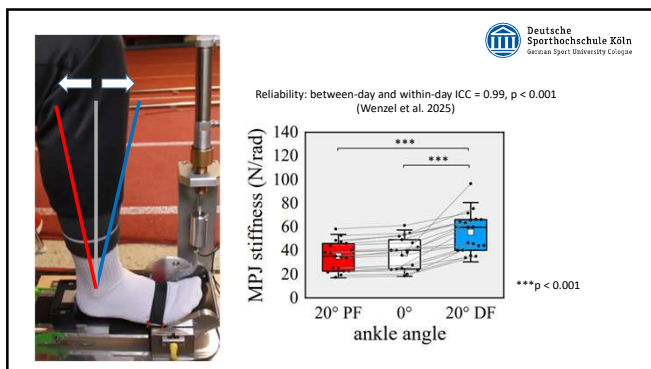
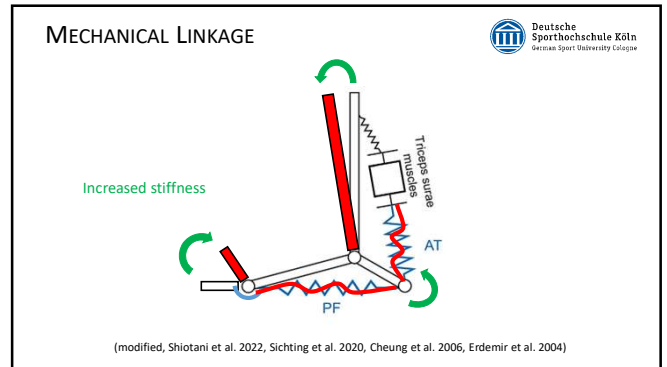
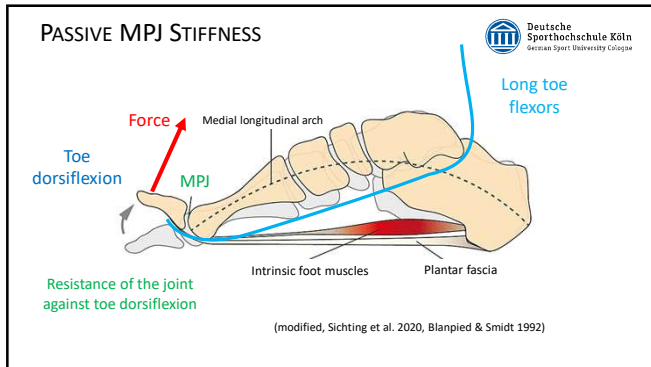
- Angular velocities 40-50°/s (Man et al. 2016, Blanpied & Smidt 1992)

- Statistics: One-way ANOVA (Goldmann et al. 2025, Wenzel et al. 2025)



Load cell (DMS, HBM, Darmstadt; accuracy 99%)

Potentiometer (MCP05, linearity 1%, Megatron, Putzbrunn, Germany)



# Human Foot Function



DIAGNOSTICS || MONITORING || TRAINING



 <https://www.linkedin.com/in/dr-jan-peter-goldmann-13b67274/>

The image is a promotional graphic for 'Human Foot Function'. It features a dark grey background. At the top left, the title 'Human Foot Function' is written in white. To the right is a white logo depicting a foot with a hand holding it. Below the title is a horizontal strip with three images of a foot on a device, with the text 'DIAGNOSTICS || MONITORING || TRAINING' above them. At the bottom left is the LinkedIn logo, and to its right is a URL: 'https://www.linkedin.com/in/dr-jan-peter-goldmann-13b67274/'.