Plantar pressure of clipless and toe-clipped pedals in cyclists - A pilot study

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Summary

To determine the effect of clipless and toe-clipped pedals on plantar foot pressure while cycling.
Seven bikers and 11 healthy volunteers were tested on a Giant ATX Team mountain bike, Tekscan Clinical 5.24 F-scan® system with an inner sole pressure sensor, a Tacx Cycle force One Turbo Trainer and a Cateye Mity 8 computerized speedometer were used. The subjects wore Shimano M037 shoes and used a standard clipless and toe-clipped pedal. The seat height was set at 100% of subject's trochanteric height. Plantar pressures were recorded over 12 consecutive crank cycles at a constant speed for each of the power outputs. The videos were analysed to record the pressure exerted at 12 positions on the foot for each variable. Whether there is any dominance of any of the metatarsals, and any difference in plantar pressures between clipped and clipless pedal.
There was a significant difference in the pressure at many positions of the foot, but the sites were different for each individual. General regression analysis indicated that pedal type had a statistically significant effect on plantar pressure at the sites of 1st metatarsal ($p=0.042$), 3rd metatarsal ($p<0.001$), 5th metatarsal (<0.001), 2nd ($p=0.018$) and 5th toe ($p<0.001$), lateral midfoot ($p<0.001$) and central heel ($p<0.001$) areas.
Clipless pedals produce higher pressures which are more spread across the foot than toe-clipped pedals. This may have implications for their use in the prevention and/or management of overuse injuries in the knee and foot.

Key Words: Hellp cycling; training; chronic exercise induced comportment syndrome; compartment pressures.

Introduction

When cycling, pronation occurs at the power phase of the crank cycle, [bottom dead centre (BDC)] causing the knee to abduct and the lower leg to medially rotate thus increasing the Q angle (1,5,8,9,16,17). The hip adducts to reduce this, but, in patients in whom pronation and/or knee abduction are too great to be compensated for, patella femoral pain (PFP) may occur (1,5,8,9,16,17).
Plantar pressure studies show that there is dominant loading of the first metatarsal/hallux using toe-clipped pedals (14,15,18,19,20). This pattern is in line with the fact that the forefoot pronates at BDC. A "transverse arch pattern" has also been described, with relatively high loading of the fifth and the first metatarsal heads (14,18,19). Therefore plantar pressure patterns can provide a possible mechanism for the aetiology of PFP and metatarsalgia. Plantar pressure changes have been examined for manipulations of power output and cadence, (14,15,18,19,20) different shoe types (13-15) and cyclist experience (20), but, to our knowledge, not pedal type.
Several papers have studied clipless pedals (2,4,7,8). In particular, the small degree of rotation that they allow reduces the twisting moments of the knee (10), and the position of the cleat can compensate for malalignment issues in the lower limb (4,8), which may prevent PFP. However, clipless pedals have been associated with knee pain, especially if there is no flotation in the pedal (7). The smaller surface area of the clipless pedal may also contribute to metatarsalgia by increasing plantar pressure (7).
The aim of this pilot study was to investigate the pattern of plantar pressure in clipless pedals. Our null hypothesis (H_o) was that there is no dominance of any of the metatarsals, and that there is no difference in plantar pressures between clipped and clipless pedal.

Methods

Participants
Seventeen subjects volunteered. Among them, there were road and mountain bikers of variable experience who have used clipless pedals, and non-cyclists (Table 1).

Procedures
Ethical approval was sought from the local research ethics committee who confirmed that application was not required. All subjects completed a written consent form, read a Patient Information Leaflet explaining the purpose of the project, and were asked to fill in a Patient Health and Cycling Questionnaire.

Table 1 - Characteristics of the Participants.

No	Sex	Age (Yrs)	Wgt (Kg)	Hgt (m)	Shoe Size (UK)	TrochHgt (m)	Prev Use of Cleats	Biking Experience	Lower Limb Injuries
1	Male	32	73.48	1.73	8	0.83	No	Road - occasional	None
2	Female	32	57.58	1.7	6	0.96	No	None	None
3	Male	33	65	1.78	9	0.96	No	None	None
4	Female	25	61	1.76	6	0.94	No	None	None
5	Female	35	50.8	1.52	4	0.84	No	None	None
6	Female	29	100	1.72	9	0.94	No	Road - occasional	None
7	Male	36	96	1.83	9	1	Yes	Mountain - 35 miles daily	None
8	Male	29	55	1.6	7	0.84	Yes	Mountain - 100 miles weekly	None
9	Female	27	59.24	1.6	5	0.89	No	Road - 50 miles weekly	None
10	Male	28	80	1.75	8.5	0.93	Yes	Mountain - 4 hrs per week	None
11	Female	33	63	1.78	8	0.96	No	None	None
12	Male	29	76	1.67	8	0.9	No	Road - occasional	None
13	Male	34	77	1.8	9	0.97	No	Once a month - 1 hour	None
14	Female	30	47	1.6	4.5	0.8	No	None	None
15	Female	33	57	1.65	5	0.92	Yes	Mountain - 4 hrs per week	None
16	Male	24	73	1.79	9	0.98	No	None	None
17	Male	28	65	1.75	9	0.96	No	12 miles a week	None
	Average	30.41	68.00	1.708	7.294	0.919			
	Standard Deviation	3.447	14.69	0.088	1.821	0.059			

Table 2 - Frame dimensions of the Giant ATX Team 2001.

Frame Size	Top tube in mm	Seat tube in mm	Seat Angle In º	Head Angle in º	Drop-out in mm	Chain stays in mm	Rake in mm	Trail in mm	Wheel base in mm
17	575	430	73	71.5	36	425	45	67	1045.7

Instrumentation

The mountain bike consisted of:

An aluminum aluxx AL 6013 hard tail Giant ATX Team 2001 frame (Giant Bicycle Inc. California, USA); (Table 2)

Marzocchi Bomber MX Comp Air XC 2004 forks (Marzocchi Inc, Bologna, Italy);

Shimano Deore XT crank set FC-M751 175mm (Shimano Inc. Osaka, Japan);

Shimano Deore XT rear derailleur RD-M750 (Shimano Inc. Osaka, Japan);

FSA (full speed ahead) XC170 alloy 90mm stem (Shimano Inc. Osaka, Japan);

Raceface riser handlebars (1.5" rise, 28" wide, 9° rearward and 4° upward angle) (Race Face Performance Products, BC, Canada) ;

Mavic wheel 559mm diameter and 17mm width (Mavic Inc, France);

Michelin slick tyres 35x559mm inflated to 50 psi (Michelin Inc. Clermont, France);

Shimano PD-M536 SPD clipless pedals (Shimano Inc. Osaka, Japan) and

Bontrager Pedal ATB medium toe clip with strap 9/16" boron axle pedals. (Bontrager Wheelworks & Components, California, USA)

The gears were set in the M9 N32 ring (mid ring of 32 teeth) at ring 14T (14 toothed ring or gear 3/9). A Cateye Mity 8 computer was fitted to the rear wheel to indicate speed. All subjects wore a Shimano M037 shoe to eliminate the effect on pressure of different shoe types (13-15).

The bike sat in a Tacx Cycleforce One Turbo Trainer. This raised the rear wheel by 4 cm off the ground. Therefore, the front wheel was raised by 4 cm using a hard platform to keep the bike level.

Plantar pressures were measured using a Tekscan Clinical 5.24 F-scan® system (Tekscan Inc. Boston, USA) The in-shoe pressure sensors (Table 3) were cut to size for each of the three shoes used (UK size 5, 8, 9) and each inner sole was connected to the computer software via a PS2 cable (10 m).

Table 3 - Inner sole pressure sensor description.

Sensor Inner Sole Elements	Values
Number of Sensing Elements	960 Sensing Elements/Foot
Spatial Resolution	4 Sensors/cm^2 (25 sensors/in^2)
Size of Sensor	Trimmable from Men Size 14 USA
Technology	Resistive
Calibration	With application of known and controlled force
Pressure Range	1-150 PSI (other ranges available)
Sensor Thinness	0.007 in. (0.15 mm)

Protocol
Seat height was adjusted to 100% of each subject's trochanteric height when wearing the cycling shoes (21). Both shoes had plantar pressure insoles inserted. Once fitted, the shoes were checked for any crinkling of the sensor, comfort, and output reading. The pressure insoles were calibrated for each individual by informing the programme of the subject's weight (Newtons) and then asking the subject to stand with all their weight on one foot at a time. The software was set to record 400 frames (the equivalent of 12 consecutive crank cycles), and the pressure in KPa. On the bike, each individual cycled for a few minutes to warm up and to test that the bike set up was acceptable. The Tacx Turbo trainer was set at resistance 4/7 and 7/7, corresponding to power outputs of 100W and 150W respectively. Instructions were given so that for each pedal type subjects cycled at 15mph at each power output. When comfortable maintaining that speed, they were informed when recording of the plantar pressures had started and finished. The subjects were able to rest while the clipless pedals were removed and the toe-clipped pedals fitted.

Data Evaluation
Eight videos were recorded for each participant (i.e. two feet at each power output for two pedal types). We evaluated pressures from the right foot. Force asymmetry has been reported between the left and right foot in cycling (22), but has been shown to be insensitive to changes in power output (23). Previous studies have used 12 locations on the foot to measure plantar pressure in cyclists (14,20) and other authors have used 8-10 positions (15,24). Twelve positions were evaluated here including hallux, 2nd to 5th toes, 1st to 5th metatarsal heads, lateral midfoot and central heel area. Each video was analysed frame by frame to determine the frame in which peak pressure occurred in the hallux. It was assumed that this was the frame at which peak pressures were exerted at each of the 11 other positions. This analysis was made for each of the 12 consecutive crank cycles at each power output.
The hallux is the site at which the highest pressure is exerted. We recorded the mean peak pressures exerted at each of the discrete sensors, and we did not consider the point in the crank cycle when this occurred (15,18-20). We acknowledge that, in this instance, it is not possible to determine where in the crank cycle the peak pressures have been exerted. No specific analysis was made, but it was presumed to be at bottom dead centre (BDC).

Statistical Analysis
A dependent 't' test was used to analyse the effect of pedal types had the plantar pressure exerted at 100W and 150W for each individual. The statistical package of SPSS 12.0 (SPSS Inc. Chicago, USA) for Windows was used to perform the paired sample t test. A Linear Regression Analysis was made using Genstat 6.0 (VSN International Ltd, Hemel Hempstead, UK) to determine the effect of pedal type, power output and person across the group.
For all tests, alpha (α) level was set at 5% i.e. p value of <0.05 (2 tailed) or a confidence interval (CI) of 95% that does not cross zero.

Results

The dependent t test showed a statistically significant difference in pressure at many of the 12 positions (Table 4). When the sites of significant p value were analysed, there

Table 4 - Significant p-values for dependent t-test.

Foot Position	Power Output (W)	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
1st MT	100					*0*	*0*	*0*	*0*	*0*	*0*		*0*	*0.03*	*0*		*0*	*0*	
2nd MT	100	*0.03*	*0.01*			*0*	*0*		*0*	*0*	*0*	*0*	*0.08*					*0*	
3rd MT	100					*0*	*0*		*0*		*0.01*	*0*	*0*	*0.01*	*0*	*0*		*0*	
4th MT	100	*0.02*				*0*			*0*	*0.01*	*0*	*0*		*0.01*					
5th MT	100		*0.01*	*0.023*	*0*	*0*	*0*	*0.01*	*0.01*	*0*		*0*			*0*				
Hallux	100		*0*	*0.002*	*0*	*0.02*	*0*		*0*	*0*	*0*	*0*	*0*	*0.04*	*0*		*0*		*0.01*
2nd toe	100	*0.01*	*0*	*0.005*				*0*		*0*		*0*	*0*	*0.02*	*0.03*	*0*		*0.03*	*0*
3rd toe	100		*0*		*0*	*0*		*0*	*0*	*0*	*0*	*0*			*0.02*		*0.02*		*0*
4th toe	100		*0*		*0*	*0.01*		*0*	*0*	*0*	*0*		*0.03*		*0*		*0*		*0*
5th toe	100		*0*		*0*	*0.01*		*0*	*0*	*0*	*0.01*	*0*	*0*			*0*	*0*	*0.03*	*0*
Mid-foot	100			*0*		*0*	*0.02*		*0*			*0*		*0*	*0*	*0*	*0*		*0*
C. Heel	100	*0.01*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*			*0*	*0*	*0*	*0*	*0*		
1st MT	150		*0*	*0*				*0*	*0*		*0*		*0*		*0*			*0*	*0.01*
2nd MT	150		*0*	*0*		*0*			*0*		*0*	*0*	*0*	*0.02*	*0.01*		*0*		
3rd MT	150	*0*		*0*		*0.01*		*0*	*0*		*0*		*0*	*0*		*0*	*0*	*0*	*0.04*
4th MT	150	*0*	*0*	*0*		*0*	*0.03*		*0*			*0.03*	*0.01*				*0*	*0*	
5th MT	150	*0.03*	*0.02*		*0*	*0*	*0*	*0*	*0*					*0.01*		*0.02*	*0*	*0*	
Hallux	150			*0*			*0*	*0.01*		*0*	*0*	*0*	*0.03*		*0*		*0*	*0*	
2nd toe	150			*0*		*0*	*0*		*0.02*	*0*	*0.03*	*0*	*0*		*0*			*0*	*0*
3rd toe	150	*0.02*		*0*		*0*	*0*				*0.02*	*0*	*0*				*0*	*0*	*0*
4th toe	150	*0.02*	*0*	*0*	*0.03*	*0.01*	*0*		*0*	*0*	*0.02*	*0*	*0*	*0.04*		*0.02*	*0*	*0*	*0*
5th toe	150	*0.01*	*0*				*0.03*		*0*	*0*		*0.01*	*0*			*0*	*0*	*0*	*0*
Mid-foot	150			*0*						*0*	*0*	*0*	*0*	*0*	*0*		*0*	*0*	
C. Heel	150			*0*	*0*	*0*		*0*	*0*		*0*			*0*	*0*	*0*			*0*

Table 5 - Summary of p-values and estimates for the linear regression analysis.

Factor Reference	p-value	estimate	p-value	estimate	p-value	estimate	p-value	estimate	p-value	estimate	p-value	estimate
Foot Position	1st Met		1st Toe		2nd Met		2nd Toe		3rd Met		3rd Toe	
Person	<0.001	43.51	<0.001	163	<0.001	28.14	<0.001	26.48	<0.001	38.2	<0.001	22.68
Pedal Type 2	0.042	-2.76	0.131	16.4	0.249	-0.992	0.018	1.871	<0.001	-5.166	0.592	0.87
Power output 150W	<0.001	20.9	<0.001	36.2	<0.001	8.756	<0.001	9.182	<0.001	9.234	<0.001	9.35
Foot Position	4th Met		4th Toe		5th Met		5th Toe		Mid-foot		C. Heel	
Person	<0.001	41.95	<0.001	35.6	<0.001	57.78	<0.001	65.34	<0.001	48.99	<0.001	29.94
Pedal Type 2	0.632	0.54	0.256	0.12	<0.001	-7.94	<0.001	-4.59	<0.001	-4.093	<0.001	-4.395
Power output 150W	0.002	3.49	0.578	6.42km\v	0.218	1.31	0.022	3.02	0.841	0.153	<0.001	2.165

was not a single location where the difference was significant for all subjects. Therefore, a linear regression analysis was completed (Table 5). The lack of correlation between plantar pressure and cycling experience has already been established (20).

Pedal type exerted a statistically significant effect at the first metatarsal, second toe, third metatarsal, fifth metatarsal, fifth toe, lateral midfoot, and central heel. The higher pressure in the second toe occurred in the toe-clipped pedal.

A significant effect was seen at the first metatarsal and toe, second metatarsal and toe, third metatarsal and toe, fourth metatarsal, fifth toe and central heel for a power output increase from 100W to 150W.

The estimated values for each person varied greatly, with no systematic pattern identified.

Discussion

Issues of Confounding

By using the same bike, the effect of confounding from frame size, handlebar position, stem size, fork height, crank set and rear derailleur size was eliminated. For this reason, all seats were set at the individual's trochanteric height. However, it could be argued that the bike set - up suits only one individual, mainly the owner. Therefore, the results may not be transferable to subjects who use a different bike. This may have practical implications, as biking overuse injuries can result from the mismatch between the bike's characteristics and the rider's biomechanics (1-9).

Problems with Analysing the Data

The F-scan® system has been used to measure pressures at the shoe-foot interface during normal walking (25) and in other sports medicine research (26-29). However, at times, it was difficult to be sure of the exact position of each toe, which could potentially be a source of inaccurate results. In addition, some of the videos had only recorded 11, not 12 crank cycles, as footage was not synchronized to start at the same point of the crank cycle for each subject.

Choice of Cycling Parameters

Ideally, pressures would have been measured at power outputs and cadences used in other studies (15,16,20-22). Using the Tacx Turbo Trainer, it was impossible to achieve such power outputs as subjects would have had to cycle at 20-25 mph. The gear setting needed to achieve these speeds was too strenuous to maintain. Most mountain biking is achieved by using gears in the mid ring (M9 N32). The speed of 15 mph was achievable by all subjects in our setting, and was considered a fair reflection of the maximum speed cycled by recreational mountain bikers and healthy volunteers while road biking.

Conclusions

This study upheld the null hypothesis that there is no dominance of any metatarsal. However, plantar pressures were found to be higher in the clipless pedal, thus rejecting the second part of the null hypothesis. We did not identify any pattern of hallux and first metatarsal dominance. Indeed, the higher pressures were spread across the whole foot, suggesting that clipless pedals produce less pronation at BDC.

Future studies may determine, the true power output of the bike at each resistance used and the actual average speed travelled.

Further studies using larger numbers of mountain bikers and more in depth statistical analysis, such as the percentage relative loading of each position of the foot, and measurement of the position within the crank cycle of peak pressure exertion, may help to confirm the apparent reduction of pronation and spread of pressure seen. We may then be able to adapt pedal types for use in cyclists at risk of or suffering from PFP and foot problems.

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