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Hallux rigidus: A cross-sectional study to evaluate clinical parameters

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ABSTRACT

Background: Hallux rigidus (HR) is a common condition with history and physical examination used to help evaluate pathology, grade clinical changes and to inform treatment.

Method: A cross-sectional study was undertaken to evaluate the demographics of and clinical parameters encountered in HR. In 110 subjects (180 feet) aged 18-70 yrs (mean 52 yrs) a standardized history and physical examination was undertaken. Clinical parameters associated with HR were evaluated. The Foot Health Status Questionnaire (FHSQ) was used to measure health-related quality-of-life dimensions.

Results: Seventy (64%) subjects had bilateral HR and 73 (66%) were female. Mean HR onset was 44 (14-68 yrs) years and median HR duration 6 years (1-33 yrs). A history of 1st MTPJ trauma presented in 22% of subjects; 74% of whom had unilateral HR. Eighty-four (47%) feet had pes planus based on a positive Foot Posture Index. A correlation between pes planus and 1st MTPJ pain was found (r= 0.84, p=0.05). In 74% of feet, hallux abductus interphalangeus angle (HAI°) was greater than normal ($\leq$10°). A correlation between HAI and reduced 1st MTPJ ROM was found (r= 0.92, p=0.05). Second toe length was the same as the hallux in 111 feet (62%). A correlation between valgus hallucal rotation and 1st MTP joint pain in HR was found (r= .78, p= .05). A positive relationship was found between 2nd toe length and 1st MTPJ pain (p= 0.001<0.05). A correlation between hallucal IPJ hyperextension and 1st MTPJ pain was found (r= 0.78, p=0.01). A positive relationship was found between lesser MTPJ pain and supination at propulsion (p<0.001). There was no evidence of Achilles tendon contracture. The FHSQ results concur with clinical findings.

Conclusions: HR was associated with female gender, bilateral involvement, older age groups, increased HAI°, 2nd toe length similar to hallux, hallucal IPJ hyperextension, lesser MTP joint pain, flat foot and certain gait alterations. HR was not associated with Achilles tendon tightness or footwear. The content validity of clinical parameters of HR needs to be established by formal research prior to their inclusion in a classification of HR.

KEY WORDS: Hallux rigidus, Clinical, Parameters, History, Physical examination

INTRODUCTION

Hallux rigidus is a term used to describe symptoms commonly associated with degenerative arthritis of the 1st metatarsophalangeal (MTP) joint. HR is associated with painful, progressive loss of dorsiflexion, and proliferative bone response, leading to increased bulk of the joint. HR is a common 1st MTP joint problem, second only in incidence to hallux valgus[1]. Symptoms associated with HR were initially reported by Davies-Colley 1887[2], although Cotterill[3] is credited with proposing the term *hallux rigidus*. The pathological changes of the 1st MTP joint and metatarso-sesamoid compartment in HR differs from hallux valgus[4] due to its different biomechanical properties[5]. Since Davies-Colley's description in 1887 numerous authors have reported on the clinical parameters of HR[6-15]. Symptoms and objective information from history and physical examination of HR are well documented (Table 1). There is, however, conflicting information on demographics and clinical evaluation, as well as widespread disagreement on certain clinical parameters (Table 2).

Table 1: Documented findings

History	**Examination**
Pain with joint motion [13, 15-18].	Restricted joint motion[6, 13, 23-25].
Intolerance of footwear [13, 21, 22].	Increased joint size[13, 20, 26]; soft tissue swelling[19, 20].
	Everted or supinated gait[16, 18, 20, 27-30].

Table 2: Disputed findings of HR

Demographic data	**Clinical data**
Family history	Functional hallux limitus
- Early onset of disease [9].	- Supports concept[28, 42-44].
- Great toe problems[13].	- Questions concept[13, 45].
Age of onset	Arch
- Adult[13, 19, 20, 31-34];	- Pes planus[3, 6, 23, 40, 46-50].
- Adolescent[6, 23, 27, 35, 36].	- Normal[51].
Presentation	Achilles tendon
- Unilteral[9, 20, 37]; Bilateral[13, 17, 38].	- Contracture[23, 52].

Gender predilection - Male[38, 39]; Female[13, 20, 30-33, 36, 40, 41].	- Normal[13].

The mean age of onset of HR is variable between studies. Early studies indicate a lower mean age of HR (Table 3) while more recent studies consistently present higher proportions of older patients with HR (Table 4).

Table 3: Age range of HR in earlier studies (1940 – 1978)			
Author	No. of cases	Age range (yrs)	Mean age (yrs)
Jack (1940)[51]	15	11-44	18.7
Bingold & Collins (1952)[23]	33	18 cases <25yrs 15 cases >25yrs	no mean
Kessel & Bonney (1958)[27]	9	9-18	12.4
Goodfellow (1966)[35]	3	13-18	15
McMaster (1978)[36]	7	12-33	21

Table 4: Age range of HR in later studies (1979 – 2003)			
Study	No. of cases	Age range (yrs)	Mean age(yrs)
Mann et al (1979)[20]	20	35-77	56.8
Drago et al (1984)[40]	42	17-80	45
Feltham et al (2001)[34]	67	23-80	None given
Hamilton et al (1997)[41]	34	None given	56.2
Thomas & Smith (1999)[31]	17	20-69	47
Easley et al (1999)[18]	57	36-70	51
Coughlin & Shurnas (2003)[13]	114 (5.3%) < 20yrs	13-70	43
Geldwert et al (1992)[32]	47	26-69	52
Kurtz et al (1999)[33]	33	35-75	50.6
Mackay et al (1997)[19]	39	18-79	56

It is clear that there are conflicting notions about the aetiology of HR[1-3, 6-10, 12-24, 26-40, 43-51]. The traumatic origin of HR has been proposed by several authors[20, 38, 37] while Jack (1940) proposed a spontaneous onset. Poor footwear[2, 23], ankle equinus[23], pes planus[3, 6, 23, 26, 40, 46-51] and functional hallux limitus[28-42-45] has also been cited.

A number of complaints can be associated with HR. These include generalized foot pain, 1st MTP joint or metatarsosesamoid joint pain, 1st MTP joint stiffness, locking and spasm/ cramp. In some cases, significant synovitis may accompany these complaints. Variability of the severity and location of 1st MTP joint pain may be dependent upon a number of factors including lifestyle and activity levels. In the early stages, discomfort predominates at the dorsal aspect of the joint and becomes more diffuse with the progression of the disease. Other complaints including metatarsalgia (due to a compensatory increase in weight bearing to unload the 1st ray during gait), inability to rise up on toes and altered gait have been documented[1, 13, 14, 20, 21].

This study aims to identify the demographics and key clinical parameters associated with a group of subjects with HR. The methodological process used and its impact on the accuracy of severity and grading of HR will be discussed.

METHODOLOGY

An observational, cross-sectional study was undertaken. This involved a quantification of specific variables applied to a sample of subjects with varying severity. It was undertaken to evaluate clinical parameters in 110 HR subjects (180 feet) aged 18-70 years with varying degrees of restricted 1st MTP joint dorsiflexion <65° (measured with a standard full-circle plastic goniometer, calibrated to 1º increments) with either pain, deformity or both. Ethical approval (Leicestershire, Northants, Rutland) was obtained, subjects gave informed consent and a pilot study was undertaken.

Careful preliminary examination of subjects' clinical notes was undertaken to remove those possessing criteria of exclusion (Table 5). An invitation letter and study information sheet was sent to suitable subjects giving them time for consideration prior to inclusion in the study.

Detailed exclusion criteria were reviewed at the time of data collection.

Table 5: Exclusion criteria
Hallux valgus-rigidus (intermetatarsal angle $\geq$ 12º). Severe multiple forefoot deformities. Significant trauma sustained to foot/ leg in previous 12 months. Neuropathy. 1st ray/ forefoot surgery (including digital/ excluding soft tissue). Morton's neuroma affecting any inter-metatarsal space. Septic arthritis of 1st MTP joint. Inflammatory arthritides. Neuromuscular disorders. Insulin dependent Diabetes Mellitus. Hypermobility syndromes. Long-term steroid use. History of severe peripheral vascular disease. Metabolic bone disease.

A standardized questionnaire and examination were used. Subjects were questioned about their history including the following: family history of great toe problems, age of onset (denoted by 1st MTP joint deformity or restriction/ pain), duration of pain or symptoms (including stiffness, locking, spasm/cramp), variability of pain, factors aggravating symptoms, factors providing relief of symptoms, affect on activity levels and types of activities restricted, contribution of occupation to HR and footwear restrictions. The body mass index (BMI) for each subject was documented to determine its effect on the clinical parameters. Repetitive 1st MTP joint trauma can result in joint damage precipitating HR. The subject's type and frequency of sporting activities was documented. The association of 1st MTP joint OA (HR) and OA at other sites was documented.

A validated questionnaire (FHSQ)[59, 60] was also completed by each subject and used to measure health-related quality-of-life dimensions: foot pain, physical function, appearance, footwear and general perceptions of foot health.

The physical examination included inspection of the foot non-weight bearing and weight-bearing. Both feet were examined (exclusion criteria permitting). The following clinical data was obtained: Rearfoot position in stance was evaluated using the Foot Posture Index (FPI)[53]. The FPI was used to quantify the degree to which the foot was pronated, supinated or in a neutral position[53]. Six foot parameters (3 rearfoot and 3 forefoot) were evaluated for each subject. Each parameter was graded as described by Redmond et al[53]. Final aggregate scores were applied to categorize type of foot posture.

Location, magnitude and timing of 1st MTP joint pain were assessed. Passive 1st MTP joint range of motion ROM was measured using the method described by Ronconi et al[54] and Greene & Heckman[55]. The total ROM (dorsiflexion & plantarflexion) was used to calculate reduction in motion and compared with normal values[55]. Active 1st MTP joint dorsiflexion was measured in a static weight bearing position. Subjects were asked to push up onto the ball of the foot (avoiding supinating) to obtain maximum 1st MTP joint dorsiflexion. Subjects' ability to rise up on toes without supinating was also evaluated.

Hallucal IPJ pain (using system described by Coughlin[22]) was assessed. Frontal plane hallucal position was determined by comparing the angle of the hallucal nail plate with the ground. Sagittal plane position (hallucal IPJ hyperextension) was measured weight bearing with a goniometer using the medial mid-axial line of the proximal and distal phalanges as reference points. Transverse plane deformity of the hallucal IPJ (hallux abductus interphalangeus) was measured with a goniometer using the dorsal mid-axial line of proximal and distal phalanges as reference points. Hallucal flexor power was measured by assessing the ability of the hallux to prevent a piece of paper from being pulled away from under it during static stance.

The location of callosities, lesser toe deformities, comparison of 2nd toe length with hallux and lesser MTP joint pain were documented. Ankle joint dorsiflexion was measured with a standard plastic full-circle goniometer (calibrated to 1 degree increments) using the technique described by Silfverskiold[56] (knee extended and flexed position). The foot was held with the talonavicular joint reduced to eliminate transverse tarsal or subtalar motion[57, 58]. The fibula and plantar-lateral border of the foot were used as landmarks (Figure 1). A right angle was considered to be neutral position. A brief subjective assessment of the subjects' gait at propulsion (by 1st author) was undertaken (Table 6).

Figure 1: Measurement of ankle joint dorsiflexion

Table 6: Observed gait parameters
Propulsion
Mid-tarsal joint pronation
Supination
Delayed heel lift
Vertical toe-off
Ab/Adductory twist at toe-off
Knee flexion
Inability to push through ground at toe-off

RESULTS

Descriptive and comparative statistical analyses were performed using SPSS for Windows version 15.0) (SPSS Inc., 233 S. Wacker Drive, Chicago, IL 60606, USA). Standard chi-square analysis (x^2) was performed on categorical data. Pearson and binary correlation coefficients were used to evaluate the non-continuous data. Differences were considered to be significant when the *P* value was ≤ 0.05.

Demographic data

The findings of the current study demonstrate that HR was associated with increased female prevalence, bilateral involvement, and older age of subjects at onset (Tables 7, 8, 9). These findings concur with those of previous research[13]. Few subjects in the current study had adolescent onset. It is recognised that this may be influenced by the minimum age of subjects (18 years) used and the fact that subjects were only taken from an adult orthopaedic clinic.

The mean age of onset of symptoms (1st MTP joint deformity or restriction/ pain) was 44 years. This is eleven years prior to the median age of presentation at a foot and ankle clinic (55 yrs) and supports the concept that this condition may be one of insidious development. Foot biomechanics, footwear type and activity levels may have some bearing on the development of symptoms and subsequent progression of disease. Overall subjects were marginally overweight (>25 Kg/m^2 = overweight), indicated by a mean BMI of 25.93 Kg/m^2 (19.53-37.26) but with no gender difference for this variable (male: 26.48, female: 25.70).

In the current study there was a pronounced difference between gender; more females presented with HR (Table 7), the mean age of HR onset was less in females (43 years) than males (51 years) and the ratio of females to males was greater in the younger age groups (Table 8).

The mean age of HR onset in the bilateral group was 50 years and unilateral group 53 years. Bilateral foot involvement was similar between genders (62% females, 68% males).

Table 7. Sample characteristics						
Subjects (feet)	Gender		Age (yrs)		Age of onset	Duration of symptoms yrs (range)
	Female	Male	Mean (range)	Median	Mean (range)	
110 (180)	73 66%	37 34%	52 (23-70)	55	44 (14-68)	6 (1-33)

Table 8. Age groups					
Years	18-30	31-40	41-50	51-60	61-70
%	5.7	10.7	18.6	37.1	27.9
F:M ratio	7:1	7:1	1:1	2:1	3:1

History data

No statistically significant association was found between HR and a history of trauma (p=0.1). Trauma history was only found in a small proportion of subjects and was more common in those with unilateral HR (Table 9).

Table 9: Foot involvement			
Bilateral (subjects) %	Unilateral (subjects) %		Trauma history (feet) %
(70) 64%	(40) 36% L (18) 45% R (22) 55%		(39) 22%
			Unilateral 74% Bilateral 26%

Onset of HR was reported to be insidious in 86 (78%) of subjects and acute in 24 (22%) subjects. 1st MTP joint pain (within the last 6 months) was reported to be severe in 26 (23.6%) subjects, moderate in 42 (38.2%), mild in 22 (20%) and not present in 20 (18.2%) of subjects. Historical categorical findings are presented in Table 10A and 10B. Subjects stated that footwear contributed to the development of HR in 23% of cases, however, pain in the 1st MTP joint was found to be associated with footwear on most days in 40 patients (36%). Short, tight, loose fitting, high-heeled and new footwear was found to aggravate symptoms of HR. Occupation contributed to HR in 29% of subjects and other factors found to aggravate HR are outlined in the discussion. There was no statistically significant correlation between HR and footwear or occupation ($p>0.1$).

Table 10A. Categorical history findings (Based on 110 subjects or 180 feet)					
Parameters *Count (%)*	Never	Rarely	Some days	Most days	Everyday
Activity levels restricted by HR	8 *(7)*	16 *(14.5)*	17 *(15.5)*	35 *(31.8)*	33 *(30)*
Footwear contributing to 1st MTPJ pain	4 *(3.6)*	20 *(18.1)*	25 *(22.7)*	40 *(36.3)*	21 *(19.3)*
Variability of 1st MTPJ pain	6 *(5.4)*	8 *(7.2)*	37 *(33.6)*	42 *(38.3)*	17 *(15.4)*
1st MTPJ pain on movement	9 *(8.1)*	2 *(1.8)*	24 *(21.8)*	35 *(31.8)*	40 *(36.3)*
1st MTPJ pain at rest	42 *(38.1)*	14 *(12.7)*	32 *(29)*	16 *(14.5)*	6 *(5.4)*
Presence of 1st MTPJ stiffness	15 *(13.6)*	10 *(9)*	26 *(23.6)*	36 *(32.7)*	23 *(20.9)*
Morning 1st MTPJ stiffness only	38 *(34.5)*	7 *(6.3)*	15 *(13.7)*	29 *(26.4)*	21 *(19.1)*
Evening 1st MTPJ stiffness only	31 *(28.1)*	14 *(12.2)*	24 *(21.8)*	28 *(25.4)*	13 *(11.8)*
1st MTPJ stiffness all day	39 *(35.4)*	11 *(10)*	23 *(20.9)*	21 *(19)*	16 *(14.5)*
1st MTPJ spasm/ cramp	50 *(45.4)*	18 *(16.3)*	32 *(29)*	9 *(8.3)*	1 *(0.9)*
Locking of 1st MTPJ	70 *(63.6)*	13 *(11.8)*	23 *(20.9)*	3 *(2.7)*	1 *(0.9)*
Ability to rise up on toes	23 *(20.9)*	24 *(21.8)*	20 *(18.1)*	21 *(19)*	22 *(20)*
Lesser MTPJ pain	111 *(61.6)*	16 *(8.8)*	33 *(18.3)*	12 *(6.6)*	8 *(4.4)*

Change in walking pattern	11 *(10)*	13 *(11.8)*	29 *(26.1)*	21 *(19)*	36 *(32.7)*
Ability to push off through ground	21 *(11.6)*	36 *(20)*	50 *(27.7)*	22 *(12.2)*	51 *(28.3)*
Roll out during propulsion	45 *(25)*	24 *(13.3)*	38 *(21.1)*	31 *(17.2)*	42 *(23.3)*

Table 10B. Categorical history findings (Based on 110 subjects)

Parameters Count (%)	None	CLO	GS	GS + C	Gels	P	B	V	A	CD	CC
Drugs used for 1st MTPJ pain	51 *(46)*	7 *(6)*	13 *(12)*	12 *(11)*	1 *(1)*	4 *(3.5)*	11 *(10)*	5 *(4.5)*	2 *(1.8)*	2 *(1.8)*	2 *(1.8)*

Legend: CLO= Cod liver oil, GS= Glucosamine Sulphate, C= Chondroitin, Gels = topical non-steroidals, P= Paracetamol, B= Brufen, V= Volterol, A= Arthrotec, CD= Co-dydramol, CC= Co-codamol.

Clinical data

Table 11 shows mean clinical findings. The confidence interval (CI) illustrates the range of measures drawn from the study sample.

Table 11. Mean Clinical findings (Based on 180 feet)

Parameters *(counts*)*	**Mean**	**± SD**	**95% CI** Lower	Upper	**Range**
Passive 1st MTPJ ROM					
- Dorsiflexion	41°	19°	37	43	0-82°
- Plantar flexion	15°	5°	11	17	0-25°
Active 1st MTPJ ROM					
- Dorsiflexion	58°	19°	53	60	0-90°
Ankle joint equinus					
- Knee extended	10°	2°	8°	10°	5°-17°
- Knee flexed	13°	3°	12°	15°	8°-25°

Legend: *= nominal data, SD= Standard deviation, ROM= range of motion

The hallucal position (frontal plane) was rectus in 91 (50.5%) feet, valgus in 75 (41.6%) feet and varus in 13 (7.2%) feet. Hallucal flexor power was weak in 10 (5.5%) feet, medium in 20 (11.1%) feet and strong in 150 (83.3%) feet. The length of the 2nd toe compared with the hallux was found to be longer in 54 (30%) feet, the same length as the hallux in 111 (61.6%) feet and shorter than the hallux in 15 (8.3%). During passive 1st MTP joint dorsiflexion pain occurred at the end-of-range in 29 (26.3%) subjects, mid-range in 41 (37.2%) subjects, beginning in 35 (31.8%) subjects and all-of-range in 5 (4.5%) subjects.

Osteoarthritis was present in joints other than the 1st MTP joint in 32 (29.1%) subjects; hips were affected in 14 (12.7%) subjects, knees in 40 (36.3%) subjects and finger joints in 56 (50.9%) subjects.

Tables 12A and 12B show categorical clinical findings.

Table 12A. Categorical clinical findings (Based on 110 subjects or 180 feet*****)						
Parameters Count *(%)*	Normal	Delayed heel lift	Supination	Vertical toe-off	Abductory twist	Knee flexion
Gait at propulsion	37 *(20.5)*	50 *(27.7)*	68 *(37.7)*	11 *(6.1)*	12 *(6.6)*	2 *(1.1)*
	None	Hallux IPJ	2nd MTPJ	3rd MTPJ	5th MTPJ	1st MH
Location of callosities*	58 *(32.2)*	67 *(37.2)*	18 *(10)*	10 *(5.5)*	18 *(10)*	9 *(5)*
	Severely supinated	Supinated	Neutral	Pronated	Severely pronated	
Foot Posture Index*	6 *(3.3)*	12 *(6.6)*	78 *(43.3)*	64 *(35.5)*	20 *(11.1)*	
	None	Hammer	Claw	Mallet	AV	
Lesser toe deformities*	9 *(5)*	13 *(7.2)*	77 *(42.7)*	18 *(10)*	63 *(35)*	

	≤ 20° DF	≤ 15° DF	≤ 10° DF	≤ 5° DF	≤ 0° DF	
Ankle joint (AJ) equinus*	5 *(2.7)*	58 *(32.2)*	107 *(59.4)*	10 *(5.5)*	0 *(0)*	
	Absent	Mild > 5°	Moderate > 10°	Severe > 15°		
Hallucal IPJ hyperextension*	60 *(33.3)*	66 *(36.6)*	46 *(25.5)*	8 *(4.4)*		
HAI° *	51 *(28.3)*	50 *(27.7)*	57 *(31.6)*	22 *(12.2)*		
Hallucal IPJ pain*	144 *(80)*	18 *(10)*	16 *(8.8)*	2 *(1.2)*		

Legend: HAI°= Hallux abductus interphalangeus angle, IPJ= interphalangeal joint, DF= dorsiflexion, MT= metatarsal head, AV= adducto-varus.

Table 12B. Categorical clinical findings (Based on 180 feet*****)		
Parameters	**Count**	**Percentage**
Location of HR pain*		
- Dorsal bump (DB)	75	41.6
- 1st MTP joint	21	11.6
- Sesamoids	10	5.5
- Proximal phalanx (PP)	4	2.2
- PP+ DC/ EHL	3	1.6
- DB + 1st MTP joint	12	6.6
- DB + PP	9	5
- DB + DC/ EHL	2	1.1
- DB + sesamoids	13	7.2
- DB + joint + sesamoids	7	3.8
- DB + DC/ EHL + sesamoids	11	6.1
- Joint + DC/ EHL	11	6.1
- Joint + PP	2	1.1

Legend: EHL= Extensor hallucis longus, DC= Dorsal capsule, ROM= range of motion.

Foot Health Status Questionnaire

Questions relating to foot pain and physical function were assessed during the last week whereas perceptions of foot health were assessed during the last month (Table 13). General health was rated as very good by 90 (88%) subjects, fair by 18 (16%) subjects and poor by 2 (2%) subjects. Severe foot pain was experienced by 41 (37%) subjects, moderate pain by 22 (20%), mild pain by 20 (18%), very mild by 9 (10%) and 17 (15%) experienced no pain. Condition of feet was rated as excellent by 4 (4%) subjects, very good by 18 (16%) subjects, good by 58 (53%) subjects, fair by 20 (18%) subjects and poor by 10 (9%) subjects. Overall foot health was rated as excellent by 5 (5%) subjects, very good by 17 (15%) subjects, good by 58 (53%) subjects, fair by 20 (18%) subjects and poor by 10 (9%) subjects. The amount of time that foot pain affected subjects emotionally was rated as no time at all by 10 (9%) subjects, a small amount of time 25 (23%) subjects, moderate amount of time 53 (48%) subjects, quite a bit of time 17 (15%) subjects and all of the time 5 (5%) subjects.

Table 13. Foot Health Status Questionnaire (110 questionnaires)

FOOT PAIN Count (%)	Never	Occasionally	Often	Very often	Always
Frequency of foot pain	6 *(5)*	9 *(10)*	30 *(27)*	57 *(52)*	7 *(6)*
Frequency of aching feet	6 *(5)*	18 *(16)*	25 *(23)*	51 *(46)*	10 *(9)*
Frequency of sharp pains	25 *(23)*	53 *(48)*	22 *(20)*	6 *(5)*	4 *(4)*
PHYSICAL FUNCTION	Not at all	Slightly	Moderately	Quite a bit	Extremely
Feet limit	15	22	33	25	15

work activity	*(14)*	*(20)*	*(30)*	*(22)*	*(14)*
Feet limit type of work	65 *(59)*	25 *(23)*	6 *(5)*	2 *(2)*	2 *(2)*
Foot health limits walking	13 *(12)*	22 *(20)*	35 *(32)*	25 *(22)*	15 *(14)*
Feet limit climbing stairs	9 *(10)*	22 *(20)*	37 *(34)*	21 *(19)*	19 *(17)*
FOOTWEAR	Strongly agree	Agree (A)	Neither A or D	Disagree (D)	Strongly disagree
Hard to find comfy shoes	9 (8)	11 (10)	27 (25)	50 (45)	13 (12)
Hard to find shoes to fit	11 (10)	9 (8)	27 (25)	50 (45)	13 (12)
Limited in shoes worn	13 (12	50 (45)	27 (25)	9 (8)	11 (10)
PERCEPTIONS FOOT HEALTH	All the time	Most of the time	Some of the time	Little of the time	None of the time
Did foot problems tire	10 (9)	25 (23)	53 (48)	17 (15)	5 (5)
Did you have lots of energy	5 (5)	18 (16)	52 (47)	26 (24)	9 (8)
Did you feel worn out	9 (8)	25 (23)	51 (46)	17 (16)	8 (7)
Did you feel full of life	5 (5)	18 (16)	52 (47)	26 (24)	9 (8)

DISCUSSION

A number of findings are commonly reported in patients with HR, these include pain on 1st MTP joint motion (particularly dorsiflexion)[13, 15- 18], restriction of 1st MTP joint motion[6, 13, 23-25], joint enlargement with dorsal bony proliferation[13, 20, 26], intolerance of constricting footwear[13, 21, 22], inability to raise up on toes and a modified gait[13, 16, 18, 20, 27-30, 61].These were verified in the current study and will be discussed alongside other demographic, history and clinical factors.

Demographics & history findings

Family History

Bonney and MacNab[9] reported that patients with a positive family history (FH) of great toe arthritis had an earlier onset of disease and Coughlin & Shurnas [13] found an association between HR and a positive FH of great toe problems in almost two-thirds of patients. What is not clear is how many of these were in fact hallux valgus (HV). In the current study 24% reported a positive FH, but they could not differentiate between HR and HV. Future HR studies may need to consider a properly controlled family study before a positive FH is concluded.

Age of onset

Much has been written about the age of HR onset but not all authors are in agreement (Table 2). Some early studies (Table 3) state that HR starts spontaneously in childhood or adolescence[35, 51] while others suggest it is categorized as either primary (adolescent) or secondary (adult)[6]. Few studies have reported on adolescent patients with HR[5, 23, 27, 35, 36]. In reviewing studies that report on age,[13, 18-20, 31-34, 40, 41, 62] the mean age at onset was 51 years. The mean age at onset in the current study was 44 (14-68) years; only 3 subjects developed symptoms at an age of less than 18 years. Given the small number of adolescent subjects with HR reported by our study and others[13, 18-20, 31-34, 40, 41, 62] and the fact that pathological specimens from both adults and adolescent patients with HR were found to be consistent with degenerative arthritis[13, 23] it is concluded that artificially dividing patients into primary and secondary categories is unnecessary.

Gender Predilection

Gould et al[38] and Hattrup & Johnson[39] both found a male predilection to HR. Gould et al[38] reported that 64% of HR patients were males and that gender predilection depended upon age. Their results were only based on 15,000/45,000 returned questionnaires sent to shoe shops, where briefed shoe fitters, asked and marked the questions. No clinical examination was undertaken. The findings were then projected into the total United States population (186 million at the time).

In complete contrast, virtually all recent HR studies (predominantly surgical intervention)[13, 20, 30, 31, 33, 36, 40, 41] show a higher female predilection (62%), a percentage comparable to the current study (66%).

This female predilection to HR may not be due to biological differences but to social and cultural factors that result in women wearing footwear that aggravate a predisposition to develop HR or aggravate pain in deformities of similar magnitude. Coughlin & Shurnas[13], in a self-selected review of 18 post-surgery HR studies, found that 62% of females were affected by HR, a finding similar to their own results (63%) and concluded that there was an association between HR and female gender. In addition they found that females were more commonly affected in all age groups, a finding comparable with the current study (Table 8). However, this finding may only reflect the higher number of females receiving surgical treatment for HR, but not the true male/female incidence in the general population, who have the condition but have not as yet, had surgical intervention. The current study shows a much higher ratio of females in the younger age groups (Table 8): Is this because 18-40 year-old females are more likely to wear inappropriate footwear?

Body mass index (BMI)

It was considered that an increased BMI may predispose subjects towards HR and contribute towards levels of pain experienced. In the current study subjects were only marginally overweight, indicated by a mean BMI of 25.93

Kg/m^2 (19.53-37.26) and there was no gender difference (male: 26.48, female: 25.70). BMI was not considered to be a predisposing factor for HR.

Bilateral involvement

Unilateral HR has been reported by some authors[9, 20, 37]. Drago et al[40] reported increased unilateral involvement in females, but presented no demographic data to support this. In the current study unilateral involvement presented in 40 (36%) subjects (equal numbers of left or right feet); 38% were female (Table 9). Other studies report bilateral HR[13, 17, 38] or bilateral presentation with unilateral symptoms. In this study bilateral involvement presented in 70 (64%) subjects (Table 9), which may reflect the predominance of older subjects (Table 7) rather than the true incidence as, with the passage of time, a higher percentage of patients are likely to exhibit bilateral disease. It may also reflect the type of clinic (surgical) from which subjects were taken. In the current study analysis was undertaken at the point of referral. Coughlin & Shurnas[13] found bilateral HR at final follow-up (79%) compared to 19% at initial examination.

In the current study a history of trauma was common in subjects who developed unilateral HR (positive trauma history in 22% study sample; 74% of whom had unilateral involvement) (Table 9). No association between HR as a whole and a history of trauma (p = 0.1) was found. These findings concur with that of other researchers[13]. A statistically significant association between unilateral HR and trauma ($p < 0.05$) was found.

A small proportion of unilateral HR subjects had the asymptomatic foot examined. In these cases it was apparent that differences between the feet existed and that they may result in different biomechanical function of the 1st MTP joint. Although these findings suggest a trend the numbers of subjects where such a comparison was possible was too small to enable definitive conclusions to be drawn. Further research in this area is warranted.

Footwear

Poor footwear has been implicated in the development of HR for many decades. Davis-Colley[2] first proposed a link in 1887. Bingold & Collins[23] and DuVries[63] cited footwear that is too short, Lorimer et al[64] footwear that is too loosely fitting and Cracchiolo[65] footwear that causes hyperextension of the great toe as a cause of HR. Some authors reported that patients with HR were intolerant to footwear[13, 21, 22]. Unfortunately, the vast majority of 'evidence' over the years has been anecdotal. The few studies that addressed the issue, found that the association between footwear and HR was not statistically significant[13, 66]. Sim-Fook & Hodgson[66] examined 118 shod and 107 unshod Chinese subjects. Only 17% of those wearing footwear and 10.3% not wearing footwear, were affected by HR. There was a marked gender bias in that 84% of the unshod were female and 67% of the shod were male. Coughlin & Shurnas[13] found that 16% of patients considered their footwear to be a contributory cause of their HR. They found no statistically significant correlation between footwear and HR to confirm this (r =0.08, p>0.1)[13].

In the current study only 23% subjects considered their footwear a contributory cause of their HR. However, the frequency of 1st MTP joint pain in HR associated with footwear was found to affect 36% of subjects on most days (Table 10A). The most common types of footwear restrictions reported by females were high heeled shoes (31%) probably because the 1st MTP joint is held in an extended position during gait. Slip-on shoes (16%) and Wellington boots (3%) may cause FHB overuse to maintain stability and subsequent sesamoid pain. In 14% of subjects dress shoes were found to compress the forefoot, this may alter 1st MTP joint biomechanics. Flat shoes (5%) may increase the requirement for dorsiflexion at propulsion. Shoes with a seam over 1st MTP joint (3%) rub the joint especially if dorsal osteophytes are present and can compress the dorsomedial cutaneous nerve resulting in dysesthesia or numbness along the medial border of the hallux. Walking boots (2%) and new shoes (1%) only contributed to HR in a few cases. No footwear restrictions were reported in a quarter of subjects, most of which were males.

<u>Factors aggravating HR</u>

In the current study subjects reported a number of factors responsible for aggravating the symptoms of HR. Whilst footwear (23%) was the most common other factors were also reported: cold/damp weather (11%), walking on uneven terrain (10%) or for long distances (9.5%), normal walking (8.2%), running (6.4%), descending stairs (6.4%), stubbing HR toe joint (4.6%), not wearing insoles (4.6%), kneeling (4.5%), driving for long periods

(3.6%), standing for long periods (2.8%), weight of bed covers (2.7%), increased body weight (0.9%). Subjects reported that prolonged activity while barefoot or in soft-soled shoes was often difficult. Only 1.8% of subjects reported that no factors aggravated their HR. Factors aggravating HR are likely to be idiosyncratic, influenced by lifestyle and general health.

Relief of HR symptoms

Subjects reported strategies responsible for immediate relief of HR symptoms. Sitting (23.6%), removal of footwear (23%), wearing of insoles with trainers (9%) and use of painkillers (5.7%) were the most common. It is interesting that so few subjects opted to use painkillers although this is reflected in the small number of subjects reporting severe 1st MTP joint pain (23.6%). A strong correlation between the use of painkillers and symptoms in these particular subjects was found ($r = .82$, $p = 0.05$). Other strategies reported included: 1st MTP joint distraction (5%), immersing joint in warm water (4.3%), use of flat stiff soled shoes (3.5%), modified gait (walking on outer border of foot) (3.4%), foot exercises (3%), massaging joint (2.9%), walking on flat surfaces (2.6%) and use of non-steroidal gel (1%). In subjects with well advanced disease no measure would obtain immediate pain relief (13%).
Subjects presented with a wide range of HR pathology and symptoms but the majority took either no pain medication (46%) or over the counter drugs (44%) whilst a few (11%) took prescription only medicines (Table 10B).

Restriction of activity levels

1st MTP joint pain in HR was found to restrict activity levels in subjects on most days (31.8%) (Table 10A) and 30% of subjects were moderately affected in their activities (Table 13). The types of activities restricted by HR included: running, long walks (particularly hill walking), walking on uneven surfaces, dancing, multidirectional sports and aerobic exercise. Predominantly activities requiring a forced excursion of the 1st MTP joint in the sagittal and/or frontal plane may precipitate pain. Transverse plane movement however, is resisted because of increased transverse plane stability promoted by bony changes in HR.

Occupation

In the current study 42% of subjects lead an active occupation but only 29% considered that their occupation contributed to HR. This concurs with the FHSQ data (30% of subjects reported being affected at work by their HR) and that of other studies who found no statistically significant correlation between HR and occupation (r = .08, p > .1)[13].

In the current study, just over one-quarter (27%) of subjects were retired, which may influence their activity levels and subsequent HR pain. In retirement some subjects may be more active while others may be less active because of ill health. This factor has not been considered in other studies.

1st MTP joint symptoms

In the current study subjects reported moderate (38.2%) and severe (23.6%) 1st MTP joint pain within the last 6 months and only 18% of subjects reported no pain (Table 10A). A painful 1st MTP joint was reported for 67% of waking hours on movement and variable on most days for 38% of subjects (Table 10A). Some subjects (29%) presented with pain at rest (Table 10A).

Subjects were asked to grade their 1st MTP joint stiffness and indicate the period during the day when they experienced joint stiffness. This was graded on a continuum between zero and ten (0= no stiffness, 10 = unable to move). In the current study 86% of subjects reported 1st MTP joint stiffness (Table 10A) and if variable, at its worst, 45% were graded as 5 out of 10. Only 20% of subjects reported no 1st MTP joint stiffness. There was a strong correlation between 1st MTP joint pain and stiffness (r = .79, p = .01) but this was not statistically significant. Morning stiffness was reported in 66% of subjects; evening stiffness in 71% and 64% had 1st MTP joint stiffness throughout the day (Table 10A).

Locking of the 1st MTP joint was reported in 36% subjects but was variable and short lasting in nature. More commonly 55% of subjects experienced cramp/ spasm of the 1st MTP joint and hallux (Table 10A) a consequence of capsulitis and FHL/ FHB tenosynovitis. Subjects reported 1st MTP joint symptoms to be worse during the heel-rise and propulsion phases of gait.

Subject's perception of their gait

In the current study 90% of subjects considered that their walking pattern had changed during the development of their HR, of which 33% considered that this change affected them everyday (Table 10A). Only 51 (28%) of feet were able to push through the ground at propulsion everyday, the remainder were affected to varying degrees of severity (Table 10A) and 135 feet (75%) rolled outwards during propulsion. The differences in frequency for each of the above variables of gait are outlined in Table 12A.

Presence of OA in other joints

An association between radiological foot OA and radiological OA at other sites has been reported[67]. In the current clinical study 29% of subjects (mainly females) with HR (1st MTP joint OA) reported OA in other joints. This was found to be most common in finger joints (51%). Whilst these findings indicate a relationship between the parameters this is not necessarily a causal relationship. Future epidemiological studies would be useful to determine whether a systemic aetiology is involved in the development of HR and provide an enhanced ability to describe the respective influences of mechanical and systemic factors in the development of this condition.

Sport

It is recognized that certain sports impart 1st MTP joint trauma and may be responsible for precipitating HR development whilst their frequency may exacerbate symptoms. In the current study 69% of subjects reported undertaking a range of sports (football, rugby, tennis, golf, badminton, rock climbing, running, walking, horse riding, yoga, aerobics and swimming) of variable frequency (1-5 times per week) prior to HR onset.

Foot Health Status Questionnaire (FHSQ)

The FHSQ evaluated health related quality-of-life dimensions of foot pain, physical function/ appearance, footwear and general perceptions of foot health. Findings from the FHSQ (Table 13) broadly concur with the history and physical results of the current study (Tables 10-12). The severity (37% - severe) and frequency (42% - very often) of foot pain documented was greater than that verbally reported (clinical study). This may be because the FHSQ data related to foot pain within the previous week rather than the last six months (clinical study). Interestingly the frequency of foot pain was found to vary (52% -very often) more often in the short term (one week) than over a longer period of six months (38% most days). Some subjects reported that their 1st MTP joint pain made them feel tired and worn out and that their pain appeared to affect them both physically and emotionally (Table 13).

The restrictions of physical function documented by subjects were related to similar activities as those found in the clinical component of the study (aggravating factors). Subjects reported that although it was possible to find footwear to fit their feet and which does not hurt their feet the number and type of footwear was limited (Table 13). A number of subjects (particularly females) were not happy with the appearance of their feet because of the enlarged 1st MTP joint/s and considered that this factor as well as joint pain limited them in their choice of footwear. The majority of subjects reported their general health as good except for two subjects who were restricted by heart disease (angina). It was interesting to note that the subject's perception of their general foot health was good (apart from 1st MTP joint) but many felt that their 1st MTP joint/s pathology limited them in vigorous physical and social activities and were concerned about the impact this may have on their long term general health.

Clinical findings

Factrs thought to contribute to development of HR

Pes Planus

Pes planus as a cause of HR has been implicated by a number of authors[3, 6, 23, 26, 40, 46-51, 61] with the understanding that excessive foot pronation results in increased plantar fascia tension and increased dorsiflexion force under the 1st metatarsal head, and thus a reduced ability of the hallux to dorsiflex. No demographic data were reported in any of these studies to substantiate the notion that pes planus is a cause of HR.

Jack[51] assessed foot posture by observing the weight-bearing arch of the foot but no criteria were documented to quantify this. Jack[51] considered an association between pes planus and HR but was unclear which comes first or whether the two develop *pari passu*. Coughlin & Shurnas[13] assessed foot posture using a Harris Beath mat to measure arch height or excess heel valgus. Only 11% of their patients had pes planus. Their results were similar to those of Harris & Beath[57] (15%) who examined 3619 normal military recruits. The Harris & Beath mat has not been tested for reliability and validity and it was considered that the results of Coughlin & Shurnas which were based on previous studies were not reliable or conclusive.

Scherer[68] suggested that calcaneal eversion can theoretically limit 1st MTP joint motion. Harradine & Bevan[69] appeared to validate this conjecture by examining the effect of static rearfoot eversion (using 3º, 5º and 8º valgus wedges in a standard shoe) on 1st MTP joint ROM. A reduced joint ROM with increasing calcaneal eversion was found. This artificially replicated three magnitudes of pronation; therefore the findings may not be representative of the full continuum of foot pronation seen in the general population. Mahiquez[70] examined the relationship between rearfoot valgus and 1st MTP joint OA and found 23% of subjects more likely to develop 1st MTP joint OA with hindfoot valgus. Halstead et al[71] found patients with 1st MTP joint OA demonstrated higher medial forefoot pressures and more pronated foot postures. Grady et al[72] retrospectively analysed 772 HR patients and found 5.5% had aetiologies of both trauma and excessive pronation while 21.7% had excess pronation only. The measurement criteria included excess pronation at mid-stance/toe-off and Kite's angle >45º.

Payne & Dananberg[73] contend that blockade of 1st MTP joint sagittal plane motion (sagittal plane facilitation theory) produces compensation within other planes. Compensatory subtalar and mid-tarsal joint pronation (frontal plane) with forefoot abduction (transverse plane) can ensue, producing flatfoot in some HR patients. Whilst the above studies provide interesting theories linking pes planus with HR none use a validated tool to quantify foot posture.

In the current study the Foot Posture Index (FPI)[53] was used to quantify the degree of pronation or supination. This is a valid, reliable and objective measure of foot function[53]. The FPI quantifies foot posture in a relaxed stance position, requiring no manipulation of the foot, marking of lines or measurement with instrumentation. Thus the controversial issues relating to goniometer assessment and validity of neutral subtalar joint positioning are avoided[74, 75]. In the current study 84 (47%) feet had pes planus (11% of which were severely pronated). The remaining 78 (43%) feet had a normal foot posture and 20 (10%) feet had a high arched supinated foot (Table 12A). A strong correlation between a pronated (pes planus) foot and 1st MTP joint pain was found (r= .84, p= .05). It is theorized that in a pes planus foot forefoot hypermobility at propulsion may promote 1st MTP joint instability, increasing ROM and pain. A correlation between increased 1st MTP joint ROM and pronated feet (r= .72, p=0.1) support this concept although this was not statistically significant. Whilst these findings indicate a relationship between the parameters this is not necessarily causal.

Functional hallux limitus

Functional hallux limitus (FHLim) is defined as reduced 1st MTP joint dorsiflexion on foot loading compared with passive non-weight-bearing and has been proposed as a cause of HR[28,42-45]. None of these authors mention ankle joint position when assessing for FHLim. If the ankle is plantarflexed when passive 1st MTP joint dorsiflexion is tested then hallux dorsiflexion is likely to increase as the flexor hallucis longus (FHL) is taken off stretch[15]. Coughlin & Shurnas[76] also question the concept of FHLim as reported in the literature, which remains theoretical conjecture and a subjective diagnosis[45], conceived to explain abnormalities seen on in-shoe pressure readings and visual gait assessments[68]. Coughlin & Shurnas[13] hypothesized that FHLim may represent the residual elevatus occasionally noted on dorsiflexion stress x-rays of patients with severe HR. In early stage HR FHLim may be a consequence of tenosynovitis of the FHL tendon which limits its excursion and subsequently that of 1st MTP joint dorsiflexion on foot loading[15]. The findings of the current study concur with those of other authors[13, 15].

2nd toe length

Three foot types are seen in the general population. Square foot (hallux and 2nd toe equal length), Morton's or Greek foot (hallux shorter than 2nd toe) and Egyptian foot (hallux longer than 2nd toe). Ogilvie-Harris et al[77] assessed 2nd toe length in ballet dancers and found a correlation between HR and a longer 2nd toe[78]. One clinician examined 59 dancers (34 female & 25 male) comparing them to a randomly selected control group of 60 subjects (30 female, 30 male). The authors defined any difference in length of <2mm as not significant recording it as normal. No radiographic evidence was used and the lack of this may have influenced the outcome of results. They reported that 40% male and 27% female ballet dancers had a long 2nd toe compared to the hallux. In the control group (in which there was no HR), 60% of males and 43% of females had a longer 2nd toe. The authors concluded that 44% of ballet dancers, with a long 2nd toe, had bilateral HR but failed to elicit the related pathomechanics.

The current study does not concur with that of Olgilvie-Harris et al[77]; 54 feet (30%) had a long 2nd toe while 111 feet (62%) had a 2nd toe the same length as the hallux and 15 (8%) a 2nd toe shorter than the hallux. Chi-square analysis of 2nd toe length and 1st MTP joint pain revealed a significant finding (p=0.001<0.05). In a radiographic study of the same subjects the proximal phalanx was found to be longer than the distal phalanx[79]. The overall length of the hallux may be a factor contributing to HR and is supported by others who have compared HR with non-HR subjects and found a longer hallux in the HR group[80]. Whilst these findings indicate a relationship between the parameters this is not necessarily a causal relationship.

Factors used as markers of severity

Increased joint size and soft tissue swelling

Increased 1st MTP joint size in HR has been documented[13, 20, 26]. This is related to the presence of osteophytes, joint distension secondary to synovitis and may provide an indirect clinical measure of joint damage. Soft-tissue swelling of the 1st MTP joint has also been reported[19, 20] and may be related to a dorsal prominence that becomes painful from constant rubbing against the shoe, capsulitis and EHL tenosynovitis resulting from stretching of soft tissues over dorsal osteophytes. This may be the reason why HR subjects sometimes complain of pain on hallucal plantarflexion. In the current study it was observed that the magnitude of joint size increased with the severity and duration of HR.

Pain with 1st MTP joint motion

Some studies have documented pain during 1st MTP joint motion[13, 15-18]. In the current study subjects reported pain during passive ROM. The timing of this pain during joint movement was documented in an attempt to quantify the severity of HR (joint damage). Twenty-six percent of subjects reported end-of-range pain suggestive of minimal joint damage, 69% of subjects reported pain at the beginning or mid-range pain accounting for mild to moderate joint damage and 4.5% reported all-of-range joint pain representing severe joint damage. This reflected the range of severity of HR within the subjects. Interestingly a strong correlation between 1st MTP joint pain and increased 1st MTP joint ROM at propulsion was found (r= .84, p= .01) but this was not statistically significant. This may explain why in a damaged 1st MTP joint where there is still free and unrestricted joint motion pain is often likely whereas, in an ankylosed 1st MTP joint where movement is restricted pain is less likely. In feet with restricted 1st MTP joint ROM pain may present in other areas (lateral forefoot) due to the compensation imposed by the restricted joint motion. During active ROM subjects reported pain primarily during heel lift and propulsion where 1st MTP joint dorsiflexion was required. In the current study subjects reported that by altering their gait pattern they could modify the severity and timing of symptoms.

Variability of 1st MTP joint pain

The natural history and symptoms of HR can vary from day-to-day and are influenced by numerous aggravating or relieving factors. In some cases, the condition takes a relatively benign course and in others symptoms are more persistent[81]. In the current study 87% of subjects were found to have daily variability of joint pain (Table 10A). It is concluded that the variability of joint pain is multifactorial and may include factors such as lifestyle, health, footwear and others (see aggravating factors). Whilst occupation does not appear to play a role in the development of HR is may be responsible for its variability.

Location of HR pain

Subjects presented with primarily dorsal bump pain (42%) (particularly early in the condition), 1st MTP joint pain (12%), sesamoid pain (9%), proximal phalanx pain (2%) or a combination of locations around the 1st MTP joint (Table 12B). Sesamoid pain appeared to be more common in established HR.

Restricted joint motion

Studies have documented restricted 1st MTP joint motion in HR (especially dorsiflexion)[6, 13, 23, 24]. The current study concurs with these findings (Table 11). Halstead et al[71] demonstrated no association between measurements obtained at the 1st MTP joint during static stance and maximum dorsiflexion during walking. In view of the different modes of compensation for HR during gait further research to compare 1st MTP joint motion in static stance and during walking would be valuable and may help inform treatment.

Passive versus active 1st MTP joint ROM

Overall passive 1st MTP joint ROM was reduced as expected. Mean dorsiflexion 41° (0-82°) was below the normal range (65°-90°)[21] and plantarflexion was also reduced, mean 15° (0-25°) (Table 11).

Active 1st MTP joint dorsiflexion increased with weight-bearing. Mean active dorsiflexion 58° (0-90°) (Table 11) was greater than mean passive dorsiflexion, this may be a result of body weight and forward momentum increasing available joint dorsiflexion however, this was still well below the normal range (65°-90°). Also, possibly because of joint pain, some subjects supinated their foot during movement reducing the need for as much dorsiflexion. These findings concur with a radiological study in which a mean hallux equinus angle of 11° was found during stance, this is outside the normal range (16°-18°)[79].

Both bone (including joint) and soft tissue changes associated with HR are responsible for a reduced joint ROM (particularly dorsiflexion). The dorsal capsule and EHL can become stretched and inflamed by dorsal osteophytes causing pain and may contribute to limited plantarflexion in HR.

Hallux abductus interphalangeus (HAI)

In the current study 129 feet (72%) presented with HAI (Table 12A). A moderate degree (> 10°) of HAI (transverse plane) was present in 57 feet (32%). In 79 feet (44%) the HAI° was greater than normal (where normal ≤10°). Strong correlations were found between HAI and 1st MTP joint pain ($r = .82$, $p = .03$) which was not significant and HAI and reduced 1st MTP joint ROM ($r = .92$, $p = .05$). It is hypothesized that the presence of HAI indicates a more progressive HR process and that with increased 1st MTP joint damage the 1st metatarsal head becomes flatter and more resistant to transverse plane movement, thus predisposing to an increased HAI.

Factors associated with or secondary to HR

Ability to rise up on toes

In HR if 1st MTP joint dorsiflexion is restricted or painful then subjects may avoid forced dorsiflexion of the joint imparted by rising up on their toes. In the current study 21% of subjects were unable to undertake this manoeuvre, the reminder could perform the task to varying degrees (Table 10A). A weak correlation between 1st MTP joint pain and ability to rise up on toes was found ($r = .40$, $p = .03$). Subjects can still perform this manoeuvre by supinating their foot.

Hallucal position (frontal plane)

Medial 1st ray deviation, increased 1/2 intermetatarsal angle and lateral deviation of the hallux may alter the pull of abductor hallucis causing it to rotate the hallux into valgus. Valgus hallucal rotation is normally associated with hallux valgus but may present in HR (Figure 2) where it may influence sagittal plane motion at the 1st MTP joint.

Figure 2: Valgus hallucal rotation in HR

In the current study valgus hallucal rotation presented in 75 feet (42%), hallux varus in 13 feet (7%) and 91 feet (51%) had a rectus hallux. A moderate correlation between valgus hallucal rotation and limited 1st MTP joint ROM ($r = .59$, $p = .01$) was found but was not statistically significant. A correlation between valgus hallucal rotation and 1st MTP joint pain was found ($r = .78$, $p = .05$). It was concluded that hallucal valgus rotation may biomechanically alter 1st MTP joint function in HR. It is unclear whether this feature progresses with time, however, in the small number of hallux valgus-rigidus subjects excluded from this study a more severe and late stage HR was seen.

Hallucal interphalangeal joint (IPJ) hyperextension

Hallucal IPJ hyperextension (dorsal sagittal plane deviation) can be seen during early stages of HR when MTP joint motion is still good. Lynn[82] considered that IPJ hyperextension is another causal factor which increases susceptibility to HR rather than being secondary to reduced MTP joint motion. In the current study 120 feet (62%) had a hyperextended hallucal IPJ of varying degrees of severity and 30% of these were greater than 10° (Table 12A). A correlation was found between hallucal IPJ hyperextension and 1st MTP joint pain (*r* = .78, *p* = .01) but this was not statistically significant. This relationship is not necessarily causal. In the current study the degree of hallucal IPJ hyperextension did not appear to increase with increasing severity of HR.

Hallucal interphalangeal joint (IPJ) pain

As sagittal plane restriction of the 1st MTP joint can result in compensatory transverse and/or sagittal plane deformity of the hallucal IPJ it was assumed that hallucal IPJ pain may develop. In the current study a painful IPJ was reported in 36 subjects (20%) and only 18 (10%) of these had moderate to severe pain (Table 12A). Chi-square analysis of hallucal IPJ pain and 1st MTP joint pain revealed no significant finding ($0.24>p>0.05$). In this group of subject's hallucal IPJ pain was not considered to be a feature associated with HR.

Hallucal flexor function

Tenosynovitis of the hallucal flexor tendons in HR may influence hallucal purchase power. The ability of the hallux to prevent a piece of paper from being pulled away from under it during static stance was not found to be impaired in HR where 150 (83%) feet had a strong (not moveable) response.

Location of plantar callosities

These were related to abnormalities of gait (pronation and inverted step). Increasing severity of 1st MTP joint pain results in more supinatory compensation and subsequently more laterally placed callosities. In 67 (37%) feet callus presented over the plantar medial hallucal IPJ. This may be related to 47% of subjects who presented with a pronated gait in which there is likely to be increased hallucal IPJ propulsion. Of the remaining 46 (26%) feet callus was located under the lateral metatarsal heads (2nd- 5th), 9 (5%) feet under the 1st metatarsal head and 58 (32%) feet presented with no callosities (Table 12A). The severity of callosities may be influenced by lifestyle and activity levels.

Lesser toe position

Coughlin[83] and Roukis et al[1] noted that the medial angulation of the 2nd toe can result from compensation during gait. In an attempt to provide medial column stability the flexor digitorum longus (FDL) muscle contracts. A “windswept” appearance to the entire forefoot, rather than just the 2nd toe may result. In the current study lesser toe clawing in 77 (43%) feet, medialisation (adduct-varus) of 3rd-5th toes in 63 (35%) feet, and other toe deformities presented (Table 12A).

Ankle equinus

A recent study concludes that gastrocnemius contracture plays a vital biomechanical role in chronic foot problems[58]. Bingold & Collins[23] suggested an association between Achilles tendon contracture and HR. Isolated gastrocnemius tightness has been reported in up to 24% of “normal” patients when defined as less than 5º dorsiflexion with the knee fully extended and the condition was implicated in the pathogenesis of midfoot, hind foot, and forefoot pathology[52] although it was unclear how many patients had HR. Coughlin & Shurnas[13] found no association between Achilles tendon tightness and HR. They defined gastrocnemius contracture as < 0º dorsiflexion when the knee was fully extended with the foot in neutral. Only 3.5% of their subjects had 5º or less of dorsiflexion although the study had no control group with which to correlate the results. In the current study 10 (5.5%) feet had 5° or less dorsiflexion with the knee fully extended and foot held in neutral (to eliminate subtalar & midtarsal joint involvement) (Table 12A). No subject had an Achilles tendon contracture <0°. The mean ankle dorsiflexion with the knee extended was 9° (5°-17°) this increased to 13° (8°-25°) with the knee flexed (Table 11). It is concluded that ankle equinus secondary to Achilles tendon tightness is not associated with HR.

Lesser metatarsal overload

Supinated gait in response to restricted 1st MTP joint motion can cause overload and pain in the region of the lesser metatarsal heads[45]. In the current study lesser MTP joint pain (transfer metatarsalgia) was in reported in 69 (38%) feet with varying degrees of frequency (Table 10A). A strong correlation between lesser MTP joint pain and a change in walking pattern (r=

.80, *p*= .05) was found. Chi-square analysis of lesser MTP joint pain and supination at propulsion revealed a statistically significant finding ($p<0.001$). It is hypothesized that 1st MTP joint restriction/ pain is responsible for altered forefoot loading and subsequent metatarsalgia experienced (Table 10A). This is supported by gait modifications found within the same proportion of subjects where 68 (37%) feet were held in supination at propulsion (Table 12A). As other gait modifications are associated with HR not all subjects will complain of forefoot pain.

<u>Altered gait</u>

It is documented that gait in HR may become increasingly antalgic as the MTP joint stiffens resulting in an everted[13, 16, 18, 20, 27, 30] or supinated[13, 51] position of the foot. The sagittal plane facilitation theory[42, 73] supports this and describes five forms of compensation for sagittal plane blockade in HR:

<u>1. *Delayed heel lift*</u>

The mid-tarsal joint is the closest to the 1st MTP joint which allows sagittal plane motion. This is seen as delayed heel lift with late midstance pronation (Figure3) and navicular adduction/plantarflexion.

Figure 3: Delayed heel lift - mid-tarsal joint pronation/ eversion

<u>2. *Vertical toe-off*</u>

Denotes continuation of delayed heel-lift where foot is lifted vertically off the ground. An apropulsive, laborious, slow gait can present where there is a lack of heel-off by the time of the contra-lateral heel contact (Figure 4).

Figure 4: Vertical toe-off

<u>3. *Inverted step*</u>

Patients with increasingly severe HR supinate their foot during gait[13] to avoid extending the 1st MTP joint and propulse from the lateral four toes (Figure 5). Weight-flow is directed to the lateral column and fails to shift medially to the first web space prior to heel lift. Lateral shoe wear results despite excessive foot pronation. This explains the paradox of a flexible pronated foot with lateral forefoot shoe wear and bulging. Dynamic in-shoe pressure measurement systems such as the F-Scan® show reduced pressure under the 1st MTP joint and lateral deviation of centre of pressure (CoP) line (Figure 6).

Figure 5: Supinated gait

Figure 6: F-Scan: reduced 1st MTP joint pressure & lateral CoP line.

4. *Abductory (external) or adductory (internal) hip rotation twist at toe-off*
Seen during mid-stance/ propulsion producing 'medial roll-off' following path of least resistance. This form of compensation is associated with FHLim as advocated by Dananberg[28]; it is responsible for medial hallucal IPJ pinch callus.

5. *Flexion compensation of the body* (seen during single limb support Figure 7).

Figure 7: Failure of knee to fully extend

In the current study all five forms of HR gait compensation were observed. At propulsion 68 (38%) feet were supinated, 50 (28%) delayed heel lift (mid-tarsal joint pronation) and 37 (20.5%) had a normal gait (Table 12A).

CONCLUSION

The purpose of this cross-sectional study was to document the key clinical parameters associated with HR. A number of difficulties and limiting factors associated with clinical evaluation and assessment of the foot were highlighted.

Only certain clinical parameters were useful to evaluate HR. Some features were either too time-consuming (plantar pressure measurement), too difficult to measure, or the reliability of their measurement[84,85] (particularly angular measurements) was in doubt.

The findings of this research are based on the defined study population. HR was associated with female gender, bilateral involvement, older age groups (a condition which develops over time), increased HAI angle, FHL tenosynovitis, a 2nd toe of similar length to the hallux and restricted and/or painful 1st MTP joint dorsiflexion. HR was also associated with pain located over the dorsal bump (particularly in the early stages), hallucal IPJ hyperextension, lesser MTP joint pain (when supinating at propulsion), medial angulation of the 2nd toe, flat foot and various specific gait alterations. Unilateral involvement was less common, and mostly associated with trauma. In bilateral cases, a positive family history could not be concluded, however a properly constructed family study may prove such an association. An association between HR (1st MTP joint OA) and OA at other sites (finger joints) particularly in women was found but not tested statistically. Future epidemiological studies would be useful to determine whether a systemic aetiology is involved in HR development and clarify the respective influences of mechanical and systemic factors in the conditions development.

HR was not associated with Achilles tendon tightness. Footwear was not found to be a contributory cause, however, it was reported to be an aggravating factor (particularly in women). There were few subjects with adolescent onset HR.

For clinical parameters of the foot to be considered valid for inclusion in a classification of HR their content validity needs to be firstly established by formal research[85]. The purpose of this research study was to establish such validity.

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Captions to figures

Figure 1: Measurement of ankle joint dorsiflexion

Figure 2: Valgus hallucal rotation in HR

Figure 3: Delayed heel-lift – mid-tarsal joint pronation / eversion

Figure 4: Vertical toe-off

Figure 5: Supinated gait

Figure 6: F-Scan shows reduced 1^{st} MTP joint pressure & lateral CoP line

Figure 7: Failure of knee to fully extend