Rheumatoid Forefoot Deformity: A Comparison Study of 2 Functional Methods of Reconstruction

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ABSTRACT. ***Objective.*** To compare the functional, radiographic, and pedobarographic results of different reconstructive methods for severe rheumatoid forefoot deformities.

Methods. A total of 138 feet in 79 patients with RAforefoot reconstructions between 1978 and 1997 were reviewed through a detailed questionnaire, clinical examination, standardized radiographs, and pedobarographic analysis. Five subgroups based on procedure to the 1st ray were identified, then divided into 2 functional categories: Group 1: stable 1st ray by means of arthrodesis or no surgery; and Group 2: a resection procedure to 1st metatarsophalangeal (MTP) joint.

Results. Sixty-one patients (106 feet) attended clinical review; 18 returned the questionnaire. There were 65 women and 14 men, with a mean age of 59 years (range 24–80): with 52 feet in Group 1 and 86 feet in Group 2. Mean age at surgery for both groups was 52 years (range 23–79). Mean age at the time of review was 55 years (Group 1) and 60.5 years (Group 2). Length of followup was significantly different: Group 1 averaged 36 months; Group 2, 102 months ($p < 0.001$). At review, no significant difference was noted in SF-36, comorbidities, WOMAC, or Foot Function Index. The disability score as defined by the American Rheumatological Society was significantly different: Group 1, 2.1 ± 0.5; and Group 2, 2.4 ± 0.6 ($p = 0.006$). Group 1 did significantly better in terms of walking distance, satisfaction with postoperative appearance of foot, relief of plantar pain, less plantar calluses, and higher AOFAS HMIP and LMIP scores. Postoperative complications occurred in 16 feet (11%); 15 feet required reoperation (10.6%). Major resection of the 1st MTP joint was associated with a significant increase in the 1st and 2nd intermetatarsal angle on radiographic review. The pattern of pressure distribution on the plantar aspect was similar regardless of the surgical procedure. The maximum contact area, maximum peak pressure, and maximum pressure time integral were located under the region of the 1st metatarsal, with a progressive decrease in values under the more lateral rays and under the lesser toes. Significantly higher pressures were seen under the 1st, 2nd, and 3rd metatarsal regions in Group 2 (1st MTP joint resection). Toe function was absent or minimal in the majority of Group 2.

Conclusion. Forefoot arthroplasty by means of a resection or stabilization provides significant pain relief. Maintenance of a stable 1st MTP joint and resection of the lesser metatarsal heads with K-wire stabilization will result in a more cosmetic forefoot, more even distribution of forefoot pressures, and more satisfied patients. (J Rheumatol 2003;30:1440–50)

Key Indexing Terms:
RHEUMATOID ARTHRITIS — FOREFOOT RECONSTRUCTION
PEDOBAROGRAPHIC ANALYSIS — RESECTION ARTHROPLASTY
METATARSOPHALANGEALARTHRODESIS

The forefoot is an important area of morbidity in rheumatoid arthritis (RA). Initial manifestation of RA occurs in the foot in 16% of patients[1]; 80–100% patients with a 10-year history have symptomatic forefoot problems[2-6]; 25–40% of all surgical procedures are done on the foot[7,8]. Symptoms start due to active inflammation with synovitis in the metatarsophalangeal (MTP) joints. The inflammatory process and associated swelling lead to capsular distention and attenuation of the supporting joint ligaments. The loss of ligamentous support stimulates structural deformity: when the forefoot broadens, the hallux drifts into a valgus position as pushed laterally by the normal weight-bearing forces. The capsular distention and subluxation at MTP joints cause dysfunction of the intrinsic muscles resulting in over-pull of the long flexors and extensors. Lesser MTP joints subluxate/dislocate dorsally and a flexion contracture of the proximal (PIP) and distal interphalangeal (DIP) joints develops. In the presence of hallux valgus and claw-toe deformities, symptoms will persist even without active synovitis, since fixed deformities produce increased pressure points resulting in erythema, bursitis, and painful callus formation. Calluses form (1) dorsally over PIP joints and at

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tips of the toes, (2) medially when prominent 1st metatarsal (MT) head is the source of painful bursitis, and (3) plantarly when lesser MT heads protrude, causing increased pressure. The forefoot pain is described as "walking on marbles."

A number of procedures have been described[9-12] and Clayton[9] has outlined the principles of forefoot reconstruction. He emphasized direct treatment at the MTP joint and decompression of the rigid joint contracture through adequate bony resection to allow the phalanges to align with the metatarsi. He advocated treating all lesser toes in the same way regardless of varying degrees of involvement of each ray. Modifications since have varied more in terms of surgical technique than his principles: location of the incision, procedure to the 1st MTP joint, degree of resection of lesser MTP joints, and methods of stabilization[4,13-20] — all reported good results. Historically, some patients with a resection arthroplasty went on to develop a stiff, painful 1st MTP joint[16,20]. The stiffened 1st ray helped prevent lesser toe subluxation and callosity formation beneath the MT heads. Henry, *et al*[21] demonstrated that the hallux retained a more reliable weight-bearing position after an arthrodesis and observed a decreased incidence of metatarsalgia and plantar callosities; postoperative gait analysis showed that toe-off in the latter part of the stance phase began earlier than normal. The altered gait was attributed to the stiffness and length of the 1st ray, which helped diminish dorsiflexion forces across the lesser MTP area[22]. Conclusions drawn: arthrodesis is better than resection[17,20,23-26].

Surgery for a symptomatic RA forefoot is deemed the most satisfactory method of treatment[9,27]. For severe deformities[28], 1st MTP fusion combined with resection arthroplasty of lesser toes is preferred. Given the paucity of clinical studies that compare outcomes of arthrodesis and resection arthroplasty, our study aims to assess the intermediate and longterm outcomes of forefoot reconstructions and to compare the results of different procedures performed in one institution over a 19-year period.

MATERIALS AND METHODS

From 1978 to 1997, 181 patients who had had a forefoot reconstruction at Wellesley Hospital, Toronto, Canada, were identified. In total, 110 were contacted directly; 49 were untraceable and 22 deceased at the time of recall. They were reviewed using a detailed questionnaire, clinical examination, standardized radiographs, and pedobarographic analysis. The questionnaire was self-administered, consisting of activity level, satisfaction with postoperative appearance, deterioration since surgery, and pain relief. A generic assessment of health was made by means of a comorbidity questionnaire and the Short Form-36 instrument (SF-36). Disability was classified using the American Rheumatological Society classification[29]. Coexisting hip and knee symptoms were assessed using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)[30]. Pain was assessed using the pain subscale of the Foot Function Index (FFI) validated for use in patients with RA[31]. The American Orthopedic Foot and Ankle Society clinical rating systems, the Hallux Metatarsophalangeal-Interphalangeal (HMIP) and Lesser Metatarsophalangeal-Interphalangeal (LMIP) scale scores, were utilized to give a more specific assessment of the hallux and lesser toes[32]. The scores were based on a scale of 100 points divided into 3 sections of pain (40 points), function (45 points), and alignment (15 points): the higher the score the better the outcome.

Standardized radiographs consisted of weight-bearing anteroposterior (AP) and lateral views of both feet and ankles. The hallux valgus, hallux dorsiflexion, and 1st–2nd intermetatarsal angles were measured using standardized techniques[32-34]. Patients were evaluated clinically for a cocked-up 1st toe deformity as defined by a rigid flexure contracture at the IP joint with variable degrees of dorsiflexion at the MTPjoint.

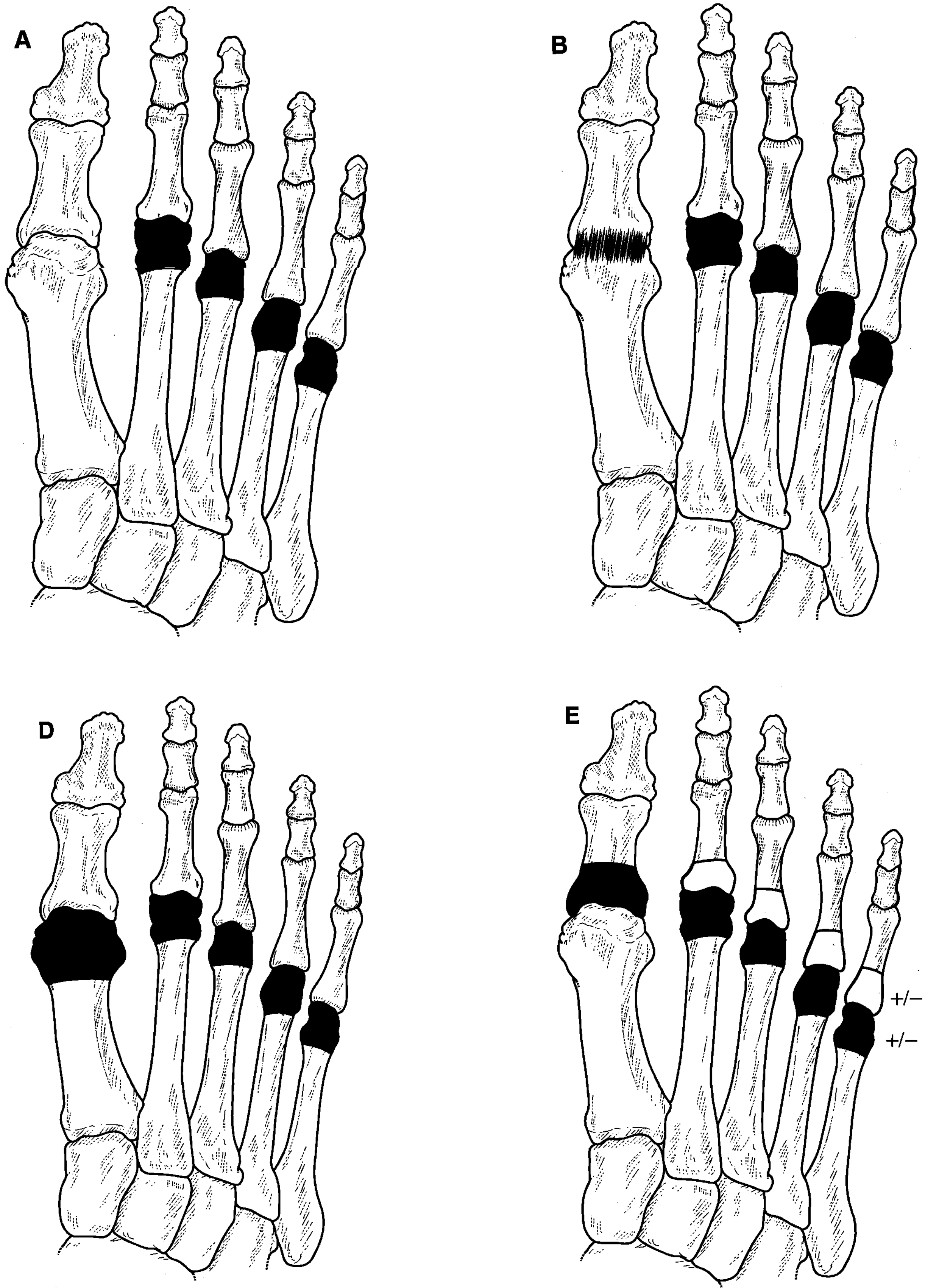
Pressure distribution beneath the foot was measured using the E-Med pedobarographic system (Novel GMBH Electronics, Munich, Germany) with a force plate of 2736 pressure sensors (4 per cm^2). Each sensor was sampled at 50 Hz and data stored in a computer. Pressure values were displayed as a conform pattern on a color graphics display unit and on a printer. The maximum pressure recorded for each sensor during the step on the force plate was used for analysis. Patients were asked to walk at a comfortable pace. Three recordings were taken of each foot during the stance phase of walking as recommended by Hughes, *et al*[35]. The force plate was placed at the end of the walkway and patients were asked not to change their stride length or cadence as they approached the force plate. The foot was divided into 1st toe (T1), 2nd toe (T2), lesser toes (T3–T5), 5 metatarsal head regions (MT1–MT5), the midfoot region, and the medial and lateral heel regions.

Pressure distribution beneath the forefoot (toes and MT heads) was evaluated by assessing 3 different pressure patterns: area of contact (cm^2), pressure time integral (PTI; Ns/cm^2), and peak pressures (N/cm^2). Data on areas of contact and peak pressures provide useful clinical information. Data on PTI are considered the most relevant method of evaluating the physiologic effect of forefoot pressures on the soft tissues since they measure both the magnitude of pressure and the time duration over which this pressure was sustained[36].

The SAS statistical software package (SAS Corp., Cary, NC, USA) allowed for all statistical analyses. Each variable was classified into one of 5 surgical subgroups based on procedure to the 1st ray: Keller, Clayton, Hoffman, Arthrodesis, and Non-operated (Figure 1). The subgroups were further classified into 2 functional categories: Group 1 for a stabilized or intact 1st ray (Arthrodesis and Non-operated) and Group 2 for a resected portion of the 1st ray (Keller, Clayton, and Hoffman) (Figure 1). For quantitative data (age, comorbidity, disability, followup, outcome measures, radiographic measurements, and E-Med data), a Student's t test helped determine any significant difference between Groups 1 and 2. For categorical data (sex, walking distance, and the presence of plantar pain, callosities, hallux valgus, and cocked-up deformity), a chi-square analysis was used to determine if there was a significant difference; if so, multiple comparisons determined where it lay. To draw comparisons among the 5 subgroups, quantitative data underwent a one-way analysis of variance to determine any significant difference. Significance for all statistical analysis was defined as a $p < 0.05$.

RESULTS

A total of 110 patients were contacted. Thirty-one did not participate in the study: 5 declined to attend, 9 did not return the questionnaire, 5 returned the questionnaire with several sections incorrectly completed, 5 were too unwell to participate, 2 were involved with other clinical studies, and 5 gave no specific reason. Forty-nine of 181 patients were untraceable: 46 from Group 2 — mean age at surgery 68 years (range 32–90) and mean time from surgery of 10.6 years (range 50–234 mo); and 3 from the arthrodesis group — mean age 67 years (range 54–79), mean time from surgery 29 months (range 19–36 mo). Seventy-nine patients (138 feet) participated in the study. Sixty-one (106 foot operations) were clinically reviewed and a further 18 returned a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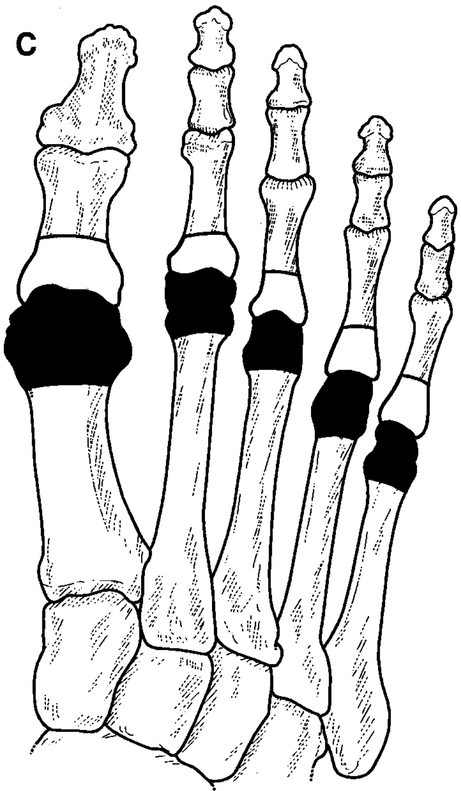

Figure 1. Five subgroups of patients were identified based on the procedure to the 1st ray: (A) Non-operated 1st ray: Resection of the lesser MTheads with no surgery on the 1st ray (n = 21 feet). (B) Arthrodesis: Resection of lesser MT heads and arthrodesis of the 1st MTP joint (n = 32 feet). (C) Clayton procedure: Resection of all 5 MT heads and base of the proximal phalanges (n = 30 feet). (D) Hoffman procedure: Resection of all 5 MT heads (n = 24 feet). (E) Keller procedure: Resection of lesser MTheads and base of the proximal phalanx of 1st toe (n = 35 feet). The 5 subgroups were further classified into 2 functional groups based on the procedure to the 1st ray: Group 1: Stable 1st ray (Aand B); Group 2: Major resection (C, D, E).

detailed questionnaire. Sixty-five were women and 14 men, with a mean age of 59 years (range 24–80 yrs). The mean age at surgery was 52 years (range 23–79 yrs). The mean followup time was 6 years and 3 months (range 6 mo–19 yrs).

Five subgroups were identified: (1) 21 feet: no surgery to the 1st toe and MT head resections to all lesser rays (Figure 1A); (2) 31 feet: 1st MTP arthrodesis and MT head resections to lesser toes (Figure 1B); (3) 29 feet: resection to 1st MT head and proximal phalanx of the hallux, together with a proximal hemiphalangectomy and MT head resection to lesser toes (Clayton, 1960) (Figure 1C); (4) 23 feet: resection to all MT heads (Hoffman, 1912) (Figure 1D); and (5) 34 feet: a proximal hemiphalangectomy of the 1st toe coupled with either a proximal hemiphalangectomy or MT head resections of lesser toes (Keller, 1912) (Figure 1E). These were categorized into 2 functional groups: Group 1: the stable 1st ray group consisting of 52 feet (Figures 1A, 1B); and Group 2: the major resection group (Figures 1C, 1D, 1E) consisting of 86 feet. Six patients had undergone a major resection on one foot and an arthrodesis (i.e., no 1st ray operation) on the other foot. For statistical analysis these patients were included in both groups.

All 1st MTP joint fusions were stabilized by small fragment AO screws in a crossed fashion or threaded K-wires. In lesser toes, K-wire stabilization was not used, except in the arthrodesis group, where threaded wires were passed through the toes and MT shafts and left *in situ* for 5 weeks postoperatively. The use of threaded pins allowed the surgeon to maintain a gap at the site of the resected lesser MT head. The presence of the gap helped establish a mobile pseudoarthrosis and prevent the development of excessive stiffness at the lesser MTPjoint level. The threaded K-wires also helped maintain the lesser toes in a functional position. Surgically the MT heads were resected either plantarly with a single transverse incision, or dorsally with 2 longitudinal incisions or a single transverse incision. Forty-nine patients underwent a plantar approach and 89 underwent a dorsal approach.

Groups 1 and 2 were analyzed and compared. No significant difference was found in age, sex, height, or weight. Average age at time of operation for both groups was 52 years. A difference in the age at the time of review was remarkable: average age in Group 1 was 54.7 ± 10.2 years and in Group 2, 60.5 ± 13.1 years. This corresponded to a significant difference in the average length of followup: 36.1 ± 43.4 months in Group 1 and 102.0 ± 52.9 months in Group 2 ($p < 0.001$) (Table 1).

The RA population in this study was similar to that of other clinical series in terms of manifestation of disease: average of 6 ± 3 comorbidities per patient, average of 8 (range 2–13) other joints involved, with no significant difference between the 2 functional groups (Table 1). The majority had had other orthopedic procedures in the past (mean number of procedures 1.7, range 0–6). In terms of disability, 4 patients were grade 1 (normal function), 49 were grade 2 (adequate function, some discomfort), 25 grade 3 (activities of daily living only, limited by discomfort), and one grade 4 (largely incapacitated). A significant difference was noted in the average disability score: 2.1 ± 0.5 in Group 1 and 2.4 ± 0.6 in Group 2 ($p = 0.006$) (Table 1). They had, on average, 2.5 other systemic diseases as assessed by the comorbidity questionnaire (Table 1). Their SF-36 scores were significantly worse than an age-matched population. When results were broken down into the 8 subsections of the overall SF-36 score, no significant difference between the 2 functional groups was noted in the overall score or in any of its subsections (Table 2). The patients' mean WOMAC score was 45.7 (SD 14.7), reflecting poor general health and significant coexistent knee and hip pathology (Table 3). No significant difference was observed in the pain subscale of the FFI (Table 3), nor

Table 1. Postoperative data, Groups 1 and 2.

	Age at Followup	Age at Operation	Followup	Comorbidity	Walking Distance*	Satisfaction with Surgery**	Disability
Group 1	54.7 ± 13.1	51.8 ± 13.5	36.1 ± 43.4	6.7 ± 3.3	2.9 ± 1.0	1.2 ± 0.5	2.1 ± 0.5
	p = 0.004		p < 0.001		p = 0.008	p = 0.006	p = 0.006
Group 2	60.5 ± 10.2	52.0 ± 10.8	102.0 ± 52.9	6.4 ± 3.5	2.5 ± 0.9	1.5 ± 0.8	2.4 ± 0.6

* 1: < 1 block; 2: 2–5 blocks; 3: 5–10 blocks; 4: no limit. ** 1: Very satisfied; 2: somewhat satisfied; 3: somewhat dissatisfied; 4: extremely dissatisfied.

Table 2. No functional difference was noted in the overall SF-36 score or any of its subsections.

	PF	RP	BP	GH	VT	SF	RE	MH
Group 1	39.8 ± 23.8	30.3 ± 42.7	42.2 ± 23.3	48.3 ± 27.9	42.2 ± 26.0	69.9 ± 27.3	57.7 ± 39.1	70.8 ± 21.2
	p = 0.579	p = 0.674	p = 0.146	p = 0.151	p = 0.219	p = 0.501	p = 0.089	p = 0.712
Group 2	37.6 ± 21.5	33.1 ± 35.9	47.4 ± 18.6	54.7 ± 23.8	47.3 ± 21.5	69.9 ± 38.7	69.4 ± 38.7	72.7 ± 19.7

Subscales: PF: Physical Function; RP: Role Physical; BP: Bodily Pain; GH: General Health; VT: Vitality; SF: Social Function; RE: Role Emotional; MH: Mental Health.

Table 3. For both groups, no significant difference was observed in the pain subscale of the Foot Function Index (FFI) or in the 3 WOMAC subsections or the overall WOMAC scores. Patients' mean WOMAC score was 45.7 (SD 14.7), reflecting poor general health and significant coexistent knee and hip pathology.

	FFI	WOMAC	WMAA	WMBB	WMCC
Group 1	21.5 ± 20.4	45 ± 15.3	38.6 ± 16.1	49.8 ± 18.5	46.5 ± 16.3
	p = 0.188	p = 0.393	p = 0.189	p = 0.928	p = 0.254
Group 2	26.7 ± 23.9	47.2 ± 14.5	42.4 ± 16.3	49.5 ± 16.4	49.7 ± 0.254

any significant difference in the 3 WOMAC sections or in the overall WOMAC scores (Table 3) of both groups.

At the time of review 44% of patients were working, the majority in full- or part-time office employment. Eighteen percent had changed jobs since undergoing forefoot surgery; only one cited surgery as the cause (unable to resume work following operation.) Walking distance was limited to less than 10 blocks in 73% of patients. Group 1 had a significantly increased walking distance (p = 0.008) compared to Group 2 (Table 1). Only 13% of patients used a walking aid. Following surgery, 62% of patients found shoe-fitting easier: Group 1 reported a satisfaction rate of 71%, compared to 57% for Group 2. The difference approached significance (p = 0.09). Among patients for whom shoe-fitting was not easier, a smaller foot following extensive resection was the most common reason.

Postoperative complications occurred in 16 feet (11%), with no significant difference between the 2 groups. All consisted of wound infections and all resolved with antibiotic therapy. Of the 16 feet, 11 were operated on with a dorsal and 5 with a plantar incision. After surgery, 22% of patients felt their feet had deteriorated; the time of deterioration varied from 6 months to 6 years, with no significant difference (p = 0.48) between the 2 groups. For reasons outlined in Table 4, 15 feet required reoperation (10.6%). All but one belonged to the major resection group; the largest number was found in the Keller resection group.

Seventy-five percent of patients were satisfied with the appearance of their foot, 80% in Group 1 and 67% in Group 2: a significant difference (p < 0.001) (Figure 2). We found no correlation between patients' willingness to have surgery again and their degree of satisfaction with appearance.

Forty-four patients derived complete pain relief following surgery; 35 reported partial relief. No patient was made worse by surgery. Sixty-seven percent of patients were very satisfied with the result and 26% somewhat satisfied (Figure 3). Group 1 reported significantly higher satisfaction rate than Group 2 (p = 0.006) (Table 1). If indicated, 85% of patients reported that they would have surgery again.

In Group 1, 27% of patients reported plantar forefoot pain, and 49% in Group 2, a significant difference (p = 0.01) (Table 5). Some complained of a diffuse pain in the plantar aspect, while others localized pain to specific sites, most commonly under the resected end of the 2nd and 3rd rays. Out of 24 feet (22%) that had plantar callosities, Group 2 had a significantly greater number: 34% in contrast to 5% in Group 1 (p < 0.001) (Table 5). In the Clayton group, almost

Table 4. Reasons for reoperation.

	Initial Procedure		Reason for Reoperation	Revision Procedure
	Great Toe	Lesser Toes		
1	Keller	MT	Pain, deformity	1st MTPjoint fusion
2	Keller	MT	Pain 5th ray	5th ray amputation
3	Keller	MT	Plantar pain	Metatarsal trimming
4	Keller	MTPP	Pain, ulceration	Metatarsal trimming
5	Keller	PP	Pain	Metatarsal head resection
6	Keller	PP	Pain	Metatarsal head resection
7	Clayton	MTPP	Pain	Metatarsal trimming
8	Hoffmann	MTPP	Pain, ulceration	Metatarsal trimming
9	Arthrodesis	MT	Painful nodule under hallux	Excision of nodule
10	Unoperated	MT	Pain, deformity	1st MTPjoint fusion
11	Unoperated	MTPP	Pain, deformity	Clayton
12	Unoperated	PP	Pain, deformity	Hoffman
13	Unoperated	PP	Pain, deformity	Hoffman

MT: Metatarsal head resection; PP: proximal phalangectomy; MTPP: metatarsal head resection and proximal phalangectomy.

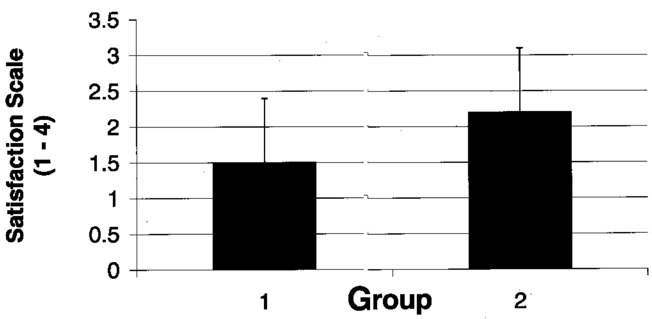

Figure 2. Patient satisfaction with appearance of their feet. Scale as follows: 1, very satisfied; 2, somewhat satisfied; 3, somewhat dissatisfied; 4, extremely dissatisfied.

half the patients experienced plantar pain; this group had the greatest amount of bony resection, involving MT heads and proximal phalanges of all toes.

The mean score for the FFI pain subscale was 24.7 (SD 22.6) (Table 3). There was no significant difference between Groups 1 and 2. A one-way ANOVA showed no statistical difference among the 5 surgical subgroups ($p = 0.295$). The pain score was worst in the Clayton group (31.6 ± 25) and best in the arthrodesis group (20.6 ± 18.8).

For the HMIP and the LMIP scale scores of both functional groups, only the patients who returned for a clinical review provided data, i.e., 106 feet in 61 patients: 42 feet in

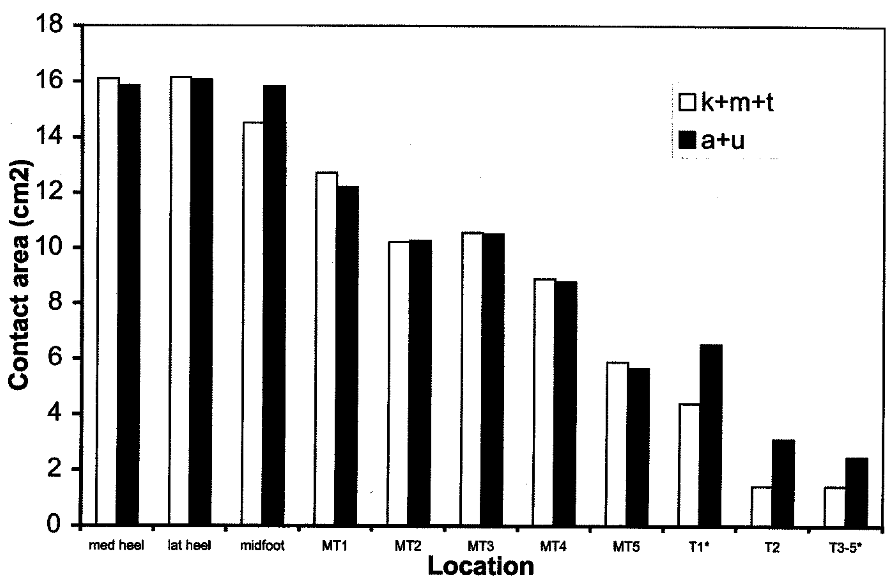

Figure 3. Contact area for the 11 masks of the foot. Group 1 consists of patients with arthrodesis and nonoperated 1st ray (black bars; a + u). Group 2 represents patients with Keller, Hoffman, or Clayton procedures with resection arthroplasty of the 1st MTPjoint (white bars; k + m + t). MT: metatarsal head, T1: 1st toe, T2: second toe, T3–T5: lesser toes. *Statistically significant difference. The increased contact area beneath T2 approached significance ($p = 0.072$).

Table 5. Symptoms experienced by patients in both groups.

	HMIP	LMIP	Plantar Pain*	Plantar Callosities**	Clawed Lesser Toes†	Cocked-up First Toe††
Group 1	75.5 ± 10.6	73.8 ± 11.0	1.7 ± 0.4	2.0 ± 0.2	1.8 ± 0.4	1.8 ± 0.4
	p < 0.001	p < 0.001	p = 0.011	p < 0.001	p = 0.003	p < 0.001
Group 2	66.3 ± 11.4	58.8 ± 13.5	1.5 ± 0.5	1.7 ± 0.5	1.5 ± 0.5	1.3 ± 0.5

* 1: Pain, 2: no pain. ** 1: Callosities, 2: no callosities. † 1: Clawed toes, 2: no clawed toes. †† 1: Cocked-up toe, 2: no cocked-up toe. HMIP: Hallux Metatarsophalangeal-Interphalangeal scale; LMIP: Lesser Metatarsophalangeal-Interphalangeal scale.

Group 1 and 64 in Group 2. The mean HMIP score for Group 2 was 66.3 ± 11.4 and for Group 1, 75.5 ± 10.6, a significant difference ($p < 0.001$). The mean LMIPscore for Group 2 was 58.8 ± 13.5 and for Group 1, 73.8 ± 11.0, a significant difference ($p < 0.001$) (Table 5).

The mean hallux valgus angle on standing AP radiographs was 25.6 ± 14.9. The lowest angle was found in arthrodesed feet (mean 24.2°); the highest in feet with no surgery to the 1st ray (mean 28.2°) (Table 6) (p = not significant). However, the 1st–2nd intermetatarsal angle was significantly greater in Group 2 compared to Group 1 ($p = 0.049$). The remainder of radiographic comparisons were insignificant.

Clinical evaluation for a cocked-up 1st toe revealed that Group 2 had a significantly greater number of patients with this deformity ($p < 0.001$). An increasing hallux valgus angle and hallux dorsiflexion angle correlated with increasing dissatisfaction with the postoperative appearance of the foot.

Pressure distribution was evaluated on 61 patients, assessing area of contact (cm^2), pressure time integral (PTI; Ns/cm^2), and peak pressure (N/cm^2). The pedobarographic analysis measured 100 feet, of which 37 were in Group 1 and 63 in Group 2. Six feet were excluded (3 patients: 2 from Group 1 and one who had an arthrodesis on one foot and a Clayton on the other) for technical problems (one patient) and an inability to walk properly across the force plate (2 patients). The overall pattern of pressure distribution was similar regardless of the procedure. The maximum contact area, maximum peak pressure, and maximum PTI were located under the 1st metatarsal, with a progressive decrease in values under the more lateral rays and lesser toes. The contact area, peak pressure, and PTI for the medial heel, lateral heel, and the midfoot regions were similar among the 5 subgroups (Figures 3, 4, 5). The forefoot contact areas for the 2 functional groups are depicted in Figure 3. Group 1 had significantly increased contact areas beneath the 1st toe and lateral toes ($p < 0.05$). The contact area beneath the 2nd toe was greater in Group 1, a difference that approached significance ($p = 0.072$). With regard to lesser toes, the primary difference was found to be that most of Group 1 had threaded K-wire stabilization for 5 weeks. Significant differences in the peak pressures and PTI beneath the MT heads were identified between the 2 groups (Figure 4). Group 1 had significantly lower peak pressures beneath the 1st to 3rd MT heads. PTI revealed significantly lower values beneath the 1st to 4th MT heads in Group 1 (Figure 5). Peak pressures were significantly greater beneath the 1st and 2nd toes in Group 1 (Figure 4); the same pattern was observed in the PTI, with no significant statistical differences (Figure 5).

Table 6. Radiology findings.

	HVAngle	Hallux Dorsiflexion Angle	IMTAngle
Group 1	25.6 ± 13.8	26.9 ± 16.6	10.6 ± 3.3
	p = 0.783	p = 0.316	p = 0.050
Group 2	26.4 ± 16.1	30.6 ± 19.5	12.2 ± 4.3

HV: hallux valgus angle on standing AP radiographs; IMT: 1st-2nd intermetatarsal angle.

DISCUSSION

It was apparent that the stable 1st ray group (Group 1) fared better in many categories than the major resection group. Two important distinctions must be made: (1) the duration of followup was significantly longer in Group 2; and (2) at the time of the clinical review, Group 2 was significantly older, and thereby had been affected by RA for a longer period, evidenced by a significantly higher disability score in Group 2 (2.4 vs 2.1). The following factors must be considered for comparability: (1) no significant differences were identified in the comorbidities and SF-36 and WOMAC scores, a reflection of the overall health of both groups; (2) only a small number of patients reported deterioration from the time of surgery; (3) significant differences were primarily related to foot function based on pedobarographic analysis, physical examination, and radiographic evaluation; and (4) patients with a successful arthrodesis were unlikely to experience a progression of deformity at the 1st ray[16,20-22,28].

Since Hoffman's original operation in 1912[11] numerous techniques in arthroplasty have been described. They vary from the type of incision and procedure on the 1st MTPjoint to the degree of resection of lesser rays and the methods of stabilization. The options for the 1st ray are MTP

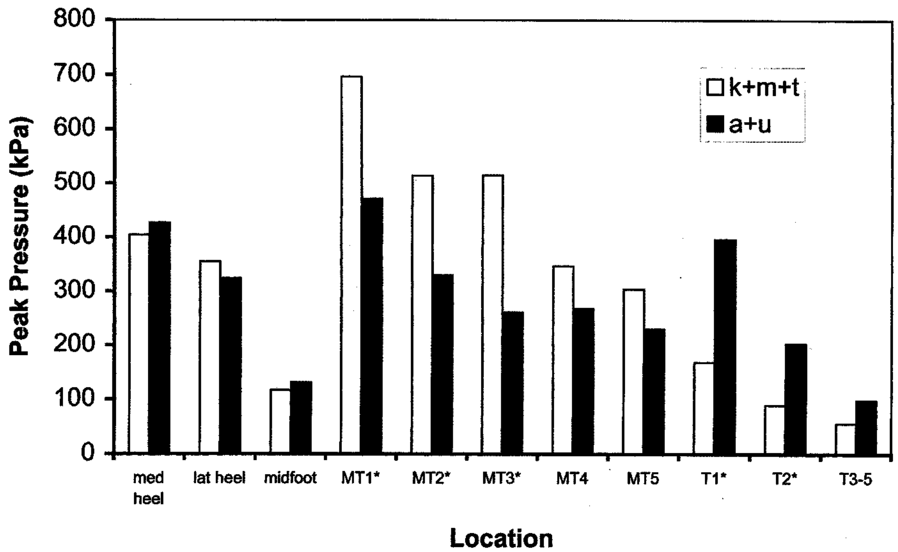

Figure 4. Peak pressures of the 11 masks of the foot. *Statistically significant difference. For definitions of groups see Figure 3 legend. In Group 1 (a + u), the peak pressures were decreased under all MTheads and increased under all the toes.

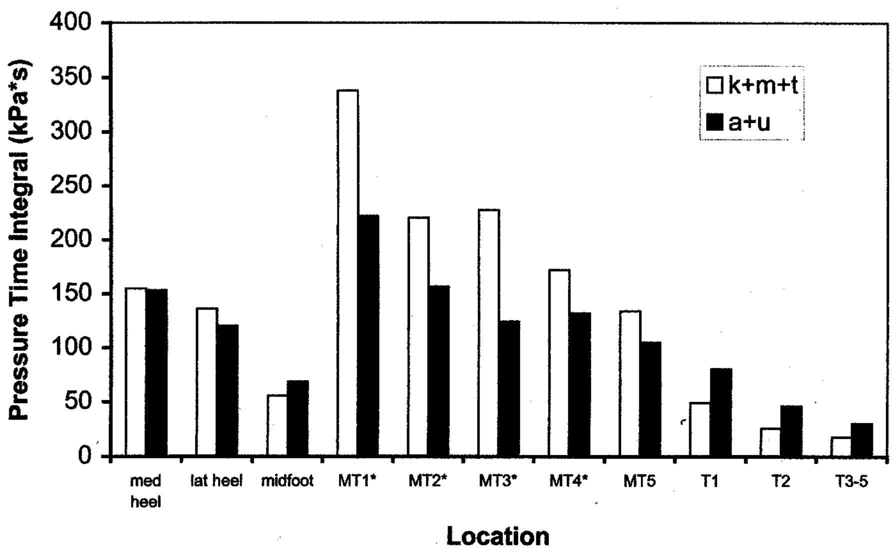

Figure 5. Pressure time integral (kPa*s; PTI) of the 11 masks of the foot. *Statistically significant difference. In Group 1 (a + u), the PTI was decreased under all the MTheads and increased under all the toes.

arthrodesis, resection, or arthroplasty. Reports indicate all have yielded good clinical outcomes[7,10,12,17,18,20,23,24,26,28,37-51] and only a few series compared the outcomes of various procedures[50,51]. Although it is retrospective, our report is the largest of comparison studies to date that assesses the surgical outcome of various reconstructions. It is one of the few to utilize validated outcome measurements and pedobarographic analyses. These factors strengthen any statistically significant observations made in the study.

Similarities. We found many similarities to other clinical reviews, as follows. (1) There was no clear advantage of dorsal longitudinal incisions over the plantar approach. (2) There was an increased incidence of postoperative infections with the dorsal approach (all resolved with a short course of antibiotics and local wound care). (3) There was a reoperation rate of 10.6%, the most common procedure being excision of a single plantar prominence, similar to other clinical series[9-12,20,26,28,38,47-49,52,53]. (4) Fewer patients in Group 1 required revision surgery (statistically nonsignificant). Most revisions in all 5 subgroups were done within 2–3 years of initial surgery. (5) The incidence of revision did not increase with longer followup. (6) The majority of patients reported no deterioration in clinical results since initial surgery. (7) All patients derived complete or partial relief of their forefoot pain and 93% were satisfied with the surgical outcome; this high satisfaction rate is similar to other noncomparative reviews[9-12,20,28,38,47,48,52,53]. (8) The patterns of plantar forefoot pressure on all patients were similar to those of other pedobarographic evaluations[14,21,35,54,55]. The maximum contact area, maximum peak pressure, and maximum PTI were located under the region of the 1st metatarsal, with a progressive decrease in values under the more lateral rays and lesser toes (Figures 3, 4, 5).

Satisfaction. Patient satisfaction was high regardless of the procedure type. However, significant differences were identified between 2 functional groups: Group 1 reported significantly higher satisfaction in terms of appearance, ease of shoe-fitting, surgical results, and fewer plantar callosities and less plantar pain. The HMIP and LMIP scores based on pain, activity levels, footwear, motion, calluses, stability, and alignment were significantly higher in Group 1. The physical outcome section of the WOMAC revealed a trend toward improved outcomes in Group 1. A greater number in Group 2 suffered a residual cocked-up 1st toe deformity and difficulties with footwear.

Pedobarographic analysis. Group 1 had more favorable outcomes: greater distribution of forces through the first and lesser toes, corresponding to an increased forefoot contact area (Figure 3); a stable 1st ray with well aligned lesser toes, allowing a more physiologic distribution of weight-bearing forces; and decreased peak pressures and PTI beneath the 1st through 3rd MT heads (Figures 4 and 5). The stabilizing effect of a functionally positioned 1st toe is confirmed on radiographs by a significantly decreased 1st and 2nd intermetatarsal angle; this measurement indicates a decreased width or splaying of the forefoot in Group 1 that would contribute to comfortable use of footwear, increased satisfaction with the appearance, and improved weight distribution through the medial 3 rays (Figures 4 and 5). The decreased forefoot contact area and increased peak pressures in Group 2 were likely caused by an excessive bone resection resulting in a dysfunctional position of the toes (cocked-up 1st toe deformity and clawing of lesser toes) and exposure of prominent diaphyseal MT stumps.

Non-union. In keeping with current techniques of joint arthrodesis[15,25], no non-union was reported. This finding supports the argument that a high non-union rate[41] is not a deterrent to performing arthrodesis in the RA population. Controversy does surround the issue of managing the 1st MTP joint when the disease process is isolated to the lesser rays; some suggest the joint be left alone[39,47], while others routinely excise the 1st MThead[6,10,11]. In this study, the revision rate for no initial disease/no surgery to the 1st MTP joint was 14%. This number not only supports the findings of previous studies[20,26,49,52,53], but also suggests it is reasonable not to operate on the 1st ray (patients need to be advised that further deformity may develop, necessitating surgery).

Type of incision. Some have advocated a plantar approach in surgery because it allows for relocation of the fat pad; however, it has been shown eventually to relocate after a forefoot reconstruction regardless of the incision[10,12,24]. More recently, relocation of the plantar plate beneath the MT shafts has been considered an important component of soft tissue rebalancing[56,57]. The plantar plate is a thick structure composed primarily of type 1 collagen that aids in the absorption of weight-bearing pressures beneath the MT heads. The plantar plates adhere strongly to the fat pad through soft tissue septa, and likely relocate with the fat pad. We found that the protective plantar soft tissue structures were relocated more reliably beneath the MT shafts when the deformities of all toes were adequately corrected — a common observation with resected lesser MT heads and threaded K-wire stabilization of the toes (Group 1/arthrodesis), or where the disease of the 1st ray was not significant enough to warrant surgery (Group 1).

Extent of resection at lesser MTP joints. This is controversial. In the past, major resections of MT heads and the base of proximal phalanges were recommended on the premise that the lesser toes had very little function after forefoot arthroplasty[9-11,39]. The degree of resection was not determined according to the severity of deformity. However, the current recommendation is to resect only the MT heads, but the optimal amount of bone remains debatable. The use of K-wires following resection has been reported to improve the cosmetic appearance, to simplify postoperative management, and to decrease recurrence of deformity[9,10,17,25]. In this study, conservative resection and threaded K-wires were associated with improved contact area, increased weight distribution through the lesser toes and improved LMIP scores. Note that conservative resection is defined as the minimal amount of bone resection needed to correct the deformity at the MTP joint.

Gait and pressure distribution. Gait patterns and the resultant forefoot pressures are not normal in the symptomatic RA population. Pressure studies in the non-operated foot have revealed a wide variance in dynamic pressure under the forefoot[54,55,58,59]. Soames, *et al*[60] showed that heel strike and toe-off are often reduced or absent, toes are dysfunctional, patients tend to walk with a shuffling gait, the foot serves more as a pedestal than a lever, and arthroplasty may not always result in a decreased forefoot pressure. Betts, *et al*[54] showed that 70% of patients had abnormal pressures under multiple sites after MT head resections, and 16 of 29 postoperative feet with abnormal pressures were asymptomatic. Phillipson, *et al*[36] showed an increase in pressure following surgery, postulating that success is not attributable to a decrease but rather to a transfer of pressure to areas better able to tolerate it. Most of these pedobarographic studies were performed following a major resection of lesser MTP joints. We found that the overall pattern of pressure distribution under the metatarsi is similar regardless of the procedure type. The highest pressures are observed under the 1st metatarsal and pressures decrease sequentially under the more lateral metatarsi (Figures 4 and 5). More favorable pressure distribution and clinical outcomes were found in patients who had a functional weight-bearing position of the first and lesser toes, namely, the arthrodesis and non-operated groups.

In summary, forefoot arthroplasty for symptomatic RAis believed to be the most satisfactory method of treatment[9,20,27]. Barton claimed that the precise method of arthroplasty did not affect the result[48], and most clinical series support this view by reporting good outcomes regardless of the procedure type[9-12,20,28,38,47,48,52,53]. This notion is valid insofar as pain relief is the primary goal of surgery and it was attained in most instances. We found no significant correlation between satisfaction with appearance and willingness to undergo surgery again. To patients, pain relief regardless of cosmesis was the primary indicator of a good outcome.

In contrast to previous belief, we found that various surgical methods do yield different results and different functional outcomes. There are significant advantages to preserving function of the 1st ray and lesser toes. We conclude an arthrodesed or unoperated 1st MTP joint combined with a sufficient MT head resection to correct the deformity and K-wire stabilization of the lesser toes yields the best results: a more cosmetically appealing forefoot, improved distribution of forefoot pressures, and an improved functional outcome.

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