Arthrodesis *versus* Mayo resection

THE MANAGEMENT OF THE FIRST METATARSOPHALANGEAL JOINT IN RECONSTRUCTION OF THE RHEUMATOID FOREFOOT

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In a prospective randomised study 31 patients were allocated to either arthrodesis or Mayo resection of the first metatarsophalangeal joint as part of a total reconstruction of the rheumatoid forefoot. Of these, 29 were re-examined after a mean of 72 months (57 to 80), the Foot Function Index was scored and any deformity measured. Load distribution was analysed using a Fscan mat in 14 cases, and time and distance were measured in 12 of these patients using a 3D Motion system. We found excellent patient satisfaction and a significant, lasting reduction of the Foot Function Index, with no statistically significant differences between the groups. There were no significant differences in recurrence of the deformity, the need for special shoes, gait velocity, step length, plantar moment, mean pressure or the position of the centre of force under the forefoot. The cadence was higher and the stance phase shorter in the fusion group.

These results suggest that a Mayo resection may be an equally good option for managing the first metatarsophalangeal joint in reconstruction of the rheumatoid forefoot.

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The painful, deformed rheumatoid forefoot may be treated with resection of the lesser metatarsal heads combined with either arthrodesis or resection of the first metatarsophalangeal (MTP) joint.¹ The latter may be of the Keller type,² with resection of the base of the first proximal phalanx, or the Mayo procedure,³ involving partial resection of the first metatarsal head. The distinction between these two types is not always clear, although forefoot arthroplasty with a Mayo resection has been well described by Kates, Kessel and Kay.⁴ The drawbacks of resection of the first MTP joint are said to be an increased risk of recurrent hallux valgus, metatarsalgia and callosities.⁵⁻⁷ These risks appear to be much higher after a Keller resection than after a Mayo excision.⁸ This may be due to differences in the biomechanical effects. A fusion of the first MTP joint may have the advantage of producing a stable load-bearing first ray with less risk of new callosities and of metatarsalgia under the resected central metatarsals.⁹⁻¹¹ However, an arthrodesis is more demanding and takes longer to perform.¹² Malposition, malunion or problems with the interphalangeal joint are possible long-term complications.^{7,13-15}

The load distribution under the forefoot after a Keller operation has been reported to show a reduction in weight-bearing under the great toe and a transfer of peak plantar pressure towards

the central metatarsals, producing a possible cause for metatarsalgia.^{8,16,17} Measurements after Mayo resection generally show increased loading underneath the first metatarsal,^{18,19} which is similar to the finding after a fusion.¹⁷ Some authors consider the duration of loading to be more important than the amplitude of the pressure in the development of pain and damage to structures in the rheumatoid forefoot.²⁰ This may be illustrated by a longer stance phase.²¹ Investigations with three-dimensional gait analysis on rheumatoid patients with symptomatic but unoperated forefeet have shown delayed and reduced forefoot loading, shorter stride length, a decreased moment of plantar flexion of the ankle and slower gait velocity compared with healthy controls.²² This system has also been used in gait analysis in children with arthritis²³ and in non-rheumatoid patients after arthrodesis for hallux rigidus.²⁴ Papers favouring fusion usually compare arthrodesis with the Keller type of resection.^{25,26} We chose to compare arthrodeses with Mayo resections in a prospective, randomised study and to investigate the results including a comparison of load distribution under the forefoot, and time and distance parameters.

Patients and Methods

Between April 1998 and June 1999, 31 patients (26 women and five men) with a mean age of

Fig. 1

Measurement of the position of the centre of force: distance from medial border/whole width of forefoot.

54 years (33 to 77) with severe painful deformity of the forefoot due to rheumatoid arthritis were included in our prospective, randomised study. They were allocated to undergo either a Mayo resection or an arthrodesis at the first MTP joint combined with resection of the second to fifth metatarsal heads. Randomisation was undertaken with a computerised system using the minimisation method, with stratification according to gender and age (over or under 45 years).²⁷ The study was approved by the regional Board of Ethics and informed consent was obtained. The inclusion criteria were rheumatoid arthritis, severe pain and deformity of the forefoot with subluxation or dislocation in two or more MTP joints, plantar callosities, bone destruction, a healthy interphalangeal joint in the hallux and no valgus deformity of the hindfoot.

Operative technique. The operations were performed under spinal anaesthesia, with the application of a tourniquet to ensure a bloodless field, using two dorsal longitudinal incisions for the resection of the second to the fifth metatarsal heads and extensor tenotomies. This dorsal release allowed a complete relocation of the lesser toes and the fat pad, making a plantar excision unnecessary. The redundant skin was left to reduce spontaneously over time. The resections were carefully performed with a small saw (Zimmer-Hall micro 100-sagittal saw; Conmed/Linvatec, Largo, Florida) with a 45° plantar angulation to produce a contoured surface for the weight-bearing area, without sharp edges and forming a smooth arch from the second to the fifth metatarsals. Through a straight medial incision at the first MTP joint, a Mayo resection or an arthrodesis was undertaken. The Coughlin first MTP joint reamer (Stryker Howmedica, Rutherford, New Jersey) was used to prepare the bone in the cases allocated to fusion.¹⁵ The joint was positioned

according to the Grondal-Stark guide-plate²⁸ and two cortical screws were used to obtain fixation without traversing the interphalangeal joint. This operative technique has been thoroughly described.²⁹ After partial resection of the first metatarsal head, which constitutes the Mayo resection, a 1.6 mm K-wire was inserted longitudinally transfixing the first MTP joint for three weeks. The lesser MTP joints were stabilised in the same way for the same period using 1.4 mm K-wires. Patients with a Mayo resection were protected in a soft dressing for six weeks. Those with a fusion had a small plaster cast along the medial side of the foot for the same period. Both groups were allowed weight-bearing, as tolerated, in a stiff-soled shoe.

The subjective pain and incapacity were investigated using the Foot Function Index,³⁰ a self-administered protocol with visual analogue scales (VAS) graded from 0 to 100, validated for rheumatoid arthritis.³¹ The score includes seven questions concerning pain, nine for handicap and five for general activity. The deformity of the foot was examined, by an independent observer not otherwise involved in the study, according to a specially-designed protocol where prominences, tenderness, subluxation or dislocation, involvement of the interphalangeal joint according to Fitzgerald³² and degree of valgus of the hallux were noted. In a simple test wearing shoes, the time to walk 20 m was measured with an ordinary stopwatch. Patients were examined pre-operatively, after six months and at three years.¹²

To investigate the long-term results, 29 of 31 patients were reviewed again after a mean of 72 months (57 to 80) using the same parameters. One man had died of unrelated causes and one woman was too ill to participate. In 14 cases (seven in each group) an additional investigation concerning the load distribution under the forefoot was performed on a Fscan mat (46 x 31 cm, type 3100, Tecscan, Boston, Massachusetts), a validated pressure-sensitive transducer system.³³ The pressure was measured in mean g/cm²/min during standing after calibration with the patient's weight. The forefoot area was defined as the distal third of the total foot length. The distance from the medial border of the foot to the centre of force under the forefoot was measured, related to the full width of the forefoot and presented as a percentage (Fig. 1). The higher the percentage, the more lateral the position of the centre of force. We measured seven healthy controls with a mean age of 36 years (21 to 56) (six women, one man) for comparison using the same procedure.

In 12 of 14 cases the time and distance of the gait were also measured with a six-camera 3D motion analysis system (Vicon Motion System, Oxford, England). Walking speed (m/s), stride length (m), cadence (steps/min), stance phase (s) and the moment of plantar flexion of the ankle (Nm) were recorded with this camera system, monitoring the patient when walking barefoot on a walkway 7.5 m long, at a self-chosen velocity with reflective markers (25 mm diameter) placed on the subject's skin to imply the position of the body segments. The 3D motion system is documented and validated.^{34,35}

Table I. The mean visual analogue scale (VAS) measurements in foot function index

	Number of patients		VAS pain		VAS handicap		VAS activity	
	Pre-operative	72 months	Pre-operative	72 months	Pre-operative	72 months	Pre-operative	72 months
Resection	16	14	48	9	56	19	16	5
Fusion	15	15	58	6	48	17	13	6

Table II. Frequency of callosities and use of insoles and adjusted shoes

	Callosities, mean		Number of patients who use insoles		Number of patients who need adjusted shoes	
	Pre-operative (n = 16)	72 months (n = 14)	Pre-operative (n = 16)	72 months (n = 15)	Pre-operative (n = 15)	72 months (n = 15)
Resection	3.9	0.9	8	8	11	6
Fusion	3.5	0.5	10	8	7	3

Owing to the location of the patient's homes it was not possible to examine all patients with both of these pieces of equipment.

Statistical analysis. The chi-squared test and Fisher's exact test were used to analyse variables, measured on a nominal scale. The Mann-Whitney U test was used to analyse the VAS measurements for time and distance and the pressure areas. The Spearman-rank-correlation coefficient was used to measure the association between variables. For comparisons over time, Friedman's ANOVA,³⁶ followed by multiple comparisons between visits based on ranks, was performed for ordered categorical data, and for nominal data McNemar's test was used.

For the variable walking time, a two-way analysis of variance (ANOVA) using the within factor time (0, 36 and 72 months) and the between factor method of operation (resection and arthrodesis) was performed.

All statistical analysis was performed using the Statistica software package (StatSoft Inc., Tulsa, Oklahoma). A value of $p < 0.05$ was considered to be statistically significant.

Results

Before operation there were no differences between the groups in mean Foot Function Index scores for pain, handicap and activity. Post-operatively, in the Mayo resection group the median VAS for pain decreased from 48 (13 to 74) to four (0 to 79) points after 36 months, and was nine (0 to 44) after 72 months ($p < 0.001$). The median handicap score decreased from 56 (14 to 81) to 27 (0 to 79) points after 36 months, and to 19 (0 to 63) after 72 months ($p = 0.013$). The median activity score decreased from 16 (3 to 38) to four (0 to 26) points after 36 months, and was five (0 to 27) after 72 months ($p < 0.003$). The reduction in all three parameters was significant compared to the scores before operation and the improvement was maintained between three and six years (Table I).

In the arthrodesis group, the median VAS for pain decreased from 58 (20 to 78) to 11 (0 to 59) points after 36 months and to six (0 to 77) after 72 months ($p < 0.001$). The median handicap score decreased from 48 (13 to 81) to 24

(0 to 67) points after 36 months and to 17 (5 to 73) after 72 months ($p = 0.003$). The median activity score decreased from 13 (0 to 53) to four (0 to 39) points after 36 months and was six (0 to 23) after 72 months. This was not a significant reduction ($p = 0.09$). In this group the reduction in pain and handicap was significant compared to before operation and was maintained for between three and six years (Table I).

Comparison between the two groups did not reveal any statistically significant differences in the Foot Function Index scores for pain ($p = 0.8$), handicap ($p = 1.0$) or activity ($p = 1.0$) after a mean of 72 months (57 to 80).

Patient satisfaction with the outcome after 72 months as measured on a VAS scale out of 100, was a median of 95 (25 to 100) in the resection group and 96 (2 to 100) in the fusion group. This difference was not significant ($p = 0.6$). Satisfaction concerning the hallux especially was a median of 90 (50 to 100) points in the resection group and 89 (2 to 100) in the fusion group. This was also not significant ($p = 0.9$). There was no significant difference between the groups in willingness to have the operation again.

Pre-operatively there was no difference in involvement of the interphalangeal joint between the groups. After six years, five patients in the fusion group and two in the resection group had a valgus deformity at the interphalangeal joint. However, this difference was not statistically significant for the two operative methods ($p = 0.38$). Only one patient in each group had painful movement in this joint, the same result was found after three years.

Concerning callosities, at three years both groups had a significant reduction from the pre-operative incidence ($p < 0.001$) and also at six years ($p = 0.003$ for resection, $p < 0.001$ for fusion), with no significant change from three to six years and no significant difference between the methods after six years ($p = 0.58$) (Table II). There was also no significant difference in the incidence of metatarsalgia ($p = 0.13$).

Lateral deviation of the lesser toes was found in six of 14 cases in the resection group and in ten of 15 in the fusion group, but this was not statistically significant ($p = 0.19$).

The patients were subgrouped according to their hallux valgus angle, as follows: $< 20^\circ$, 20° to 40° , $> 40^\circ$. Pre-oper-

Fig. 2

Mean (SD) time to walk 20 m with shoes (in seconds).

atively there was no significant difference between the two groups in the severity of the hallux valgus deformity. In the resection group, there was a significant reduction in the hallux valgus deformity from before operation to 36 months after, which remained unchanged at six years ($p = 0.02$). Here, eight patients belonged to the most severe subgroup before operation, but only one patient was still in this subgroup after both three and six years.

Of 15 fusions, 14 healed with a mean hallux valgus angle of 16° (2° to 29°) and an angle of inclination, the angle between the floor and the long axis of the first digit, of a

mean of 13° (0° to 31°). Before operation there were no differences between the groups concerning the use of insoles or adjusted shoes, and there were none after six years (Table II).

For the timed 20 m walk in the resection group there was a reduction from a mean of 20 s (15 to 32) pre-operatively to 16 s (15 to 32) at the last follow-up compared with a reduction from 19 s (15 to 26) to 15 s (10 to 29) in the fusion group, a significant reduction in both cases ($p < 0.001$) but with no difference between the groups after a mean of 72 months (57 to 80) ($p = 0.53$) (Fig. 2).

Concerning the load-bearing under the forefoot and the gait analysis, we found a mean pressure over one minute of 372 g/cm^2 (286 to 451) in the resection group, 341 g/cm^2 (148 to 489) in the fusion group and 365 g/cm^2 (309 to 419) in the control group. The differences were not statistically significant between the groups ($p = 0.65$) or between each group and the controls (resection $p = 0.85$, fusion $p = 0.61$). The centre of force was placed at a mean of 47% lateral relative to the whole forefoot width in the resection group, 51% in the fusion group and 54% in the control group. These differences were not statistically significant between the operated groups ($p = 0.41$), but were significant between the resection group and the controls ($p = 0.04$). None of the operated patients made a footprint of their big toe during standing, whereas all of the controls did so (Table III).

The data for walking speed, step length, moment of plantar flexion, cadence and stance phase are shown in Table IV. There were no statistically significant differences in velocity ($p = 0.42$), step length ($p = 0.63$) or moment of plantar flexion ($p = 0.26$). Cadence (steps/min) was a mean of 114 (110 to 117) in the resection group and 123 (112 to 129) in the fusion group. The stance phase was a mean of 0.90 s (0.82 to 1.05) in the resection group compared to 0.81 (0.76 to

Table III. Load distribution data measured with Fscan mat

	Resection group	Fusion group	Control group
	Operated foot (mean) n = 7	Operated foot (mean) n = 7	(mean) n = 7
Pressure under forefoot standing ($\text{g/cm}^2/\text{min}$)	372	341	365
Position of centre of foot % of width of forefoot 0% = medial border of foot 100% = lateral border of foot	47	51	54
Footprint of digit 1 on Fscan mat	0	0	7

Table IV. Gait analysis data measured with 3D motion Vicon system

	Resection group	Fusion group
	Operated foot (mean) n = 6	Operated foot (mean) n = 6
Walking speed, barefoot (m/s)	1.0	1.1
Step length (m)	0.53	0.56
Plantar moment (Nm/kg)	1.1	1.0
Cadence (steps/min)	114	123
Stance phase (s)	0.90	0.81

0.89) in the fusion group. There was a statistically significant difference between the groups in both parameters ($p = 0.04$ both) (Table IV).

Discussion

Arthrodesis and resection are the two major surgical options for the first MTP joint in reconstruction of the rheumatoid forefoot.¹ In the literature the good to excellent success rates for resection vary from 51% to 93%.^{5,6,37,38} The major complaints have been the high recurrence of hallux valgus, metatarsalgia and plantar callosities, up to 53%, 36% and 61%, respectively.⁵⁻⁷ In these studies the Keller rather than the Mayo type of resection was used.

In the 1970s it was noted that a stiff first MTP joint seemed to produce a better outcome,^{39,40} and fusion grew in popularity with high degrees of patient satisfaction.⁹⁻¹¹ The cosmetic appearance was improved.²⁶ The hallux was shown with the Harris foot mat to bear weight in 50% more cases after fusion than after a Keller resection.¹⁶ However, the operative technique is more demanding. The alignment of the hallux is important but can be difficult to achieve.^{7,14,15} The rate of pseudarthrosis varies from 0% to 26% to 44%^{11,38,41} and may require re-operation.¹³ Interphalangeal joint degeneration can develop.^{5,15,26} The mean operating time has been shown to be longer for a fusion than for a Mayo procedure, 106 compared with 90 minutes.¹² Some retrospective studies comparing resection, mostly of the Keller type, to fusion have indicated better results after fusion, with resection having a higher degree of recurrent hallux valgus, higher pressure under the second and third metatarsal heads and more callosities under the forefoot.^{5,25} Other reports have contradicted these findings.^{7,13,38} It is possible that a stiff first MTP joint, even though cosmetically pleasing, may impede gait. Sagittal plane blockade of the first MTP joint is known to reduce efficient advancement of the centre of mass of the body.⁴² A reduction in ankle power, shown after arthrodesis of the first MTP joint for hallux rigidus, supports this view.²⁴

The higher cadence we found in our fusion group may also be a consequence of the loss of movement at the first MTP joint.

Our randomised study has demonstrated no significant differences in outcome and patient satisfaction between the two treatments. A previous systematic review from 2005 did not find any other prospective randomised material in this field.⁴³

Many of the disadvantages reported after resection may be a consequence of the defunctioning of the hallux produced by a Keller excision arthroplasty. The proximal migration of the sesamoids and the absence of active flexion in 68% after a Keller procedure, compared to 21% after a Mayo operation, supports this.⁸ Several studies have shown that the transfer of weight-bearing from the hallux to the central metatarsal heads and subsequent metatarsalgia is likely after a Keller resection.^{8,16,17} Thomas, Kinninmonth and Kumar⁴⁴ have recently shown high patient satisfaction

after forefoot arthroplasty with the Mayo resection at the first MTP joint with recurrent plantar callosities in only two of 37 feet. These reports highlight a marked difference in the outcome between the Keller and Mayo procedures, thereby supporting our choice of the Mayo excision.

In untreated rheumatoid arthritic feet studies an absence of the normal rolling action has been shown,^{34,45} delayed and reduced forefoot loading,²² and varying degrees of lateralisation of the loading.^{37,46,47}

Numerous methods have been used to measure loading of the foot.^{8,16-20,24,33,37,42} To minimise errors in measurement, we preferred not to divide the footprint into small areas. As none of our patients made footprints with their toes, the distal third of the foot was easy to distinguish as the 'forefoot' where the mean pressure could be measured. The width of this area was measured and defined as 100%, to which the position of the centre of force was related. Neither in mean pressure per minute nor in position of the centre of force did we find any statistically significant differences between the two groups. This may account for the lack of difference in recurrent callosities or metatarsalgia between the two groups.

In our gait analysis measurements of time and distance parameters, there were no statistically significant differences between the groups in either velocity or step length. A higher cadence in the fusion group was found and is discussed above. The stance phase differed and was shorter in the fusion group. Theoretically, a fusion should provide the foot with a more stable first ray and hence a stronger push-off. An insufficient push-off causes the foot to leave the ground prematurely, which might be recorded as a reduced stance phase.²¹ In our study we did not find a shorter stance phase in the resection group, that would indicate an impaired (or less effective) push-off in this group.

Figure 2 shows the reduction in time measured for walking 20 m before operation and at follow-up. In spite of having a chronic, progressive joint disease and being several years older, the patients walked significantly faster six years after surgery than before.

In a prospective randomised study comparing Mayo resection with fusion of the first MTP joint as part of a total reconstruction of the rheumatoid forefoot, after a mean of six years, we found continued patient satisfaction and a lasting reduction of the Foot Function Index, with no statistically significant differences between the groups. Our results indicate that the simpler Mayo resection is a satisfactory method to manage the first MTP joint in total rheumatoid forefoot reconstruction.

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