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Original Research

Radiographic and Clinical Comparison of Proximal Interphalangeal Joint Arthrodesis Between a Static and Dynamic Implant

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ABSTRACT

Hammertoe deformation is a frequent motive for consultation in forefoot surgery, and proximal interphalangeal joint arthrodesis is a classic treatment for fixed deformation, which tends to be achieved more and more thanks to specific implants. This work evaluated and compared clinical improvement, radiologic fusion, and complication rates between dynamic (Difuse®) and static (TinyFix®) implants from Biotech Ortho. A total of 95 patients (110 feet and 166 toes; 97 static and 69 dynamic implants) were included. Mean age was 63.6 (±12.6) years in the dynamic group and 62.3 (±14.01) years in the static group. Epidemiologic and intraoperative radiologic data were collected. Pain, toes deformity, complications, and radiologic findings (bone fusion and osteolysis) were recorded at 4 months postoperatively and at the last follow-up. Mean follow-up was 11.5 (range 4 to 28) months, and the position of the implants was more often satisfying in the dynamic group ($p = .01$). Fusion rates at 4 months were 67% and 80% in the dynamic and static groups, respectively ($p = .05$). Radiologic osteolysis occurred more frequently in the dynamic group ($p = .05$ at 4 months), and pain was still present in 3% in the dynamic group at the last follow-up compared with 7% in the static group. Complication rate was 7% in the dynamic group (implant fractures) and 4% in the static group. Revision was considered more often in the dynamic group ($p = .01$). The static titanium implant seems superior to the dynamic memory shape implant in Nitinol alloy with regard to fusion ($p = .04$), complications ($p = .03$), and revision rates ($p = .01$). The literature review seems to support the good results of static implants compared with the rest of the available arthrodesis implant solutions.

Hammertoe and claw toe deformations of the lateral toes are frequent reasons for consultation in forefoot surgery. However, the claw position is physiologic during walking (anterior gait) (1) when this deformation becomes permanent dorsal or plantar calluses may appear (2).

The genesis of such deformation implies metatarsophalangeal complex malfunction worsened by dorsal friction with the shoe (3). When the deformation is reducible, its initial treatment is conservative and may need shoe modification, callus paring, and use of plantar orthosis. In case of fixed deformation, functional treatment is most often inefficient and surgery becomes a necessity. Interphalangeal joint arthrodesis is the main solution and needs bony contact between phalanges with a physiologic plantar flexion angle to allow gait contact (4). It had been maintained for a long time with pins; however, surgeons seem to use interphalangeal devices more often because Kirschner wires need removal, are harder to accept by patients, and are thought to have higher complication (around 10%) (5,10,15) and postoperative symptoms persistence (27%) (15) rates.

The goal of this retrospective work was to assess and compare clinical improvement, radiologic fusion, and complication rates after proximal interphalangeal joint (PIPJ) arthrodesis between 2 implants: dynamic and static.

Patients and Methods

Inclusion Criteria

This was a continuous retrospective series and included all patients operated between February 2011 and November 2013 for toe deformation by 2 orthopedic unit operators (J.L.B. and R.D.) who were specialized seniors in foot surgery. During this

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period, every arthrodesis was performed using 2 kinds of implants (TinyFix® and Difuse®) from Biotech Ortho (Salon de Provence, France). The decision on implant type was based on ancillary availability. TinyFix® was a static pure-titanium implant (Fig. 1), and Difuse® was a dynamic shape memory Nitinol TiN alloy implant.

Series

During the 23 consecutives inclusion months, 95 patients had a claw or hammertoe (s) corrective surgery with a PIPJ arthrodesis implant after consultation for forefoot disorder in a foot specialized orthopedic unit at a university hospital. In total, 110 feet (166 toes) were operated. Mean age was of 62.8 ± 13.5 (range 21 to 86) years. Eleven (12%) patients were male, and 84 (88%) were female. Etiologies and surgical technique used in the first and lateral rays are presented in Tables 1 and 2. Fifteen patients had a bilateral surgery, and each patient received the same implant type. Patient with local foot infection were excluded, and no internal implant was used in such cases.

Sixty-nine (42%) dynamic and 97 (58%) static implants were inserted. The second toe was corrected in 99 (61%) cases, the third in 29 (17%) cases, the fourth in 19 (11%) cases, and the fifth in 19 (11%) cases.

Concomitant flexor tenotomy was performed in 25 (22%) cases, extensors in 11 (10%) cases, both in 4 (4%) cases, and no additional procedure in 70 (64%) cases. Flexor tenotomy was used in case of severe deformity and extensor tenotomy if the metatarsophalangeal joint remained in hyperextension after PIPJ arthrodesis.

Both groups were statistically comparable regarding sample size, age ($p = .61$), sex ($p = .37$), and etiology ($p = .21$).

Surgical Technique

The surgical technique was similar in both cases and analogous to classically described techniques (1). A dorsal and transversal approach centered on the proximal interphalangeal space was performed. Extensor apparatus was transversally cut, and arthrolysis with collateral ligaments was done at the same time to expose the head of the proximal phalanx and the base of the middle phalanx. Articular surfaces preparation was achieved with an oscillating saw to resect the head of the proximal phalanx and abrade the middle phalanx base. Proximal and distal medullar canals were prepared with a dedicated ancillary (3 different lengths). The implant was first inserted in the proximal phalange and then in the distal one. Intraoperative radiographic control confirmed contact between arthrodesis surfaces (coaptation), implant positioning, and the absence of complication (Figs. 2 and 3). The extensor tendon was carefully stitched to ensure implant coaptation. Further surgical procedures on the tendon, lateral metatarsal, or first ray were performed at the same time. Weightbearing was entitled straightaway with a postoperative shoe (Sober type) for a month.

Assessment Method

All patients had a physical examination and a forefoot plain X-Ray (front, side, and three-fourth views) at 4 months and at the latest follow-up. For each operated toe, pain, toe position, arthrodesis fusion, and eventual complication (implant fracture, bone cortex breakage, and implant migration) were recorded. Pain was assessed by asking the patient a simple binary question (did he or she feel pain or not), and fusion was achieved if 2 corticals merged on the anteroposterior x-rays. Clinical evaluation was performed by the 2 senior surgeons mentioned previously (J.L.B. and R.D.). Radiologic assessment was entrusted to another independent surgeon (M.F.). X-Rays were performed before surgery; intraoperatively; and at 21 days, 4 months, and 1 year postoperatively.

The primary aim of the investigation was to evaluate fusion rates, and the secondary aim was to evaluate complication rates.

Statistical analyses were conducted with BioStat TGV® (Institut Pierre Louis UMR S 1136 INSERM, Paris, France) software. Student's *t* test was used to compare quantitative variables, and a chi-square or Fisher's test was used for qualitative analysis. The significance threshold was set at .05. Patients signed a consent form to participate in the study, and the protocol followed Helsinki ethical criteria.

Results

The mean follow-up was 11.5 (range 4 to 28) months. In total, 108 (98%) of the 110 operated feet were reviewed on the fourth month and 20 (19%) were lost to the latest follow-up. No patient was secondarily excluded.

Perioperative X-Rays

Radiographic analysis found 107 (65%) well-centered implants. Fifty-five implants (33%) were too proximal, whereas 4 (2%) implants were too distal, with a good coaptation of arthrodesis surfaces in 108 (65%) cases and intraoperative complications in 12 (7%) cases: 7 proximal fractures of the first phalange and 5 distal fractures in the second phalange (Table 3).

A statistically significative difference was found in the distally or centrally positioned implants for both groups. The static implant seemed to be harder to insert in phalanges, with a higher rate of proximal insertion difficulties. However, no difference in coaptation or perioperative complication was found.

Complication and Revisions

No statistical difference was found in the complication rates between both groups ($p = .3$); however, 3 implant fractures were noticed in 3 dynamic implants (4%).

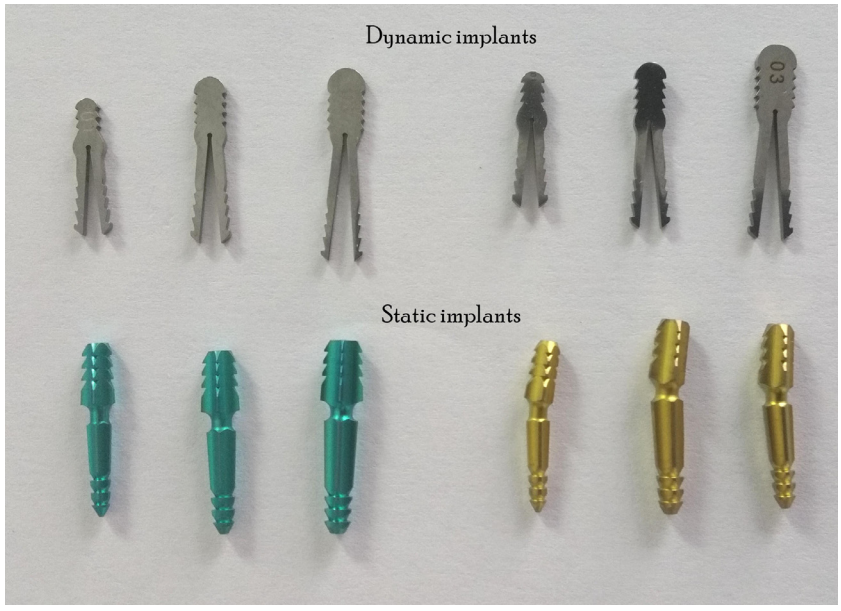

Fig. 1. Static and dynamic implants with different lengths and angulations.

Table 1
Etiologies and treatments

	Series	Dynamic Implant	Static Implant	*p*	Static TinyFix Implant
Feet	110	42	68		68
Age (y)	62.78 ± 13.45 (range 21 to 86)	63.62 ± 12.6 (range 22 to 82)	62.26 ± 14.01 (range 25 to 88)	.611	62.26
Etiologies, % (n)	Hallux valgus 72% (80) Hallux rigidus 7% (8) Hammertoes only 12% (13) Rheumatoid arthritis 3% (3) Neurologic 3% (3) Other 3% (3)	Hallux valgus 67% (28) Hallux rigidus 12% (5) Hammertoes only 14% (6) Rheumatoid arthritis 0% (0) Neurologic 2% (1) Other 5% (2)	Hallux valgus 77% (52) Hallux rigidus Hammertoes only 10% (7) Rheumatoid arthritis 4.5% (3) Neurologic 3% (2) Other 1.5% (1)	.21	Hallux valgus 77% (52) Hallux rigidus 4.5% (3) Hammertoes only 10% (7) Rheumatoid arthritis 4.5% (3) Neurologic 3% (2) Other 1.5% (1)

Table 2
Lateral metatarsal surgery types

Lateral Metatarsal Surgery	Patients
None	42 (38)
Weil M2	20 (18)
Weil M2-M3	38 (35)
Weil M2-M3-M4	1 (1)
Weil M4	1 (1)
DMMO 2-3-4	1 (1)
DMMO 2-3-4-5	1 (1)
Resection-arthroplasty	3 (3)
Other	2 (2)

Abbreviation: DMMO, distal metatarsal mini-invasive osteotomy.
Data presented as n (%).

Fig. 2. Perioperative control after static implant positioning.

Revision surgery was more frequent ($p = .01$) in the dynamic group: 5 further surgeries were needed, essentially for claw deformity recurrence. Implant fractures needed revision in only 1 case because of arthrodesis nonunion (Fig. 4). These results were evaluated at the last follow-up.

Fig. 3. Perioperative control after dynamic implant positioning.

Clinical and Radiographic Results

Pain in toes decreased by 8% between radioclinical analysis at 4 months and at the latest follow-up. Bone union increased by 24%. The osteolysis rate remained stable, and toes were well aligned, whereas claw deformity increased by 3% (no statistical significance; Tables 4 and 5).

There was a significant difference in osseous healing when using static implants compared with delayed healing in the dynamic group at 4 months ($p < .001$) and at the latest follow-up ($p = .04$; Tables 4 and 5, Fig. 5). A statistical link was found in osteolysis risk at 4 months, with a lower rate in the static implant group ($p = .05$).

Discussion

The static implant gives significantly better results than the dynamic implant (bone fusion and complication rates). These findings were not predictable because insertion of the static implant was harder to perform, with lower rates of good radiologic positioning. The arthrodesis

Table 3
Perioperative results

Implants	Dynamic Implant (N = 69)	Static Implant (N = 97)	*p*
Centered	52 (75)	55 (57)	.01
Proximal	15 (22)	40 (41)	.01
Distal	2 (3)	2 (2)	NS
Coaptation	46 (67)	62 (64)	NS
Complication	5 (7)	7 (7)	NS

Abbreviation: NS, not significant.
Data presented as n (%).

Table 5
Last follow-up results in both dynamic and static implant groups

Implants	Dynamic Implant (N =69)	Static Implant (N = 97)	*p*
Pain	2 (3)	7 (7)	.31
Fusion	46 (67)	78 (80)	.04
Osteolysis	8 (12)	4 (4)	.08
Toe aligned	67 (97)	94 (97)	1
Valgus deformation	0 (0)	0 (0)	1
Varus deformation	2 (3)	3 (3)	1
Residual claw toe	4 (6)	4 (4)	.72

Data presented as n (%).

Fig. 4. Nonunion caused by implant fracture.

Fig. 5. Fusion after 1 year (static implant).

Table 4
Four-month results in both dynamic and static implant groups

Implants	Dynamic Implant (N =69)	Static Implant (N = 97)	*p*
Pain	9 (13)	13 (13)	NS
Fusion	23 (33)	61 (63)	.0003
Osteolysis	8 (12)	3 (3)	.05
Well aligned	67 (97)	93 (96)	NS
Valgus deformation	(0) 0	(0) 0	NS
Varus deformation	2 (3)	(4) 4	NS
Residual claw toe	(0) 0	3 (4)	NS

Abbreviation: NS, not significant.
Data presented as n (%).

fusion was quicker and more often obtained with the static implant, and osteolysis at 4 months was more frequent with the dynamic implant and was always associated with nonunion of the arthrodesis. Postoperative complications were comparable between both groups, but the recurrence rate of claw deformity was higher in the dynamic group. The principal senior operator (J.L.B.) abandoned the dynamic implant and thus only used the static implant.

The high number of toes in both samples in this continuous series, the homogeneity of both groups, and the presence of 2 foot-specialized senior operators can be considered as strong points of this work; however, its retrospective aspect is a limitation. We made the choice not to use any functional score, because the claw treatment was most often associated with the correction of other deformities (first ray lateral metatarsal surgeries: in about half of the cases, first ray pathology is associated with another toe deformity or metatarsalgia [16,17]).

The dynamic characteristics of the implant might lead to higher rates of osteolysis and nonunions in this group, which could be explained by the Nitinol TiN shape memory alloy leading to poorer bone integration (i.e., nonunion and implant fracture risk factors) than static pure-titanium implants. Three cases of dynamic implant fractures were associated with nonunion, necessitating 1 revision.

Recent literature comparing the clinical and radiologic outcomes of toe interphalangeal arthrodesis implants is scarce. Most studies are comparable with ours regarding the sample sizes, follow-up, and data collection (Table 6). Smart Toe® (Stryker, Mahwah, NJ) is one of the most frequently reported implants in the literature (4 recent studies between 2013 and 2015). Clinical and radiologic outcomes seem to be

Table 6
Series comparison

Series	Treatment	No. of Patients (Toes)	Mean Follow-Up, Months	Mean Age, Years	Painful Patients, n (%)	Fusion, n (%)	Complication, n (%)	Revision, n (%)
Lehman and Smith (11) 1995	Peg	76 (137)	36	60	5 (7)	130 (95)	10 (13)	5 (7)
Coughlin (10) 2000	K-wire	63 (118)	61	57	5 (8)	95 (81)	6 (10)	–*
Caterini and Farsetti (12) 2004	Screw	24 (51)	31.2	48	7 (14)	48 (94)	7 (14)	7 (14)
Ellington et al (8) 2010	Implant StayFuse	27 (38)	31	62	–	23 (60.5)	6 (16)	3 (8)
Fazal et al (9) 2013	Implant StayFuse	140 (150)	18	69.5	7 (4.7)	110 (73)	8 (5.3)	4 (3.3)
Sandhu et al (13) 2013	Implant Smart Toe	35 (65)	27	62.2	–	61 (93.8)	4 (6.1)	0 (0)
Scholl et al (5) 2013	Implant Smart Toe	– (58)	8 to 94	61.47	–	40 (68.9)	12 fractures (20.7)	5 (8.6)
Scholl et al (5) 2013	K-wire	– (28)	8 to 94	61.47	–	23 (82.1)	2 fractures (7.1)	3 (10.7)
Coillard et al (4) 2014	Implant Ipp-On	117 (156)	12	65.8	6 (4.7)	124 (83.8)	5 (3.2)	1 (0.9)
Khan et al (6) 2015	Implant Smart Toe	82 (82)	6	56.5	7 (8.5)	79 (96.3)	2 (2.4) 1 fracture (1.2)	–
Catena et al (7) 2014	Implant Smart Toe	24 (42)	12	63	5 (12)	34 (81)	11 (26) 2 fractures (5)	–
Kramer et al (14) 2015	K wire	876 (2698)	20.8	57.5	–	–	121 (4.5)	104 (3.9)
Richman et al (15) 2017	CannuLink	39 (54)	12.9	61.4	3 (7.7)	12 (22.2)	2 (5.6)	0 (0)
Richman et al (15) 2017	K wire	60 (95)	12.9	61.7	3 (3)	–	12 (12.5)	5 (5.3)
Our study: Dynamic group	Implant Di-Fuse	42 (69)	12.3	63.6	2 (3)	46 (67)	5 (7)	5 (7)
Our study: Static group	Implant TinyFix	53 (97)	11	62.3	7 (7)	78 (80)	4 (4)	0 (0)

* Data not available in the publication.

comparable with ours, in which radiologic fusion rates vary from 68.9% (Scholl et al [5]) to 96.3% (Khan et al [6]) versus 67% and 80% for dynamic and static implants, respectively, in our series. The review article of Guelfi et al (18) describes a 60.5% to 100% fusion rate. The literature review found higher pain rates at the latest follow-up in the series of Catena et al (7) (19%) compared with 3% and 7% with dynamic and static implants, respectively, in our series. Nitinol alloy seems to be linked to a higher implant fracture rate: 1.2% in the series of Khan et al (6) and 20.7% in the series of Scholl et al (5), versus 4% and 0% for dynamic and static implants, respectively, in our work.

In some studies, overall complication rates may be high when using the Smart Toe® implant, as shown in the study of Catena et al (7) (22% complication rate: infection [5%], wound necrosis [5%], broken implant [5%], migration of implant [5%], and cortical disruption [2%]). The StayFuse® implant (Tornier, Montbonnot-Saint-Martin, France) is linked with lower fusion rates: from 60.5% in the study of Ellington et al (8) to 73% in the study of Fazal et al (9). Integra's Ipp-On® implant (Integra, Milton, Australia) seems to offer equivalent radioclinical results to ours: 83.8% fused on x-ray, 4.7% of patients had pain after 1 year, a 3.2% complication rate, and 0.9% of revision surgeries in the work of Coillard et al (4) (117 patients, 156 toes, 12-month follow-up). The CannuLink® implant (Middlesex, UK) results described in the study of Richman et al (15) are also consistent with literature outcomes, with 7.7% of patients not completely satisfied by their results (pain) and no revision.

Kirschner wires allow a good arthrodesis fusion rate (81% in Coughlin [10] and 82.1% in Scholl et al [5]) compared with implants and complication rates described previously (rates of fracture of the wire, infection, and vascular impairment and recurrent deformity) of 7.1%, 10%, and 19% in the studies of Scholl et al (5), Coughlin (10), and Richman et al (15), respectively. The work of Guelfi et al (18) found 3 studies with revision rates ranging from 0% to 10.7%. Richman et al (15) mentioned 27% remaining symptomatic and 5% requiring a revision surgery, probably because of healing delay or local infection (3%). Larger studies should be performed to assess the interest of an interphalangeous fusion implant versus Kirschner wires, especially focusing on cost effectiveness and patient satisfaction (19,20).

In conclusion, the static implant offers a higher fusion rate and fewer complications than the dynamic Nitinol memory shape implant. The literature review seems to support the good results of static implants compared with the remaining available arthrodesis implant solutions. Further studies are needed to evaluate and compare these different kinds of implants.

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