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Realignment Surgery as Alternative Treatment of Varus and Valgus Ankle Osteoarthritis

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In patients with asymmetric (varus or valgus) ankle osteoarthritis, realignment surgery is an alternative treatment to fusion or total ankle replacement in selected cases. To determine whether realignment surgery in asymmetric ankle osteoarthritis relieved pain and improved function, we clinically and radiographically followed 35 consecutive patients with posttraumatic ankle osteoarthritis treated with lower leg and hindfoot realignment surgery. We further questioned if outcome correlated with achieved alignment. The average patient age was 43 years (range, 26–68 years). We used a standardized clinical and radiographic protocol. Besides distal tibial osteotomies, additional bony and soft tissue procedures were performed in 32 patients (91%). At mean followup of 5 years (range, 3–10.5 years), pain decreased by an average of 4 points on a visual analog scale; range of ankle motion increased by an average of 5°. Walking ability and the functional parts of the American Foot and Ankle Society score increased by an average of 10 and 21 points, respectively, and correlated with achieved reversal of tibiotalar tilt and the score of Takakura et al. Revision surgery was performed in 10 ankles (29%), of which three ankles (9%) were converted to total ankle replacement. We believe the data support realignment surgery for patients with asymmetric ankle osteoarthritis.

Level of Evidence: Level IV, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
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Surgical treatment for patients with symptomatic ankle osteoarthritis (OA) is controversial, particularly in mechanically induced, malaligned ankle OA in which joint cartilage is partially preserved. These patients typically are in their economically important, active middle ages because early trauma is the predominant (70–80%) etiology of their ankle OA.[49,58] Currently, treatment recommendations after failed nonoperative therapy are polarized between fusion[2,11,33] and total ankle replacement (TAR).[6,22,27,55,57] The main reasons for controversy relate to the long life expectancy and high activity demands of these patients.[11,57] Ankle fusion may enable a higher activity level, but degeneration of neighboring joints occurs in 44% to 50% after an average of 7 to 8 years[35,51] and in 100% after 22 years.[10,17] Although TAR may preserve the neighboring joints from overload and wear,[27] it allows only a certain amount of deformity correction and ligament balance.[57] In case of failure, loss of bone stock may complicate revision arthroplasty and fusion[25,46] to an extent that even below-knee amputation may be needed.[11,44]

These issues are not discussed so much in treating hip or knee OA because arthroplasty of these joints has documented longevity and good functional results. For total knee arthroplasty, 97% and 83% survival rates are reported after 10 and 16 years with revision as the end point and 99% survival at 10 and 18 years with poor knee score as the end point.[5] In one study 90% survival in total hip arthroplasty has been reported after a minimum of 30 years with revision as the end point.[8] Nevertheless, osteotomies are generally used, ie, for unicompartmental knee OA to unload the degenerated joint area[16,59] and for hip OA to improve joint coverage and congruence,[18,34] in active, young patients to postpone arthroplasty in these patients until they are older and less active. In contrast, surgery to preserve the arthritic ankle is rare; only four outcome studies are available in the literature. All of them focused on evaluation and correction of the distal tibia only[9,45,49,50] despite the fact that the ankle is coupled in a kinematic chain influenced by the integrity of the forefoot, hindfoot, and leg. In addition, patient demographics differed regarding OA,[45] patient age,[49] and etiology of deformity.[45]

We hypothesized: (1) realignment surgery would improve overall pain (as measured by a visual analog scale [VAS]); (2) realignment surgery would improve ankle function (range of motion [ROM], walking ability, and general activity as measured by the American Foot and Ankle Society [AOFAS] ankle score[26]); and (3) the functional outcome (postoperative ROM, walking ability, and general activity as measured by the AOFAS ankle score) would correlate with the achieved alignment.

MATERIALS AND METHODS

We prospectively evaluated ankle pain, function, and alignment in 35 consecutive patients (nine women, 26 men) with asymmetric posttraumatic OA (Table 1) of one ankle for whom we recommended realignment surgery between 1996 and 2003. All patients were referred for TAR or fusion because previous nonoperative treatment or débridement had failed. All ankles had a partially preserved joint surface visible on radiographs, which directed us to attempt ankle reconstruction. We included patients with (1) frontal plane malalignment with the center of rotation and angulation located within 3 cm of the ankle as measured on weightbearing anteroposterior (AP) radiographs; (2) asymmetric, unicompartmental joint degeneration limited to less than ½ the tibial or talar surface as verified by arthroscopy and/or arthrotomy; (3) calcaneocrural malalignment of maximal 30° valgus or varus. We excluded patients with (1) comorbidities limiting daily activities or compliance with the postoperative protocol; (2) total deltoid ligament insufficiency; and (3) combined deformities of the ankle with the knee or hip. The average age of the patients at surgery was 43 years (range, 26–68 years), the average body weight was 80.3 kg (range, 54–125 kg), and the average body mass index was 25.4 kg/m^2 (range, 18–33 kg/m^2). The minimum followup was 3 years (mean, 5 years; range, 3–10.5 years). No patient was lost to followup. All patients agreed to participate in the study and signed written consent. The study was performed in accordance with the World Medical Association Declaration of Helsinki.

Five clinical variables were documented by three of the authors (BH, VV, GIP): (1) Pain was measured by a VAS (1, no pain; 10, maximal pain imaginable); (2) Ankle dorsiflexion and plantar flexion ROM were measured under fluoroscopy; (3) Inversion and eversion ROM was measured as a percentage of the uninvolved contralateral joint as required by the AOFAS ankle score[26]; (4) Calcaneocrural angle was measured with a goniometer in a standing position looking from posterior to the heel. Normal values were set at an average 5° ± 4° valgus[47] (today, the Saltzman hindfoot view[41] is used for standardized hindfoot documentation but was not available during the study period); and (5) The AOFAS ankle score was completed (minimal points, 0; maximal points, 100; subscores: 40 points for pain, 50 points for function [general activity, 10 points; walking ability, 18 points; ankle and subtalar ROM and stability, 22 points], and 10 points for hindfoot alignment).[26] To allow interpretation of subjective and objective data, subscore data are presented. The AOFAS ankle score is the contemporary standard score in foot and ankle regional outcome measurement.[7]

Radiographic measurements were performed by three of the authors (BH, VV, GIP) with standing radiographs of the whole leg in the frontal and sagittal planes and compared with the uninjured site. The following angles were measured (Fig 1): tibial anterior surface angle (normal value, 93° ± 3°[47]); tibial lateral surface angle (normal value, 81° ± 5°[47,50]); tibiotalar tilt angle (normal value, 0°[47]); and malleolar angle (normal value, 82° ± 4°[47]). We assessed chronic lateral ankle instability with standard talar tilt and anterior drawer tests.[39] If the instability pattern remained unclear, we used stress radiographs.

We graded ankle OA and tibiotalar joint tilt using frontal-view weightbearing radiographs according to Takakura et al[50]: Grade 0, parallel joint, no tibiotalar tilt and no signs of arthritis; Grade 1, parallel joint, no tibiotalar tilt but signs of subchondral sclerosis or osteophyte formation; Grade 2, tibiotalar tilt with varus and valgus alignment without subchondral bone contact;

TABLE 1. Etiology of Asymmetric Ankle Osteoarthritis

Injury	Total		Latency Time (years)		Medial Ankle Osteoarthritis		Lateral Ankle Osteoarthritis	
	Number	*Percent*	*Mean ± SD*	*Range*	*Number*	*Percent*	*Number*	*Percent*
Sprains	11	31	11.6 ± 5.4	2–20	7	54	4	18
Fractures								
Tibial pilon	9	26	2.7 ± 4.4	0.3–14	3	23	6	27
Tibia and fibula shaft	7	20	10 ± 6.7	0.4–18	2	23	4	18
Malleolar	6	17	11.2 ± 15	0.8–40	0	0	6	27
Flake of talus	1	3	0.8		0	0	1	5
Lisfranc	1	3	20		0	0	1	5
Total	35	100	8.9 ± 8	0.3–40	13	100	22	100

SD = standard deviation

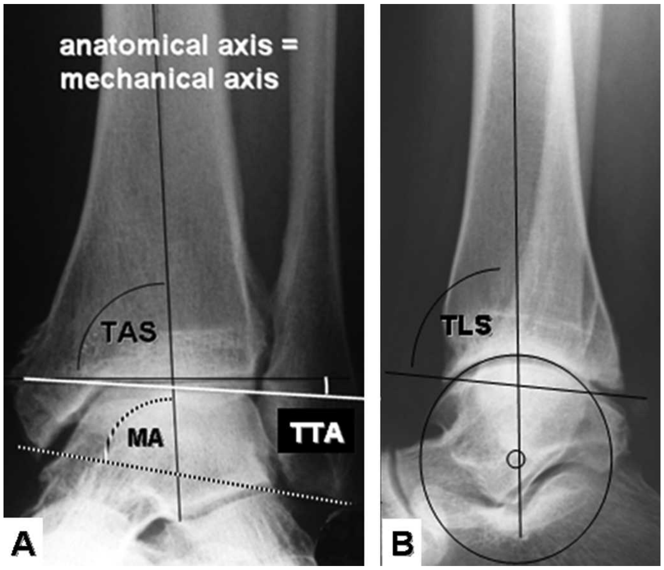

Fig 1A–B. The ankle sector of weightbearing radiographs of the lower leg shows angles around the ankle used to analyze asymmetric ankle OA. (A) In normal knees and hips, the anatomic axis of the tibia runs parallel to the mechanical axis of the leg. Ankle misalignment was analyzed in the frontal plane with the tibial anterior surface angle (TAS), the tibiotalar tilt angle (TTA), and the malleolar angle (MA). (B) In the sagittal plane, the tibial lateral surface angle (TLS) was measured. The small circle marks the center of rotation of the joint, which normally is located in line with the anatomic tibial axis.

Grade 3, tibiotalar tilt with varus and valgus alignment with subchondral bone contact; and Grade 4, total joint loosening with total subchondral bone contact. In addition, we used this grade to evaluate effectiveness of joint unloading if a Grade 2 or 3 (tibiotalar tilt) changed to Grade 1 (parallel tibiotalar joint).

The aim of surgical reconstruction was to realign the hindfoot and to obtain a stable and parallel ankle space in the frontal plane by shifting heel contact point (end of load axis) from the concave side of the deformity to the convex side to unload the diseased joint area. In the sagittal plane, the aim of realignment was to shift the rotational center of the ankle (lateral talar process) under the anatomic axis of the tibia.[32] The step-by-step procedure followed an algorithm for medial and lateral ankle OA (Fig 2). All surgical procedures were performed or supervised by the senior author (BH).

At the beginning of the operation, all patients underwent arthroscopy or arthrotomy to assess the extent and degree of cartilage degeneration according to Outerbridge[38]: Grade 0, no cartilage damage; Grade 1, cartilage softening; Grade 2, cartilage damage with stripping off superficial cartilage layers; Grade 3, deep cartilage ulceration without visible subchondral bone; and Grade 4, visible subchondral bone. Grade 4 lesions were treated by microfracturing. We considered mosaicplasty (autologous osteochondral transplantation) for circumscribed chondral lesions involving the subchondral bone of approximately 1 cm^2, and this was performed through arthrotomy and osteotomy of the medial malleolus if necessary. Solitary cysts in the subchondral bone, greater than 5 mm in diameter, were retrograde drilled under fluoroscopy and grafted. Osteophytes were removed if they were believed to cause pain, impingement, or motion restriction.

We simultaneously evaluated the fibula and tibia to minimize surgical incisions for supramalleolar correction: medial approach to correct isolated tibial malalignment; anteromedial approach to correct frontal and sagittal plane tibia malalignment; and anterolateral approach to correct combined fibula and tibia malalignment.

Special consideration had been given to the soft tissue envelope in severe scarring after initial injury or previous surgery. Because open wedge osteotomy at the tibia tensioned scarred skin, closing wedge osteotomies were preferred. Medial closing wedge osteotomies of the tibia were believed to loosen the tension of the tibialis posterior tendon; consequently, further destabilization of the initial valgus position occurred. Compensation was achieved with a medial sliding calcaneal osteotomy and associated soft tissue procedures. Shortening of the whole leg with a tibia closing wedge osteotomy was not considerable and within the normal interindividual range of 1 cm. In patients with preexisting shortening of the leg, we considered open wedge osteotomies.

For fibula osteotomy, we considered the malleolar angle. Significance was set if an angulation of at least 5° difference to the uninjured site was present.[47] However, after lateral malleolar fracture rotational deformity or syndesmosis subluxation of the fibula was evaluated by computed tomography, even in cases of normal malleolar angle. The fibula was approached through a longitudinal lateral incision. Usually, we made a z-shaped osteotomy to shorten or lengthen the fibula, whereas we made an oblique osteotomy to correct malrotation. A lag screw and one-third tubular AO plate were used for fixation.

Tibia malalignment was planned for overcorrection; the aim was a tibial anterior surface angle 85° to 90° (varus) in lateral ankle OA and a tibial anterior surface angle 90° to 95° (valgus) in medial ankle OA. Extensive overcorrection was avoided to limit shear forces. In all cases, the osteotomy was planed approximately 3 cm above the joint line to ensure proper screw fixation distally to the osteotomy (Fig 3). Usually we performed the osteotomy from a medial approach as an open wedge (for varus deformity) or closing wedge (for valgus deformity) osteotomy. With additional sagittal plane deformity, the approach was from anteromedial and an anterior open wedge osteotomy was performed for additional extension deformity and an anterior closing wedge was done for flexion deformity (Fig 2). We used Kirschner wires to guide the osteotomy. If beneficial during one- and two-plane correction, the cortex at the tip of the planned wedge was preserved to enhance stability of fixation and to use it as a hinge to translate the heel contact point to the convex side of the deformity. The cortex was not preserved if excessive translation would create a relevant zigzag deformity requiring correction. The intact fibula did not hinder isolated tibial correction. In 24 patients (69%), we used implants providing angular stability (cervical plate, blade plate, or 3.5-mm AO plate with interlocking screws). We filled open wedge tibia osteotomies with bone allograft in four patients and with autograft in five

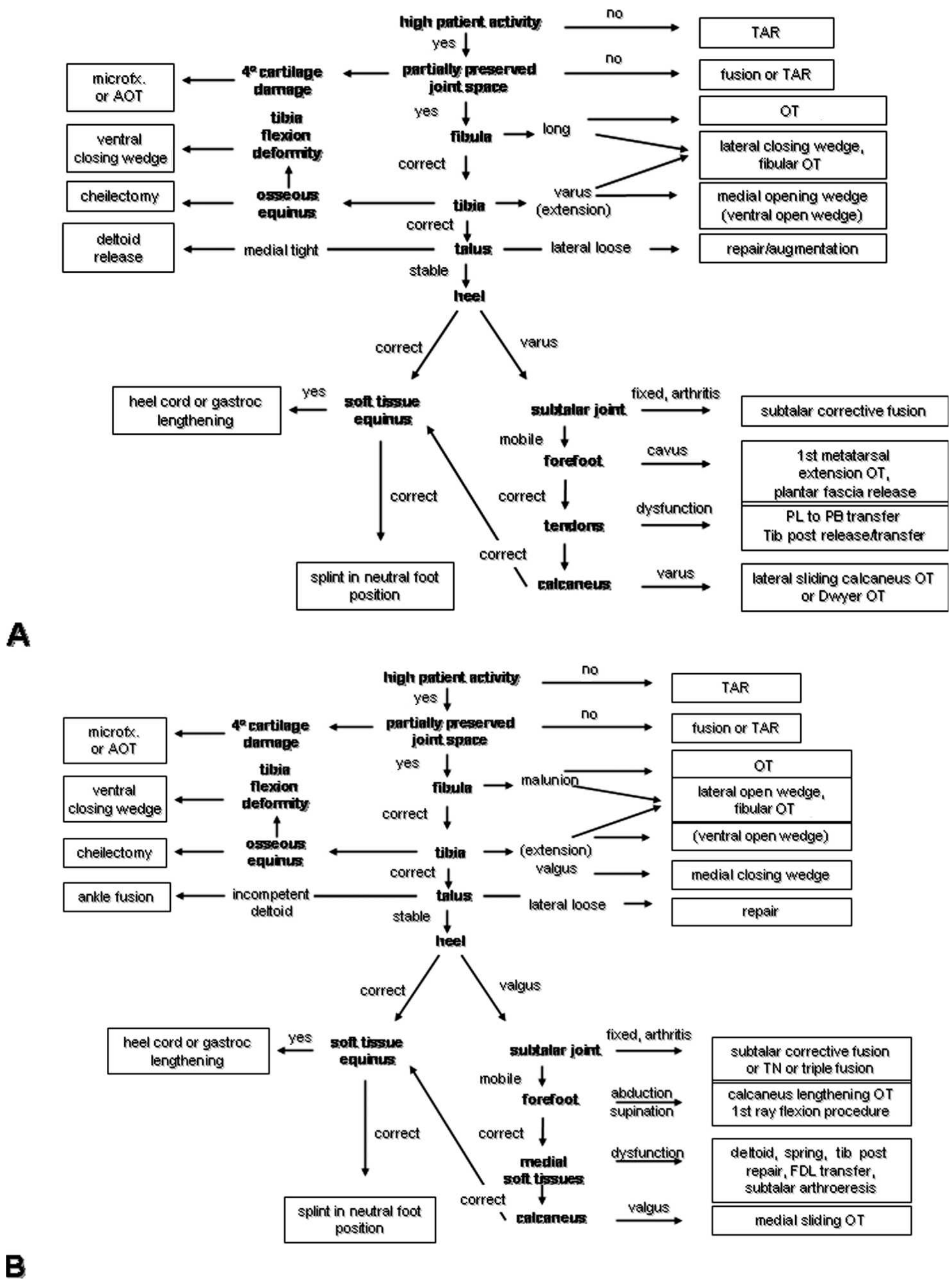

Fig 2A–B. Algorithms for (A) medial ankle OA and (B) lateral ankle OA are shown. Realignment procedures run from proximal to distal. Key elements are the distal tibia and the heel. Heel varus (A) or valgus (B) is caused by intrinsic (fixed deformity) or extrinsic (flexible deformity) disorders. Therefore, primary heel realignment focuses on correction of extrinsic reasons (tendon imbalance, forefoot deformities). If additional heel deformity persisted or an intrinsic reason of heel deformity was present (fixed deformity, subtalar arthritis), the correction was performed at the heel. The aim of realignment surgery is to move the heel to the convex side of the ankle deformity to reverse the collapse of the degenerated part of ankle OA. Realignment was continued until heel angulation was within 0° to 5° valgus and a plantigrade forefoot was reached. microfx = microfracturing; AOT = autologous osteochondral transplantation; TAR = total ankle replacement; gastroc = gastrocnemius; OT = osteotomy; PL = peroneus longus tendon; PB = peroneus brevis tendon; tib post = tibialis posterior tendon; TN = talonavicular joint; FDL = flexor digitorum longus tendon

patients (harvested by Dwyer closing wedge calcaneus osteotomy in four patients and iliac crest in one patient).

Reconstruction of the lateral ligaments was performed using the modification of Gould et al[19] of the Brostrom procedure.[3] Augmentation was achieved with a plantaris autograft.[39] We assessed chronic anteromedial ankle instability according to Hintermann et al.[21] The anterior deltoid and the spring ligament were reconstructed by imbrications and sutures.[21] We used two AO screws for fibula fixation in unstable syndesmotic ligaments. In severe varus ankles in which the deltoid ligament was tight and caused talar tilt, we performed a medial release. Even in long-standing valgus deformities, the lateral ligaments were not contracted.

For a fixed hindfoot deformity, we evaluated medial ankle OA for a lateral sliding calcaneus osteotomy and lateral ankle OA for a medial sliding calcaneus osteotomy. The degree of tibial correction was subtracted from the preoperative hindfoot deformity during preoperative planning. During surgery after the fibula and tibia osteotomies, the calcaneocrural angle was reassessed with the tibiotalar joint held parallel under fluoroscopy and by looking from posterior to the heel. Hindfoot correction was limited to 0° to 5° valgus to reduce medial soft tissue tension with higher valgus angles but allow passive hindfoot pronation with walking. We performed calcaneus osteotomy over a lateral incision and fixed it with one or two cannulated compression screws. A medial sliding osteotomy of the calcaneus was per-

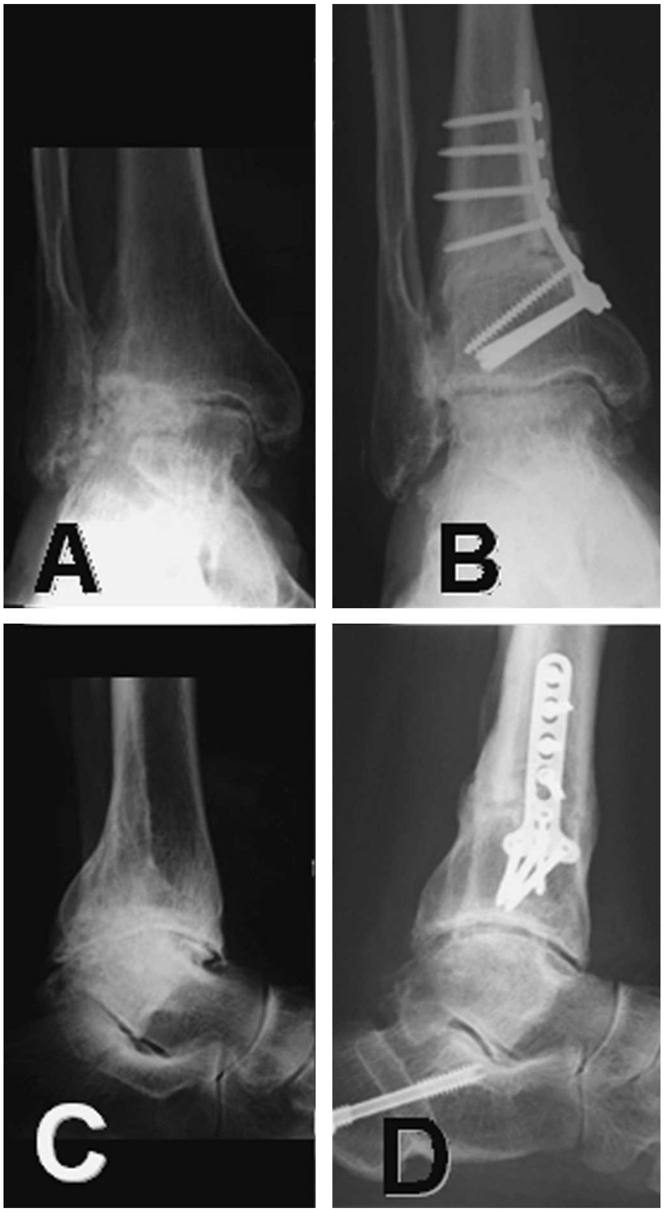

Fig 3A–D. (A, C) Radiographs show the ankle of a 65-year-old man 16 years after ankle fracture. After failed nonoperative management, he refused ankle fusion several times and referred himself to undergo TAR. On weightbearing films, the joint degeneration appeared limited to the lateral compartment. Based on the patient's demands to continue running sports, realignment surgery was decided. A medial closing wedge tibial osteotomy and a medial sliding osteotomy of the calcaneus were performed. (B, D) Three years later, his joint line was still preserved; the collapsed part of ankle OA was stretched out to a parallel tibiotalar joint space on the frontal view. The patient was satisfied; he has no pain during activities of everyday living. At last followup, he still was participating in running sports with only mild symptoms after exercise.

formed in valgus deformities and a lateral sliding or lateral closing wedge osteotomy (Dwyer)[29] of the calcaneus was performed in varus deformities. For a symptomatic osteoarthritic subtalar joint, we corrected the fixed hindfoot with subtalar fusion. The subtalar joint was débrided over a curved lateral incision and the subtalar joint was fixed with two cannulated compression screws.

For a mobile (passively reducible) deformity, we evaluated the hindfoot for tendon- or forefoot-induced deformities. The flexible pes planovalgus deformity typically is caused by posterior tibial tendon dysfunction. We performed evaluation and staging as recommended by Johnson and Strom.[24] Flexible flat foot deformity with an abducted forefoot (uncovering of the talar head greater than 40%) was considered for lateral lengthening osteotomy of the calcaneus in combination with medial soft tissue procedures as suggested by Hintermann et al.[23] Valgus heels without forefoot abduction were considered for a medial sliding osteotomy of the calcaneus and medial soft tissue procedures as suggested by Myerson et al.[37] Medial soft tissue procedures encompassed repair and imbrications of the anterior delta and spring ligaments combined with posterior tibial tendon repair and/or augmentation with flexor digitorum tendon transfer as suggested by Hintermann et al[23] and Myerson et al.[36] In one patient, a severe ankle pronation sprain had exacerbated the preexisting congenital valgus and pronation deformity and had caused lateral ankle OA over time. In this case, we performed a subtalar arthroereisis with a sinus tarsi screw instead of lateral calcaneus lengthening as suggested by Viladot et al.[56]

Peroneal tendon imbalance was presumed in medial ankle OA caused by repetitive supination trauma and evaluated as suggested by Younger and Hansen.[60] The peroneus longus tendon was exposed over a lateral skin incision beneath the insertion of the peroneus brevis tendon. The peroneus longus tendon was cut pretensioned and fixed by transosseous sutures to the base of the fifth metatarsal and side to side to the peroneus brevis tendon while the foot was held in maximal pronation and dorsiflexion. In one case, the peroneus brevis tendon was ruptured and was repaired.

Permanent equine position of the foot after arthroscopic or open cheilectomy and distal tibial osteotomy was evaluated for lengthening of the heel cord and performed using either Hoke's percutaneous triple hemisection technique for the Achilles tendon[30] or the Strayer maneuver to release the gastrocnemius.[30] We assessed the source of contracture with the Silfverskiold test.[11,30]

Three patients (9%) had a distal tibial osteotomy as an isolated procedure; the other 32 patients (91%) had additional surgical procedures to unload ankle OA and to reconstruct the mechanical alignment of the foot and ankle (Table 2).

Postoperatively, the foot was placed in a cotton wool compression dressing. Regional catheter anesthesia increased tolerance of long-term compression. In general, 2 to 3 days after surgery, the splint compression dressing was replaced by a removable cast that ensured protection against uncontrolled movements. A rehabilitation program was started, including active and passive ankle motion. Nonweightbearing toe touch was permitted for the first 8 weeks until radiographic control. Progres-

TABLE 2. Surgical Procedures for Asymmetric Ankle Osteoarthritis

Location	Procedure	Valgus Ankle Osteoarthritis (number)	Varus Ankle Osteoarthritis (number)
Tibia	Medial closing wedge osteotomy	18	0
	Medial open wedge osteotomy	0	7
	Lateral closing wedge osteotomy	0	4
	Lateral open wedge osteotomy	1	0
	Posterolateral closing wedge osteotomy	0	2
	Anterolateral closing wedge osteotomy	1	0
	Anterolateral open wedge osteotomy	1	0
	Anteromedial closing wedge osteotomy	1	0
Fibula	Shortening osteotomy	0	9
	Lengthening osteotomy	3	0
	Osteosynthesis	2	0
	Syndesmotic screws	1	0
Calcaneus	Medial sliding osteotomy	6	0
	Lateral sliding osteotomy	0	1
	Dwyer osteotomy	0	4
	Lateral lengthening osteotomy	1	0
	Subtalar corrective fusion	0	1
	Sinus tarsi screw (subtalar arthroereisis)	1	0
Mid/forefoot	Lisfranc flexion arthrodesis	1	0
	Extension osteotomy metatarsus one	0	1
	Flexion-adduction osteotomy metatarsus one	1	0
Tendons	Posterior tibial tendon repair	2	0
	Flexor hallucis transfer to posterior tibial tendon	1	0
	Achilles tendon lengthening	1	0
	Peroneus longus to brevis transfer	0	1
	Peroneus brevis suture	0	1
Ligaments	Lateral repair	5	7
	Medial repair	5	2
	Medial release	0	5
Cheilectomy		8	8
Cartilage	Microfracturing	3	1
	Tibial cyst grafting	2	0
	Mosaicplasty	1	0
	Total number of procedures per patient	Mean 3 (range, 1–7)	Mean 4.2 (range, 2–8)

sive weightbearing with proprioceptive and coordinated training was permitted when radiographs showed the osteotomies were fused. Gradual return to nonstrenuous physical and sports activity was permitted, but strenuous sports activities were not recommended.

At followup, all but six of the patients were clinically and radiographically evaluated by three of the authors (GIP, VV, AL) according to the preoperative protocol. Six of the 12 patients living in foreign countries did not return for the last followup. Therefore, the AOFAS ankle score questionnaire was completed by telephone by one author (GIP) and the clinical evaluation, standing clinical photographs, and weightbearing radiographs of the foot and ankle were performed by their family physicians and sent for evaluation.

Additional assessment included time for bony healing after osteotomy, complications, and performance of subsequent revision surgery. We considered the operations unsuccessful if recurrent symptoms led to fusion or TAR. All measurements on radiographs were performed by two observers (GIP, VV) with an interval to blind the observers to the clinical results. All variables were compared with the preoperative situation (Table 3).

Statistical analysis was performed by one author (AB) who otherwise was not connected to the study. Kolmogorov-Smirnov normality test was used for Gaussian distribution testing of all study variables. For significance testing of all study variables, Student's t test was performed. We used Pearson's correlation to relate deformity variables with the AOFAS score. The level of significance was set at $\alpha = 0.05$. We analyzed all data using SPSS (Version 11.0 for Windows; SPSS Inc, Chicago, IL).

RESULTS

The VAS pain score decreased ($p = 0.0001$) from a preoperative score of 7 (range, 4–10) to a followup score of 3 (range, 1–6) (Table 3; Fig 4A). Ten patients (29%) were completely pain-free at followup. Eighteen patients (51%) had mild pain (VAS 2–4), four patients (11%) had moderate pain (VAS 5–7), and three patients (9%) had severe pain (VAS 8–10) and had revision surgery to TAR.

The average functional and radiographic variables changed substantially from preoperative to last followup in

TABLE 3. Preoperative and Followup Values for Functional and Radiographic Variables

Variable	Preoperative		Followup		p* Value
	Mean ± SD	*Range*	*Mean ± SD*	*Range*	
Pain (VAS: range, 1–10)	7 ± 1.6	4–10	2.7 ± 1.6	1–6	0.0001
Ankle ROM (DF + PF°)	32.8° ± 14°	5°–60°	37.7° ± 9.4°	20°–55°	0.001
Subtalar ROM (percent of contralateral side)	48.1% ± 27%	< 25%–> 90%	61.7% ± 29%	< 25%–> 90%	0.01
Ankle stability (yes/no)	22/13		32/0		
AOFAS activity (range, 0–10 points)	3.9 ± 2.3	0–7	8.1 ± 2.0	4–10	0.0001
AOFAS walking ability (range, 0–18 points)	6.1 ± 4.7	0–16	16.4 ± 1.9	12–18	0.0001
AOFAS ROM and stability (range, 0–22 points)	15.1 ± 4.5	8–22	20.1 ± 2.5	15–22	0.0001
AOFAS function (range, 0–50 points)	24.3 ± 8.7	8–42	44.6 ± 4.6	32–50	0.0001
AOFAS ankle score[26] (range, 0–100 points)	38.5 ± 17.2	10–67	85.4 ± 12.4	52–100	0.0001
Talocrural angle	5.0° ± 13.7°	−20°–23°	3.4° ± 2.4°	0°–8°	0.3
Takakura score (range, 0–4)†	2.3 ± 0.6	1–3	1.3 ± 0.5	1–2	0.0001

* Significance was set at $p < 0.05$; †ankle osteoarthritis and alignment score of Takakura et al[50]; SD = standard deviation; VAS = visual analog scale; ROM = range of motion; DF + PF° = sum of dorsiflexion and plantar flexion in degrees; AOFAS = American Orthopaedic Foot and Ankle Society

most cases (Table 3; Fig 4). For ankle ROM, the range of values decreased but the mean value increased (p = 0.0001) at followup (Fig 4B). Changes were different for medial and lateral ankle OA (Table 4). The Takakura score decreased (p < 0.0001) on average from 2.3 (range, 1–3) to 1.3 (range, 1–2) at followup. In 25 patients (71%), the Takakura score was decreased, indicating a reversal of tibiotalar tilt at followup. A parallel tibiotalar joint space (Takakura Grade 1) was present in 22 patients (63%) at followup (Fig 5).

The AOFAS ankle score did not correlate with the preoperative Takakura score (r = −0.3, p = 0.08) or with the amount of preoperative tibial or calcaneocrural deformity (tibial anterior surface angle: r = 0.17, p = 0.3; tibial lateral surface angle: r = −0.14, p = 0.4; calcaneocrural angle: r = 0.2, p = 0.3). However, the postoperative AOFAS ankle score correlated with the postoperative Takakura score and the tibiotalar tilt angle (Table 5).

Ten ankles (29%) were revised after primary realignment surgery (Table 6). In three ankles (9%), joint degenerations progressed to end stage and were converted to TAR at 12, 22, and 24 months, respectively, after realignment surgery (case example; Fig 6). The other seven ankles (20%) were revised successfully. In seven patients (20%), the implanted plates caused discomfort and were removed during followup.

DISCUSSION

Despite their limitations, fusion and TAR are established treatment options for persistent painful ankle OA.[6,11,22,55,57] There is little published evidence for the use of realignment surgery as an alternative treatment.[9,45,49,50] Therefore, we clinically and radiographically followed 35 patients with posttraumatic ankle OA treated with lower leg and hindfoot realignment surgery. We hypothesized realignment surgery would improve pain and clinical function of patients with asymmetric ankle OA. In addition, it was questioned if the outcome would correlate with the achieved alignment.

Limited conclusions may be drawn from our study owing to the relatively short followup. This cohort would need to be evaluated at 10 years minimum to know whether the results persisted for sufficiently long times for the surgery to be worthwhile. To evaluate the value of one realignment procedure, randomized, controlled studies limited to one procedure would be ideal. However, complex deformities typically need complex and varied individual procedures.

It is known distal tibial malalignment substantially decreases the tibiotalar joint contact area, which consequently leads to a pressure increase on cartilage.[52] The effect of pathologic pressure on subchondral bone[13] and living cartilage is known to cause circumscribed joint degeneration, cartilage wear, and debris,[40] a likely source of painful synovitis.[12,20,31] Therefore, asymmetric ankle OA seems caught in a vicious circle.[43] We believe realignment surgery has the potential to break this circle. This contention is supported by the pain reduction, which correlated with the achieved realignment (postoperative Takakura score, Table 5). Pain reduction after realignment surgery in our cohort is consistent with the results of other studies (Table 7).[9,45,49,50] Similar to the ankle, knee cadaver studies suggest unloading osteotomies allow controlled joint pressure redistribution and reduction,[1] with improvement of pain and function in unicompartmental knee OA.[4]

Our results in functional outcome (Hypothesis 2) are similar to the results of other studies (Table 7). Functional loss in OA is associated with pain, reduced ROM, and muscle atrophy.[14] However, in animal models, limping

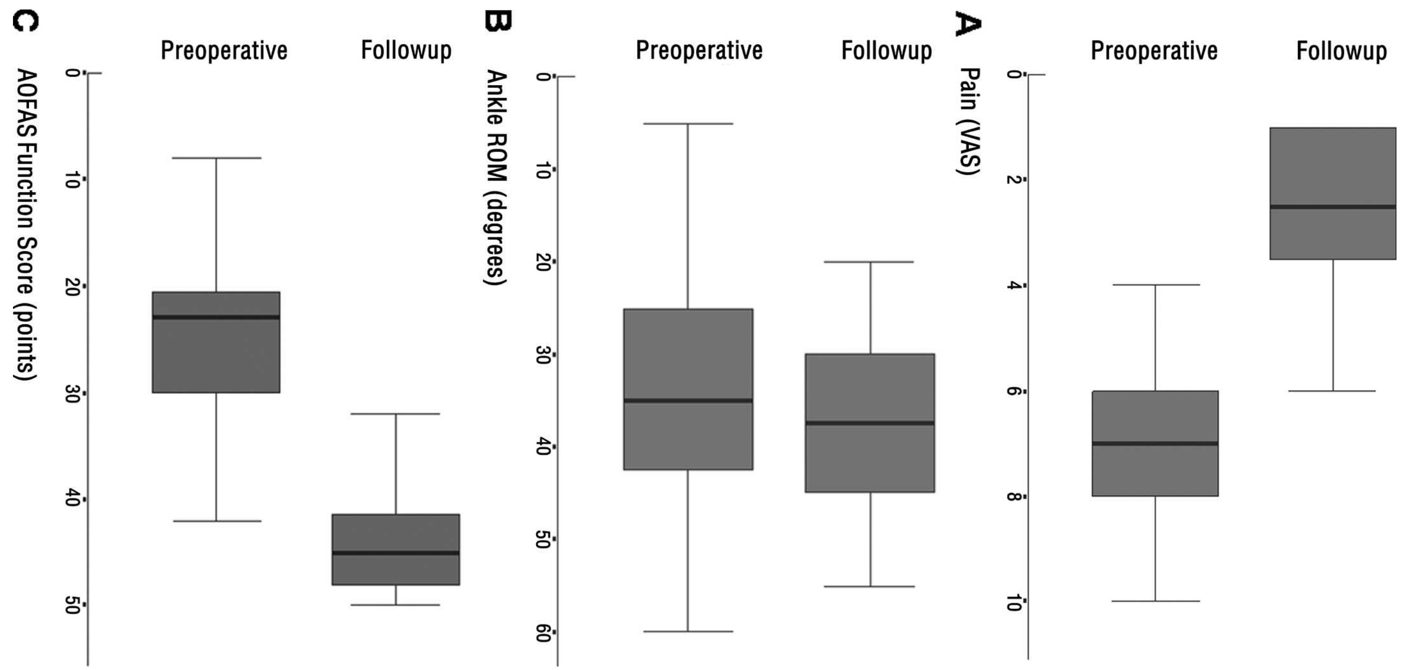

Fig 4A–C. The box plots (box = median, quartiles; whiskers = minimum, maximum) compare preoperative and followup values for (A) pain (VAS: no pain, 1; maximal pain, 10 points), (B) ankle ROM (sum of dorsiflexion and plantar flexion in degrees), and (C) subscore for function of the AOFAS ankle score[26] (maximum 50 points; minimum 0 points). All these variables changed substantially ($p < 0.05$) (Table 3) at followup.

TABLE 4. Preoperative and Followup Values for Varus and Valgus Ankle Osteoarthritis

	Varus Ankle Osteoarthritis (n = 12)					Valgus Ankle Osteoarthritis (n = 20)				
	Preoperative		*Followup*			*Preoperative*		*Followup*		
Variable	*Mean ± SD*	*Range*	*Mean ± SD*	*Range*	**p* Value**	*Mean ± SD*	*Range*	*Mean ± SD*	*Range*	**p* Value**
Tibial anterior surface angle	83.5° ± 4.3°	78°–90°	91.7° ± 2.5°	90°–98°	0.0001	96.5° ± 4.4°	86°–103°	88.5° ± 1.6°	85°–90°	0.0001
Tibial lateral surface angle	84° ± 7.7°	64°–90°	84.5° ± 3.3°	80°–90°	0.8	86.6° ± 4.5°	76°–96°	84.8° ± 2.6°	80°–89°	0.1
Tibiotalar tilt angle	6.1° ± 4.7°	0°–16°	1.9° ± 2.7°	0°–8°	0.002	3.2° ± 1.5°	0°–6°	0.5° ± 0.8°	0°–2°	0.0001
Malleolar angle	80.6° ± 4.1°	74°–86°	84.7° ± 1.9°	82°–88°	0.02	80.3° ± 2.7°	76°–86°	80.7° ± 1.4°	78°–83°	0.7
Calcaneocrural angle	−11.5° ± 5.2°	−20°–2°	2.7° ± 2.6°	0°–8°	0.0001	14.8° ± 4.2°	5°–23°	3.9° ± 2.3°	0°–8°	0.0001
Ankle ROM (DF + PF°)	32.7° ± 14.2°	5°–55°	38.8° ± 8.6°	25°–50°	0.047	33° ± 14.8°	10°–60°	37° ± 10.1°	20°–55°	0.02
Subtalar ROM (percent of contralateral side)	35.8% ± 19.6%	< 25%–> 90%	55% ± 28%	< 25%–> 90%	0.03	55.5% ± 28.7%	< 25%–90%	84.5% ± 3.3%	< 25%–90%	0.1
Outerbridge grade (range, 0–4)†	3.5 ± 0.8	2–4				3.4 ± 0.9	2–4			
Takakura score (range, 0–4)‡	2.2 ± 0.6	1–3	1.4 ± 0.5	1–2	0.005	2.4 ± 0.6	1–3	1.3 ± 0.4	1–3	0.0001
Ankle ligaments (lateral loose/medial tight/medial loose)	7/5/2		0/3/0			8/0/5		0/0/0		

*Significance was set at $p < 0.05$; †Outerbridge grade of cartilage degeneration[38]; ‡ankle osteoarthritis and alignment score of Takakura et al[50]; SD = standard deviation; ROM = range of motion; DF + PF° = sum of dorsiflexion and plantar flexion in degrees

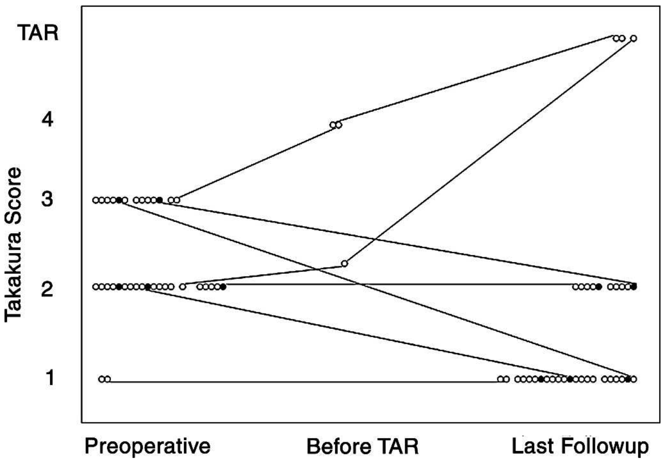

Fig 5. A graph plots the individual changes of OA and the alignment score of Takakura et al[50] with time. Each circle indicates one ankle (patient). The lines connect groups with similar development; the black circles mark each fifth ankle in a group. Three ankles were converted to TAR within 2 years. Followup indicates a mean of 5 years (range, 3–10.5 years).

and decreased leg use caused by OA could be completely reversed by proper analgesics alone.[15] This shows the key role of pain in functional disability. Consequently, muscle rehabilitation capacities have been seen after pain relief with TAR in ankle OA.[54] Takakura et al[49,50] reported on decreased ankle ROM after unloading supramalleolar osteotomy of ankle OA. However, decreased ROM did not influence physical activity of their patients. The functional outcome score[50] increased considerably (Table 7), and even strenuous sports activities were possible.[49] However, Cheng et al[9] reported an increase in ROM after unloading supramalleolar osteotomy of ankle OA. Pain reduction was the reason. Our findings were similar; improvement of pain correlated with walking ability and general activity measured by the AOFAS ankle score, whereas the same subscores did not correlate with achieved ROM (Table 5).

We found special surgical procedures such as subtalar fusion or arthroereisis reduced ROM. However, average ROM of the cohort improved for the ankle and subtalar joints (Fig 4B; Table 3). Range of motion may be gained by removal of motion restraints like removal of osteophytes[48] and Achilles tendon lengthening.[42] Another reason could be realignment surgery sets the joints of the foot back into their physiologically functional ranges; this may be especially true for varus ankle OA. Physiologic hindfoot inversion is larger than eversion[47]; consequently, distal tibia valgus deformities are better compensated in the subtalar joint than varus.[53] We found patients with preoperative hindfoot varus experienced greater ankle and subtalar ROM benefit. In contrast, ROM of the subtalar joint did not improve for valgus OA (Table 4). We believed sufficient subtalar compensation of distal tibia valgus deformities may have caused lesser ROM restriction initially. Consequently, patients with severe ROM restrictions may experience a stronger gain of motion after realignment surgery than patients with no ROM restrictions. However, patients with normal ROM may lose some motion intrinsic to surgery.

Concerning the correlation of alignment with clinical outcome, Takakura et al[49,50] and Cheng et al[9] aimed for tibial anterior surface angle overcorrection and noted a reversion of joint collapse with increased width of the degenerated joint space during followup. Arthroscopic evaluation by both groups showed uniform improvement

TABLE 5. Correlation of Pain, Function, and Alignment at Followup

	Function				Alignment	
Variable	*Ankle ROM (DF + PF°)*	*General Activity**	*Walking Ability**	*Total Score**	*Takakura Score†*	*Tibiotalar Tilt Angle*
Pain (VAS)	r = −0.18 p = 0.3	r = −0.59‡ p = 0.0001	r = −0.76‡ p = 0.0001	r = −0.83‡ p = 0.0001	r = 0.5‡ p = 0.004	r = 0.5‡ p = 0.004
Ankle ROM (DF + PF°)		r = 0.05 p = 0.8	r = 0.3 p = 0.1	r = 0.23 p = 0.2	r = −0.14 p = 0.5	r = −0.15 p = 0.4
General activity*			r = 0.75‡ p = 0.0001		r = −0.29 p = 0.1	r = −0.26 p = 0.2
Walking ability*					r = −0.42‡ p = 0.02	r = −0.35‡ p = 0.048
Total score*					r = −0.57‡ p = 0.001	r = −0.37‡ p = 0.042
Takakura score†						r = 0.79‡ p = 0.0001

*Measured by the American Orthopaedic Foot and Ankle Society ankle score[26]; †ankle osteoarthritis and alignment score of Takakura et al[50]; ‡significant Pearson's correlation (r) at $p < 0.05$; ROM = range of motion; DF + PF° = sum of dorsiflexion and plantar flexion in degrees; VAS = visual analog scale

TABLE 6. Complications and Therapy

Complication Type	Complication	Therapy	Number
Progressive osteoarthritis	Total joint degeneration	Total ankle replacement	3
Recurrent deformity	Varus, allograft absorption medial open wedge	Redo tibia open wedge, autograft	1
	Valgus, autograft absorption lateral open wedge	Closing wedge medial tibia	1
Initially incomplete	Varus, fibula over length	Shortening osteotomy	1
Realignment	Equinus, osseous anterior impingement	Open cheilectomy	1
	Valgus, nonunion old fibula fracture	Redo fixation, grafting	1
General	Nonunion tibia	Redo fixation, grafting	1
	Superficial wound infection	Débridement	1
	Late wound healing	Nonoperative	1
	Deep vein thrombosis	Nonoperative	1
Total			12

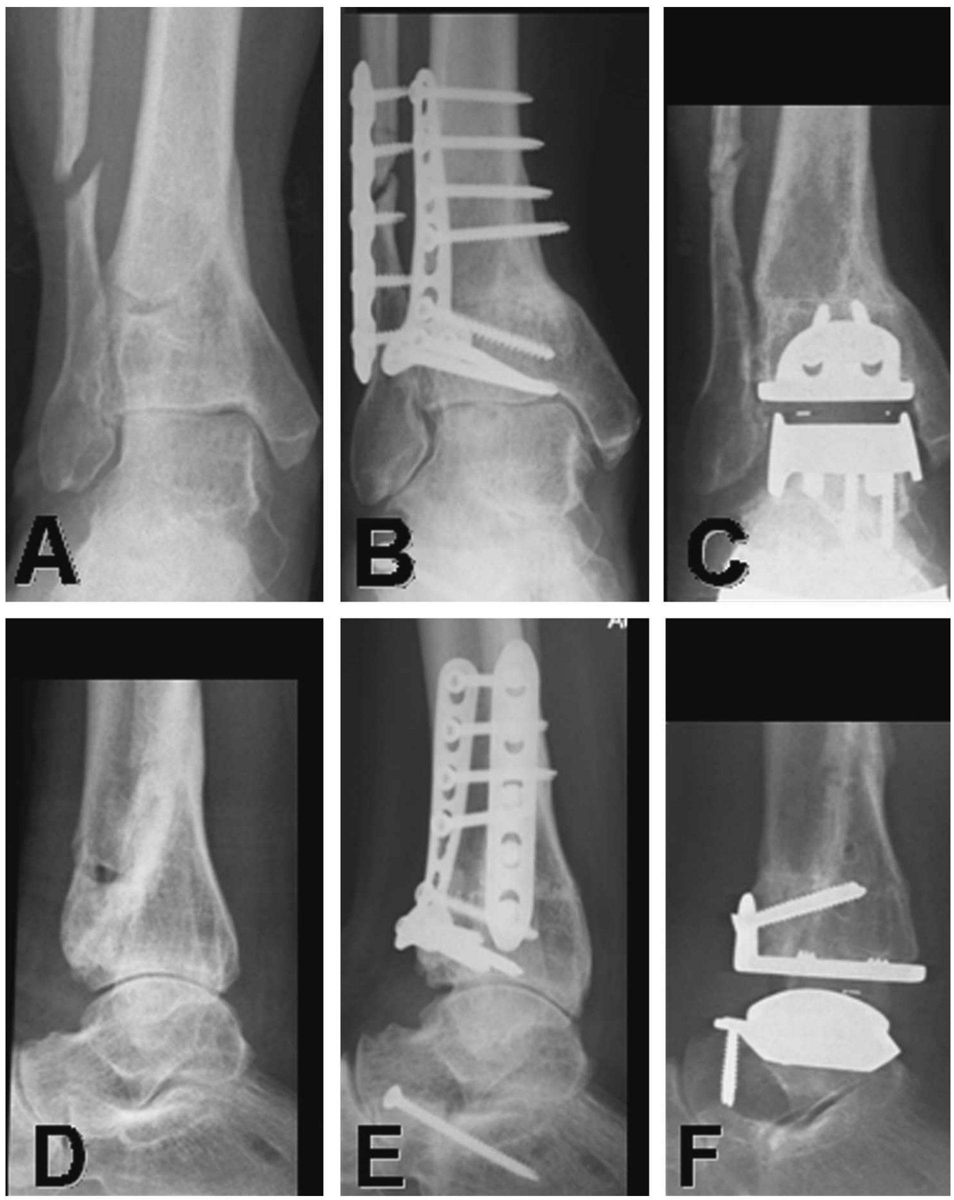

Figure 6A–F. A 47-year-old female physician experienced an open fracture of the lower leg that was fixed at the local hospital. Four months after osteosynthesis, she referred herself. On examination, she had mild valgus of the hindfoot (calcaneocrural angle 5°) with forefoot abduction, limited ankle dorsiflexion, and severe pain with ambulation (VAS 10). (A, D) Radiographs showed malunion of the tibia with lateral ankle OA (despite varus deformity of the distal tibia) and nonunion of the fibula. Her measurements were tibial anterior surface angle 79°, tibial lateral surface angle 88°, malleolar angle 87°, tibiotalar tilt angle 2°, tibiotalar distance 1 mm at the lateral joint space, and Outerbridge Stage 4 verified by arthroscopy. Her realignment surgery consisted of an anterolateral closing wedge tibia osteotomy and fibula grafting and fixation, lateral lengthening of the os calcis, and arthroscopic microfracturing of the talus. A lateral approach was used for tibia and fibula realignment to circumvent the scarred skin at the medial tibia. (B, E) The measurements achieved were tibial anterior surface angle 88°, tibial lateral surface angle 76°, tibiotalar tilt angle 1°, and tibiotalar distance 1 mm at 3 months followup. However, severe pain (VAS 8) returned within months and she had revision surgery to TAR 12 months after realignment surgery. Severe inflammation was present which may be caused not only by mechanical reasons.[28] (C, F) At the last followup 26 months after TAR, she had no pain and worked 100%, and her ankle ROM (sum of dorsiflexion and plantar flexion) was 30°.

TABLE 7. Current Outcome Studies of Realignment Surgery for Ankle Osteoarthritis

		Characteristics of Arthritis			Realignment Surgery		Results			
Study	**Number of Patients**	*Takakura Grade of Arthritis*	*Etiology of Osteo-arthritis*	*Deformity*	*Tibial Osteotomy*	*Additional Procedures*	*Complica-tions*	*Mean Score**	*Mean Followup (years)*	*Revision Surgery*
Takakura et al[50]	18	2 or 3	All primary	All varus and extension	5 dorsolateral closed wedge 1 oblique 12 anteromedial open wedge	3 lateral ligament reconstruction 18 fibula shortening	4 delayed union	83.9 (55.7)† 3 fair 9 good 6 excellent	6.8 (2.6–12.8)	
Takakura et al[49]	5 (of nine patients; 4 younger than 16 years)	All 2	All trauma	All varus	All medial open wedge All fibula oblique	None	1 delayed union	80.2 (58.4)† 3 fair 1 good 1 excellent	6.8 (2–13.2)	
Cheng et al[9]	18	2 or 3	6 trauma 12 primary	All varus and extension	All anteromedial open wedge All fibula oblique	None	2 implant failure 1 infection	88.5 (49.6)‡ 10 good 8 excellent	4 (2–6.8)	2 refixation 1 débrided
Stamatis et al[45]	8 (of 13 patients; 5 without ankle osteoarthritis)	All 2	3 trauma 5 primary	5 varus 3 valgus	5 medial open wedge 3 medial closed wedge All fibula oblique	5 Achilles lengthening 4 arthroscopic débridement 1 calcaneal osteotomy	1 delayed union	83.6 (45.9)§ 82 (56.7)†	2.5 (1–5)	1 refixation
Current study	35	1–3	All trauma	13 varus 22 valgus	Table 2	Table 2	Table 6	85.4 (38.5)§	5 (3–10.5)	Table 6

*Followup score, with preoperative score shown in parentheses; †outcome score used by Takakura et al[49,50]: maximum 100 points: pain, 40 points; activity, 20 points; walking, 20 points; range of motion, 20 points; grading: excellent = 90–100 points, good = 80–89 points, fair = 70–79 points, poor = < 70 points; ‡outcome score used by Cheng et al[9]: maximum 100 points: pain, 50 points; function, 40 points; range of motion, 10 points; grading: excellent = 85–100 points, good = 70–84 points, fair = 45–69 points, poor = < 45 points; §American Foot and Ankle Society ankle score[26]: maximum 100 points: pain, 40 points; function, 50 points; alignment, 10 points in cartilage disease from Outerbridge Grades 3–4 to 1–2; biopsies of the new joint surface showed fibrous cartilage.[9,50] We concur with these findings. Reversal of tibiotalar joint tilt, as graded by the Takakura score, showed correlation with walking ability and pain improvement and overall AOFAS ankle score (Hypothesis 3, Table 5). Therefore, achieving joint-space widening, at best a parallel tibiotalar joint space (Takakura Grade 1), shows effective unloading of the diseased joint area. In contrast, Stamatis et al[45] aimed for neutral tibial anterior surface angle but used concomitant surgical procedures to realign the foot. No gain or loss in tibiotalar joint space width was noted at followup compared with that preoperatively (all remained Takakura Grade 2). However, Stamatis et al[45] reported a similar good outcome, but their average followup was considerably short, with five of eight patients having no more than 2 years followup. In our series, two patients had conversion surgery to TAR 22 and 24 months after realignment surgery. Therefore, cautious conclusions may be drawn from the data of Stamatis et al.[45] Despite that, we do concur with Stamatis et al[45] to correct all existing foot disorders. To our opinion unloading surgery has to shift the load axis from the concave side of the joint deformity to the convex side, not only back to the center of the ankle. This may be achieved by correction above and/or below the ankle joint because the weightbearing axis runs down to the contact point of heel to ground.

Combining the experiences in the literature with our findings, it seems worthwhile to perform realignment surgery for ankle OA with mechanically induced, partially degenerated joint surfaces. Realignment surgery was able to postpone the originally planned ankle fusion or TAR in 91% of our cohort (32 ankles). In addition, realignment surgery does not "burn bridges" and often is indicated in misaligned ankles to allow and facilitate later fusion or TAR.[57]

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