



The Ability to Achieve a Specific Target Angle on Weightbearing Radiographs After Valgus High Tibial Osteotomy for Medial Knee Arthritis Is Not Predictable

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Purpose: Standing radiographs are commonly used to plan angular correction in valgus tibial osteotomy for varus gonarthrosis. Most clinical studies have reported postoperative alignment as overall averages or means. The purpose of this study was to compare the preoperatively planned angle of correction measured on weight-bearing radiographs to the follow-up angle measured on weightbearing radiographs in individual patients 6 weeks after surgery and to analyze factors that could potentially affect achieving the planned degree of surgical correction. Our objective was to analyze factors potentially affecting the accuracy and ability to achieve the preoperatively planned correction angle (the target angle) in the individual patient. **Methods:** We studied 35 tibial osteotomies (13 Coventry closing wedge osteotomies and 22 Maquet barrel vault osteotomies) performed for varus gonarthrosis between 1981 and 2019 to determine how accurately the target angle, based on preoperative standing weight-bearing radiographs, was achieved according to the postoperative radiographs in each individual. We reviewed 35 knees in 34 patients who had complete pre- and postoperative radiographs for review. **Results:** Overall, only 14 of 35 (40%) of the patients were corrected to within $\pm 2^\circ$ of the planned target angle. Valgus tibial osteotomy based on preoperative weightbearing radiographs is unpredictable in its ability to achieve the target angle on postoperative weightbearing radiographs when using either the Coventry or the Maquet surgical technique. The tendency was to undercorrect with either of the techniques. Larger (greater than 10°) preoperative varus alignment did not make it more difficult to achieve the target angle. Male or female sex and body mass index had no effect on the ability to achieve the target angle. **Conclusions:** Valgus tibial osteotomy planning based on preoperative weightbearing is unpredictable in its ability to achieve the target angle on postoperative weightbearing radiographs. Overall, only 40% of our patients were corrected to within $\pm 2^\circ$ of the planned target angle. The tendency was to undercorrect, with either the Coventry or the Maquet technique. Contrary to our hypothesis, larger preoperative varus alignment (greater than 10°) did not make it more difficult to achieve the target angle. The Coventry technique was as accurate as the Maquet technique. **Level of Evidence:** Level IV.

Tibial osteotomy is most commonly performed to treat medial compartment arthritis with varus alignment to reestablish anatomic valgus alignment of the knee. The purpose of a valgus tibial osteotomy is to

surgically alter the alignment of the leg to dynamically unload the medial compartment. Several studies have shown that the clinical success rate of tibial osteotomy is very successful in the short-term and midterm timeframes if “adequate angular correction,” as defined by various authors over the years (Table 1),¹⁻²⁰ is achieved, but results tend to deteriorate with time. The clinical results have been much less successful if “adequate” valgus correction is not achieved. Coventry³ stated that 10-year survival was 94% if the postoperative anatomic valgus was greater than or equal to 8° but only 63% if there were only 5° of anatomic valgus. Regardless of the specific surgical technique, inherent in any surgical technique is preoperative planning to determine the size of the correction. Multiple recommendations have been made in the literature regarding the degree of correction necessary to

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Table 1. Recommended Postop Target Angles

Study	Year	Recommendation
Anatomic Axis Alignment		
Shoji ¹	1973	5°
Insall ²	1984	10°
Coventry ³	1993	8°
Akamatsu ⁴	1997	10°
Aglietti ⁵	2003	10°
Sprenger ⁶	2003	8°-16°
Koshino ⁷	2004	10°
Huang ⁸	2005	8°-10°
Flecher ⁹	2006	6°
Puddu ¹⁰	2007	10°
Akizuki ¹¹	2008	10°
Howells ¹²	2014	10°
Mechanical axis alignment		
Maquet ¹³	1976	2°-4°
Krempen ¹⁴	1982	3°
Brower ¹⁵	2006	4°
62.5% of the medial-to-lateral width of the proximal tibia alignment		
Dugdale ¹⁶	1992	
Aoki ¹⁷	2006	
Bae ¹⁸	2009	
Lee ¹⁹	2012	
Kondo ²⁰	2018	

achieve “adequate” postoperative valgus alignment (Table 1).¹⁻²⁰

Most series in the literature report only averages, means or ranges of postoperative alignment. It seems logical to assume that if a surgeon fails to achieve “adequate” correction, “inadequate” correction could adversely affect clinical results. The purpose of this study was to compare the preoperatively planned angle of correction as measured on weight-bearing radiographs to the follow-up angle as measured on weight-bearing radiographs in each individual patient 6 weeks after surgery and to analyze factors that could potentially affect achieving the planned degree of surgical correction. Our hypothesis was that it would be more difficult to achieve the preoperatively planned correction with larger body mass indexes (BMIs) and larger degrees of preoperative varus and that the Coventry “closing wedge” surgical technique would be less accurate than the Maquet “barrel vault” surgical technique.

Methods

Between 1981 and 2019, 65 knees in 64 patients were scheduled for valgus tibial osteotomies performed using either the Coventry³ and, later on, the Maquet^{13,21} surgical technique. Complete pre- and postoperative radiographs were available for 34 patients and 35 knees. The target angles were prospectively determined based on standard standing anteroposterior radiographs of both knees, with the knees fully extended, taken on 14 × 17 radiographs.¹⁸ The radiographs were taken

both preoperatively and postoperatively and without any external support. The limb alignment was measured on each radiograph by using the anatomic axis method by the senior surgeon (GKM). Full-length mechanical axis films were taken in several cases, but the size of correction was the same whether the anatomic or mechanical axis was used. This is consistent with all knee literature.^{22,23} Therefore, for purposes of the study, only the anatomic axis was used to determine prospectively the planned correction.

We arbitrarily defined anatomic varus alignment as negative angles and anatomic valgus as positive angles. We defined the preoperative angle as the anatomic axis angle measured on the preoperative radiographs. We defined the target angle as the anatomic axis angle that we prospectively planned to achieve during surgery. We defined the planned correction as the difference between the preoperative angle and the target angle. We defined the postoperative angle as the anatomic axis angle measured on the radiographs taken 6 weeks after surgery. We defined the actual correction as the difference between the preoperative angle and the postoperative angle. We defined the error in correction as the difference between the postoperative angle and the planned correction.

Based on the preoperative radiographs, the anatomy of the knee, the gender, and the preoperative angle, surgical correction was individually and prospectively planned by the senior operating surgeon (i.e., the target angle). The target angle was most commonly 5°-8° of anatomic valgus in males and 8°-10° of valgus in females. To allow for healing of the osteotomy so that the patient could be weightbearing without external support, the anatomic axis (i.e., the postoperative angle) was measured on the standing radiographs taken 6 weeks after surgery using the same radiologic technique.

Surgical Technique

The closing wedge osteotomy technique was performed as using the Coventry technique.¹ The barrel vault osteotomy technique was performed as reported by Miller¹⁷ and Maquet.²

Results

There were 35 knees (12 males [1 bilateral] and 22 females with prospectively measured alignment and complete preoperative and postoperative radiographs (Table 2). Because some patients had tibial osteotomies performed in the same time frame but did not have complete preoperative and postoperative radiographs available for review, this was not a consecutive series. There were 19 right knees and 16 left knees. The average age was 58 (range 35-68), and the average BMI was 34.7 (range 21.2-58.2). There were 13 Coventry closing wedge osteotomies and 22 Maquet barrel vault osteotomies (1 bilateral in a male). All patients were

Table 2. Baseline Study Data

ID	Preop angle	Target angle	Planned correction	Postop angle	Actual correction	Error in correction	Side	Gender	Age	Height	Wt	BMI	Type
1	-6	8	14	12	18	4	R	Male	60	64	175	30.0	C
2	-5	8	13	6	11	-2	R	Female	69				C
3	0	10	10	6	6	-4	R	Female		63	145	25.7	C
4	-2	8	10	14	16	6	L	Female	51	66	150	24.2	C
5	-3	10	13	-5	-2	-12	L	Female	60	65	325	54.1	C
6	-3	8	13	8	11	-2	L	Male	65	68	215	32.7	C
7	-5	10	15	6	11	-4	R	Female	59				C
8	-15	10	25	9	24	-1	R	Female	63	62	250	45.7	C
9	-3	2	5	0	3	-2	R	Male	60	70	205	29.4	C
10	-5	11	16	14	19	3	L	Female	61	66	175	28.2	C
11	-6	10	16	5	11	-5	R	Male	59	69	340	50.2	C
12	-3	10	13	8	11	-2	R	Female	60	65	225	37.4	C
13	-1	10	11	8	9	-3	L	Female	64				C
14	-11	4	15	6	17	2	R	Female	55	63	211	37.4	M
15	-5	10	15	6	11	-4	L	Female	58	66	270	43.6	M
16	0	10	10	0	0	-10	L	Female	48				M
17	-7	10	17	5	12	-5	R	Female	59	63	208	36.8	M
18	-3	8	11	9	12	1	R	Male	59	72	231	31.3	M
19	-10	3	13	4	14	1	R	Female	57	63	200	35.4	M
20	-7	10	17	8	15	-2	L	Female		64	155	26.6	M
21	-3	7	10	7	10	0	L	Male	61	72	170	23.1	M
22	-7	9	16	5	12	-4	L	Female	61				M
23	-22	11	33	10	32	-1	L	Male	35	62	180	32.9	M
24	-8	8	16	4	12	-4	L	Female	46	68	165	25.1	M
25	-8	4	12	5	13	1	R	Female	59	64	215	36.9	M
26	0	10	10	5	5	-5	R	Female	68				M
27	-10	7	17	7	17	0	L	Male	58	70	240	34.4	M
28	-2	10	12	5	7	-5	L	Male	39				M
29	-3	10	13	6	9	-5	L	Female	60	66	175	28.2	M
30	-5	8	13	0	5	-8	R	Male	62	69	200	29.5	M
31	-5	8	13	-5	0	-13	R	Male	57	74	165	21.2	M
32	-3	8	11	0	3	-5	R	Female	60	65	350	58.2	M
33	-2	8	10	3	5	-5	R	Male	62	70	203	29.1	M
34	0	10	10	10	10	0	R	Male	59	70	375	53.8	M
35	2	8	12	5	7	5	L	Male	62	70	203	29.1	M
Avg.	5.1	8.5	13.7	5.6	10.7	2.6			58	67	219	34.7	

fully weightbearing without external support 6 weeks after surgery.

The preoperative angle (Fig 1) in 35 knees averaged -5.1° (i.e., 5.1° of varus-range, 22° of varus-to-neutral alignment). The target angle in 35 knees averaged 8.5° (range 2° - 11° of valgus). The planned correction in 35 knees averaged 13.7° (range 5° - 25°). The postoperative angle averaged 5.6° of valgus (range 0° - 10°). There were 7 knees that were overcorrected by an average of 2.8° (range 1° - 6°), 3 knees that were corrected to exactly the target angle, and 24 knees that were undercorrected by an average of 3.4° (range -1° to -13°). In the group of 24 patients with undercorrected angles, there were 2 with no change from the preoperative angles (ID #16 and #31, both Maquet osteotomies), and 1 patient actually had an increase in the preoperative varus alignment by 2.0° (ID #5, a Coventry osteotomy). Overall, only 14 of 35 (40.0%) of the knees were corrected to within $\pm 2^\circ$ of the target angle.

In the 13 knees treated by the Coventry technique (Fig 2), the preoperative angle averaged -4.4° (i.e., 4.4° of varus, range 15° of varus to neutral alignment). The target angle in 13 knees averaged 8.8° (range 2° - 11° of valgus). The planned correction averaged 13.2° (range 5° - 25°). The postoperative angle averaged 7.0° of valgus (range 0° - 14°). There were 3 knees that were overcorrected by an average of 4.3° (range 3° - 6°), No knees were corrected to exactly the target angle, and 10 knees were undercorrected by average of 3.7° (range -1° to -12°). One patient actually had an increase in preoperative varus alignment by 2.0° (ID #5). Overall, only 5 of 13 (38.5%) knees were corrected to within $\pm 2^\circ$ of the target angle.

In the 22 knees that underwent the Maquet technique (Fig 3), the preoperative angle averaged -5.6° (i.e., 5.6° of varus range, 22° of varus-to-neutral alignment). The target angle in 22 knees averaged 8.2° (range 4° - 11° of valgus). The planned correction averaged 13.8° (range 5° - 25°). The postoperative

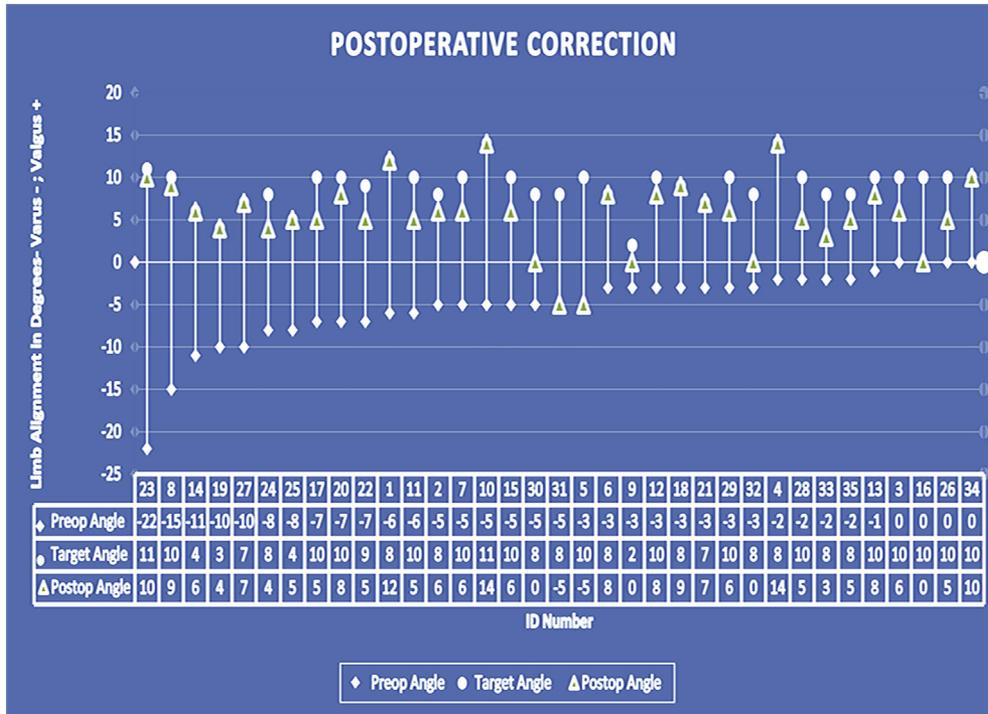


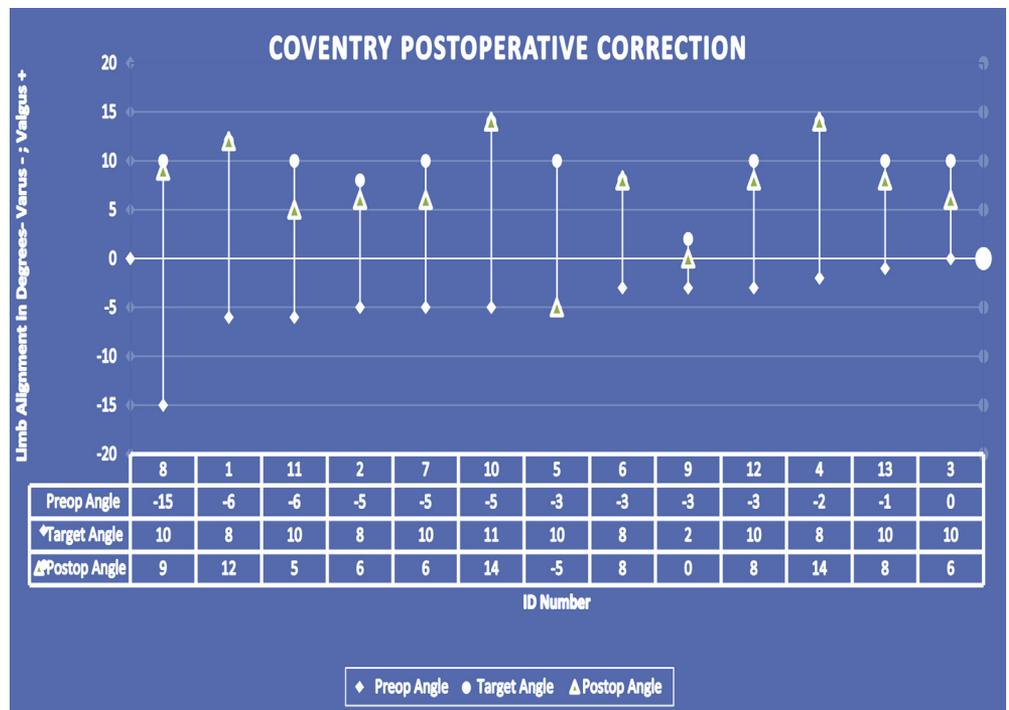
Fig 1. Postoperative correction, overall. Target angle, the prospectively planned valgus angle. Preoperative and postoperative angles. The angles measured on the preoperative and postoperative radiographs.

angle averaged 4.8° of valgus (range -5° to 14°). There were 4 knees that were overcorrected by an average of 1.25° (range 1°-2°), 3 knees that were corrected to exactly the target angle, and 15 knees that were undercorrected by an average of 4.9° (range -1° to -13°). No patient had an increase in preoperative varus alignment after surgery. Overall, only 8

of 22 (36.4%) of the knees were corrected to within ± 2° of the target angle.

In the 21 females (Fig 4), the preoperative angle averaged -5.1° (i.e., 5.1° of varus range, 15° of varus-to-neutral alignment). The target angle in 21 knees averaged 8.7° (range 4°-10° of valgus). The planned correction averaged 13.9° (range 10°-25°). The

Fig 2. Coventry postoperative correction. Tibial osteotomies performed using the Coventry technique. Target angle, the prospectively planned valgus angle. Preop and postop angles, the angles measured on the preoperative and postoperative radiographs.



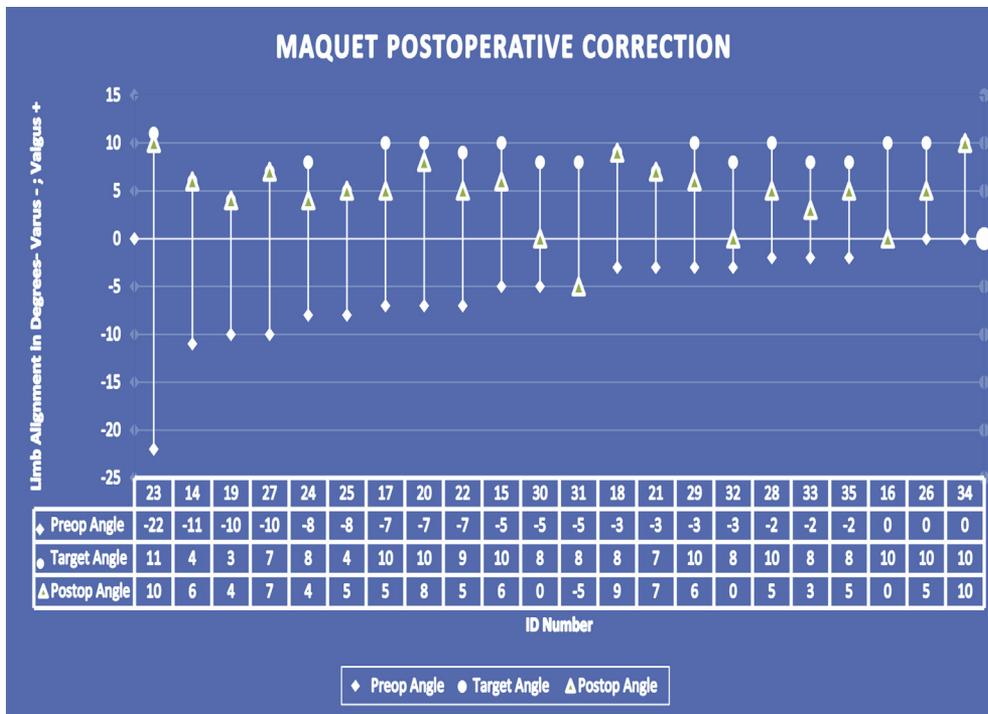


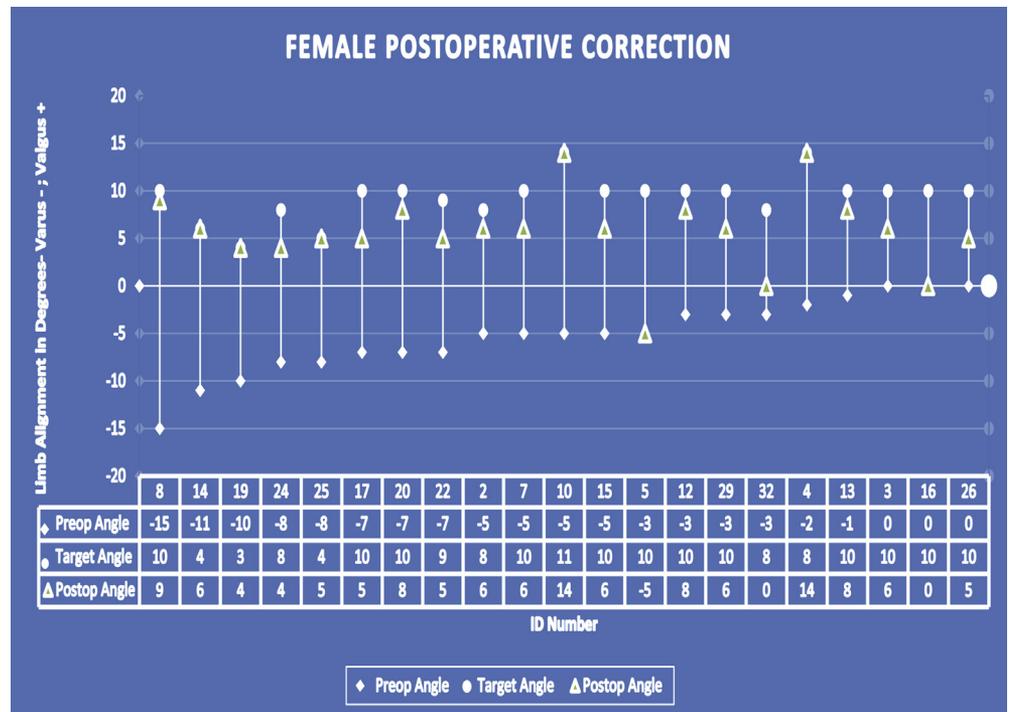
Fig 3. Maquet postoperative correction. Tibial osteotomies performed using the Maquet technique. Target angle, the prospectively planned valgus angle. Preop and postop angles, the angles measured on the preoperative and postoperative radiographs.

postoperative angle averaged 5.7° of valgus (range -5° to 14°). There were 5 knees that were overcorrected by an average of 2.6° (range 1°-6°). No knees were corrected to exactly the target angle, and 16 knees were undercorrected by an average of 1.9° (range -1° to -12°). One patient had an increase in preoperative

varus alignment after surgery by 2.0° (ID #5). Overall, 7 of 21 (33.4%) of the knees were corrected to within ± 2° of the target angle.

In the 13 male knees (Fig 5), the preoperative angle averaged -5.5° (i.e., 5° of varus range, 22° of varus-to-neutral alignment). The target angle in

Fig 4. Female postoperative correction. Tibial osteotomies performed in females. Target angle, the prospectively planned valgus angle. Preop and postop angles, the angles measured on the preoperative and postoperative radiographs.



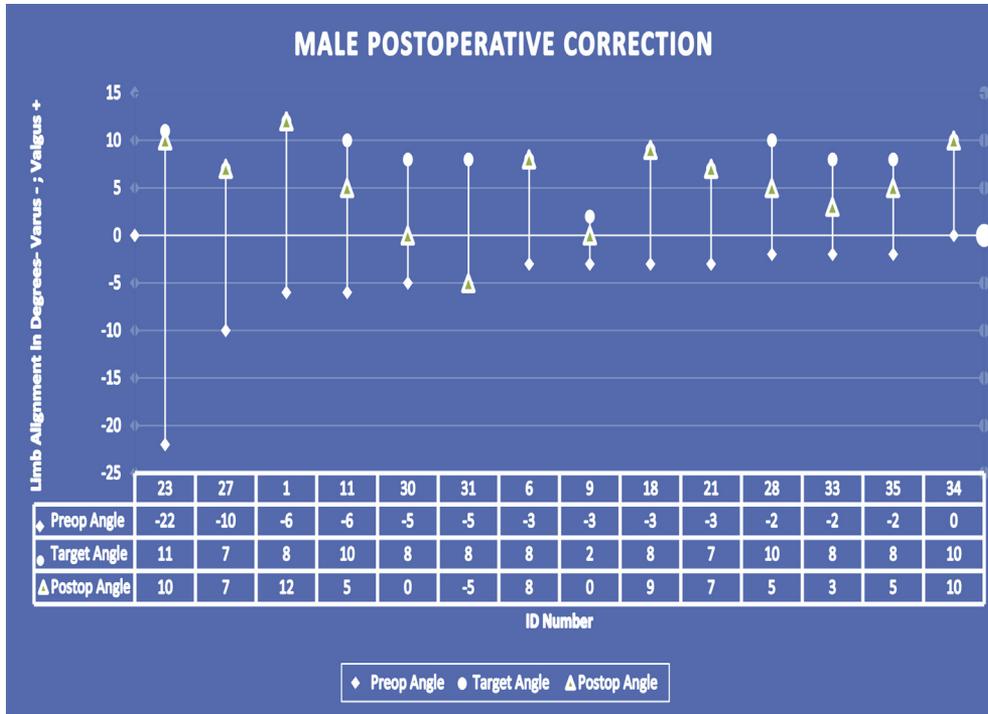


Fig 5. Male postoperative correction. Tibial osteotomies performed in males. Target angle, the prospectively planned valgus angle. Preop and postop angles, the angles measured on the preoperative and postoperative radiographs.

13 knees averaged 8.7° (range 2°-11° of valgus). The planned correction averaged 13.8° (range 5°-25°). The postoperative angle averaged 5.8° of valgus (range -5° to 13°). There were 2 knees that were overcorrected by an average of 4.5° (range 4°-5°), 3 knees that were corrected to exactly the target angle and 8 knees that were undercorrected by an average of 8.5° (range -1° to -3°). No patient had an increase in preoperative varus alignment after surgery. Overall, 6 of 13 (46.2%) of the knees were corrected to within ± 2° of the target angle.

None of the demographic, radiographic or surgical technique factors in this study achieved statistical significance. Although the individuals (ID #32 and #34)

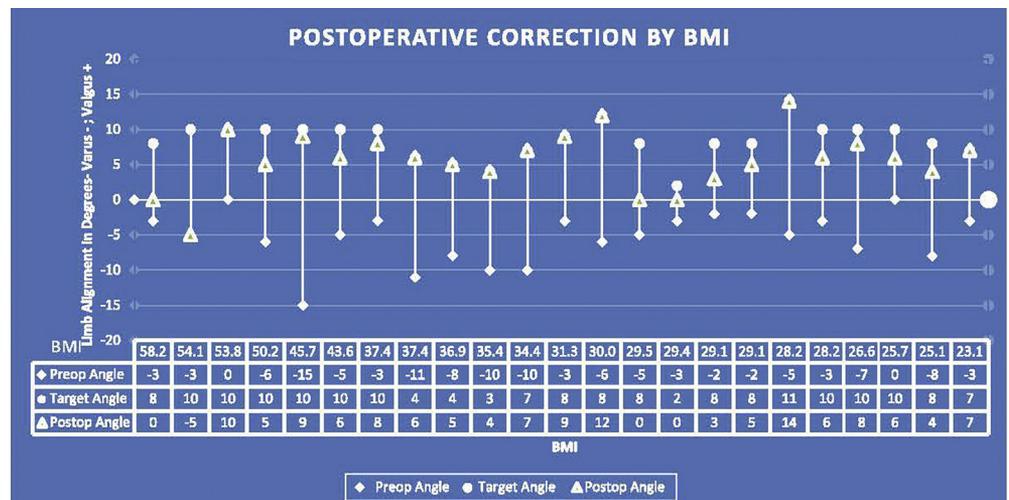
with the 2 largest BMIs were poorly corrected by Maquet osteotomies, there was no apparent effect of BMI on the rest of the individuals (Fig 6).

A reliability study was performed by comparing the angular measurements obtained by the senior surgeon compared to blinded reviewers AM and SE. The average measurement difference among the reviewers was 1.2° on the preoperative radiographs and 1.5° on the postoperative radiographs.

Discussion

Our study showed that the ability to surgically achieve a specific target angle within ± 2° in a specific

Fig 6. Postoperative correction by body mass index (BMI). Osteotomies sorted by highest to lowest BMI. Target angle, the prospectively planned valgus angle. Preop and postop angles, the angle measured on the preoperative and postoperative radiographs.



patient was successful in less than 40% of the patients. Surgical technique, BMI and gender had no apparent effect on the accuracy. Recommended target angles in the literature have generally been 2°-3° of mechanical valgus or 7°-10° of anatomic valgus (Table 1).¹⁻²⁰ Alignment based on 62.5% of the width of the proximal tibia has been shown to be equivalent to 3° of mechanical valgus alignment.¹⁶ The original method of determining the target angle was the "1 mm per 1° of correction" advocated by Coventry,³ which ignored simple geometry regarding the width of the tibia. Dugdale¹⁶ also documented that the length of the tibia and femur as well as an increase in the lateral joint line (i.e., the stretch of the lateral side structures) also could affect the weightbearing axis and, therefore, could affect bony angular measurements. Brower¹⁹ found that neither isolated knee flexion or leg rotation without knee flexion changed the alignment axis, but simultaneous flexion and rotation had a large effect on the alignment.

Several surgical techniques based primarily on preoperative radiographs have been advocated. Historically, the closing wedge osteotomy popularized by Coventry³ (and, more recently, the opening wedge and combination opening/closing wedge) has been advocated. Because weightbearing radiographs are obviously not possible in the operating room, several methods have been used to determine the intraoperative correction. Goniometers, metal rods, the Bovie cord method, radiograph-based templates, and correction in the postoperative period with external fixation devices have all been used. However, any method dependent on external landmarks may encounter intraoperative difficulties, especially in the obese and in individuals with deformities.

Various aspects of knee alignment and tibial osteotomies have been studied. Specogna²⁴ stated that plain radiographs and digital radiographs were equally accurate in determining alignment. Odenberg²⁵ stated that there was excellent reliability in the interobserver determination of alignment on plain radiographs (a maximum of 2°). However, he studied only 8 radiographs. Several authors have reported that the reproducibility of standing radiographs is poor.²⁵⁻²⁷ Schmidt²⁶ stated that the accuracy of measurement by 2 reviewers in 30 asymptomatic individuals with a goniometer was 1° ± 0.5°, and full-length weightbearing radiographs were no more accurate than standard 14" × 17" anteroposterior film. Our own reliability study confirmed equivalence accuracy.

Ilahi²⁷ found an average disagreement of 3.7° (and a maximum of 6°) among 4 reviewers measuring the alignment on 36 radiographs. Ogata²⁸ recommended supine radiographs, as opposed to weightbearing radiographs, and stated that weightbearing radiographs did not correlate well with the postoperative correction.

Sabharwal²⁹ stated that there was an average of 18° of difference between preoperative weightbearing films and operative fluoroscopy when he used the Bovie cord method, and he did not recommend this method in the obese. Bae¹⁸ stated that the computer navigation was more accurate than conventional instrumentation in achieving the mechanical axis, but there was only a 1.5° difference between the 2 methods, which may not have been clinically significant. In his follow-up study in 2016, Bae³⁰ stated that there was no difference in clinical results between computer navigation and conventional instrumentation.

Our ability to achieve the target angle accurately on the basis of standing radiographs was unpredictable (i.e., less than half of the patients in our series (40.0%, 14/35) were corrected to within ±2° of the target angle). None of the factors studied in our series consistently correlated with the ability to achieve the planned target angle. Two patients (ID #30 and ID #34) had only 50% corrections on the standing films, but valgus stress radiographs showed 90% of the target angle, which would seem to indicate that the planned angular bony correction was largely achieved at surgery, but either we did not plan sufficient correction or the correction actually achieved was not sufficient to statically unload the medial compartment and reestablish standing static valgus alignment on radiographs. It is our opinion that the inability to achieve consistently the planned correction according to weightbearing radiographs is probably multifactorial.

The amount of correction necessary to unload the medial compartment dynamically is not known. Sundaram³¹ stated that there was no correlation between the correction of the deformity to physiologic valgus and the clinical results. Prodromas³² stated that patients with tibial osteotomy and low adduction moments preoperatively did much better after tibial osteotomy than patients with high adduction moments, and he stated that static alignment did not directly correlate with dynamic joint alignment. Shaw³³ also offered a somewhat similar theory, opining that because the mechanical axis of the entire body in a single leg stance while walking is actually somewhat medial to the knee itself; correction according to the mechanical or anatomic axis of the limb may not be equivalent to the true weight-bearing line of the body's center of gravity and may not be sufficient to shift the weightbearing dynamically from the degenerated medial to the lateral compartment. Ramsey³⁴ noted that the muscle and gait compensation typical of patients with osteoarthritis were only partially corrected, even after apparently clinically successful opening wedge tibial osteotomy. We also cannot comment on the maintenance of correction over time. Although none of the patients in this series had opening wedge osteotomies, Lee³⁵ stated

that gradual loss of correction can occur with opening wedge osteotomies for up to 1 year, which could contribute to clinical failure even though the initial correction was "adequate."

Future studies with computer navigation may achieve more accurate bony correction, but much larger series with longer term follow-up will be required to substantiate clinical utility. Static weightbearing radiographs may not correlate with the dynamic forces involved in walking. Therefore, achieving any specific static alignment may not be a critical issue in valgus tibial osteotomies. Perhaps, single-leg weight-bearing radiographs or gait analysis would more accurately depict the weightbearing forces of walking.

Limitations

The surgical planning was prospective, but this was not a consecutive series because we did not have complete postoperative standing radiographs for every osteotomy done during the study's timeframe. Obviously, this is a single-surgeon series, which risks bias, but the radiographs were measured by staff not involved in the surgery. We cannot confirm or deny the literature's target-angle recommendations because this study was limited to a radiologic analysis. We also cannot extrapolate these results to other valgus high tibial osteotomy techniques (i.e., opening wedge) but because this was a radiographic evaluation, we would anticipate similar results with similar radiographic evaluations of other surgical techniques.

Conclusions

Valgus tibial osteotomy planning based on preoperative weight-bearing radiographs is unpredictable in its ability to achieve the target angle for postoperative weight-bearing radiographs. Overall, only 40% of our patients were corrected to within $\pm 2^\circ$ of the planned target angle. The tendency was to undercorrect using either the Coventry or the Maquet technique. Contrary to our hypothesis, larger preoperative varus alignment (greater than 10° varus alignment) did not make it more difficult to achieve the target angle. The Coventry technique was as accurate as the Maquet technique.

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