Gait Analysis of Stapling for Genu Valgum

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Summary: Many authors have advocated stapling or epiphysiodesis of the distal medial femur as a means of correcting genu valgum. However, in the literature, aside from clinical improvement (appearance, pain, function), objective evidence of kinetic and kinematic improvement is lacking. Therefore, the authors undertook a prospective gait analysis evaluation of a series of patients treated for genu valgum, comparing pre- and postsurgical measurements to document the benefits of normalizing the mechanical axis. These results indicate that after surgery knee and hip angles and knee moments were returned to within the normal range for a similarly aged control group.

Key Words: genu valgum, stapling, gait analysis, knee kinetics and kinematics

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Adolescent genu valgum is a common reason for orthopaedic referral. Significant valgus is accompanied by complaints of awkward gait, difficulty running, anterior knee pain, and occasionally patellofemoral instability. On full-length radiographs, lateral displacement of the mechanical axis can be determined and correlated with clinical symptoms. It is intuitive that there is a direct relationship between the degree of deformity and the severity of symptoms due to eccentric loading of the lateral compartment of the knee, but this has not been documented in the literature. Many authors have advocated stapling or epiphysiodesis of the distal medial femur as a means of correcting genu valgum.[2–5,7,9,11–13,15,16] Our study was designed to demonstrate this correlation and strengthen the rationale for prophylactic correction of progressive or persistent genu valgum.

METHODS

Institutional review board approval was obtained from the University of Utah for this prospective study of consecutive patients with genu valgum. Participating subjects were asked to complete a short questionnaire, which included a question that asked if any other family members had notable genu valgum. Sixteen subjects completed the preliminary and follow-up data analysis. Patient anthropometric and family history data for these subjects are detailed in Table 1. One patient had bilateral valgus deformity due to malnutrition and one had an iatrogenic unilateral deformity; the remainder had idiopathic bilateral deformities. Accompanying diagnoses included one patient with bilateral clubfeet, which were well corrected, and two with unilateral Legg-Perthes who had previously undergone corrective osteotomies. There were eight boys and eight girls with a mean age of 12 years 8 months at the time of treatment, which consisted of stapling of the medial distal femoral physis. The staples were removed once the deformity was corrected; the elapsed time until staple removal depended on the rate and amount of growth needed to restore the mechanical axis to neutral. Staple insertion (and removal) was performed in the standard fashion, on an outpatient basis and without postoperative immobilization.

Each patient had full-length anteroposterior weightbearing radiographs to document limb lengths and the mechanical axis; these were performed preoperatively and at the time of staple removal. Radiographic analysis included limb length measurement and determination of the mechanical axis, which involved drawing a line from the center of the femoral head to the center of the ankle and noting its displacement from the center of the knee. Each subject also underwent gait assessment to determine lower body kinematics and kinetics before and after treatment using a video-based system for kinematics (Vicon Motion Systems, Lake Forest, CA) combined with four force plates for kinetics (AMTI, Watertown, MA). Five trials of left and right kinematics and kinetics were collected and averaged for each subject. Fifteen subjects had preoperative gait analysis at an average of 17 days before surgery; the remaining subject was seen 31 days after staples had been inserted. Following correction of genu valgum, 10 patients were seen just before staple removal (average 25 days) and the remaining 6 were seen after the staples had been removed and they were walking comfortably (average 20 weeks). The focus of data analysis was on frontal plane parameters, including knee valgus and hip abduction angles and moments. Internal joint moments are presented; thus, in the frontal plane, knee valgus causes a laterally shifted ground reaction force relative

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TABLE 1. Anthropometric Data

			Height		Mass		BMI			
Subject	Gender	Age*	cm	%	kg	%	kg/m^2	%	Family History	Predictive Factor
1	F	13 + 0	144	3	28	−6	13.5	−5	N	↓ Stature
2	F	12 + 10	168	95	68	96	24.1	90	N	Obese
3	F	12 + 4	151	36	42	44	18.4	51	Y	FH
4	F	7 + 5	119	18	21	19	14.8	28	Unknown	Malnutrition
5	F	12 + 5	151	33	43	46	18.7	54	Y	FH
6	F	13 + 6	152	15	74	97	32.0	100	Y	Obese, FH
7	F	12 + 4	157	70	50	76	20.3	74	Y	FH
8	F	9 + 7	149	97	40	86	18.0	70	N	↑ Stature
9	M	13 + 11	162	43	70	93	26.7	96	Y	Obese, FH
10	M	14 + 1	165	51	42	13	15.4	1	N	↓ Stature
11	M	13 + 2	180	105	68	95	21.0	78	N	↑ Stature
12	M	15 + 0	172	57	61	63	20.5	71	N	
13	M	12 + 0	153	68	40	47	17.1	37	Y	FH
14	M	13 + 4	172	95	71	97	24.0	92	Y	FH, Iatrogenic, obese
15	M	14 + 3	169	75	82	99	28.7	100	N	Obese
16	M	15 + 3	173	55	91	100	30.4	100	N	Obese

BMI, body mass index; FH, family history.
Height, weight, and BMI are based on current CDC growth charts.
*Years + months.

to the knee joint center, which results in an increased varus internal moment necessary to support the load. The distance between the knee joint center and the mechanical axis (line from hip joint center to ankle joint center) was also determined using the marker data. Mean values over single limb stance as well as selected maxima and minima were statistically evaluated. Pre- and postoperative data were compared using paired *t* tests, and pre- and postoperative data were separately compared with a group of 11 age-matched control subjects using *t* tests. Left and right limbs were treated individually, giving 31 samples of pre- and postoperative data and 22 samples of control data.

RESULTS

Although the majority of cases were characterized as idiopathic, anthropomorphic data suggested a strong correlation with both height and weight for many of the subjects. Five subjects were characterized as obese, two had increased stature, and two had decreased stature. In addition, one subject had previously suffered from malnutrition, and one had a unilateral iatrogenic deformity, though he was additionally predisposed by being overweight. Of the remaining five subjects, four reported that they had at least one immediate family member with notable genu valgum. The one patient with normal anthropometrics and no family history had bilateral clubfeet.

Following stapling, genu valgum was corrected and circumduction gait resolved in all patients; the mean time to correction was 10 months (range 6–16 months). There were no perioperative complications. There were no staple failures, and there have been no rebound phenomena or overcorrection. Gait analysis data are represented in Figures 1 to 4 by box-whisker plots of preoperative, postoperative, and control group data examined during the single limb support phase of

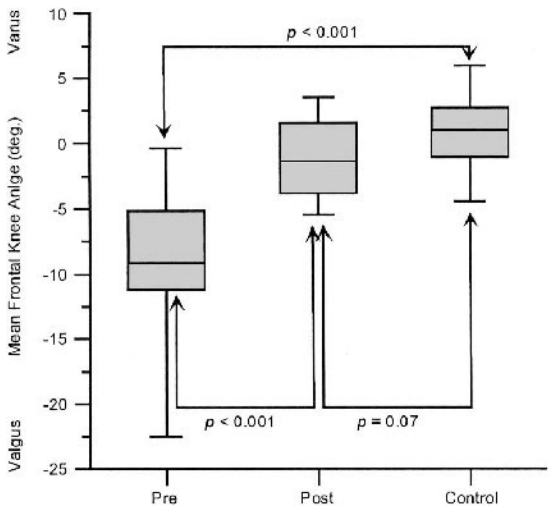

FIGURE 1. Comparisons of mean single limb stance frontal plane knee angles. The presurgical group had significantly more valgus than the control group; after stapling, there was no difference.

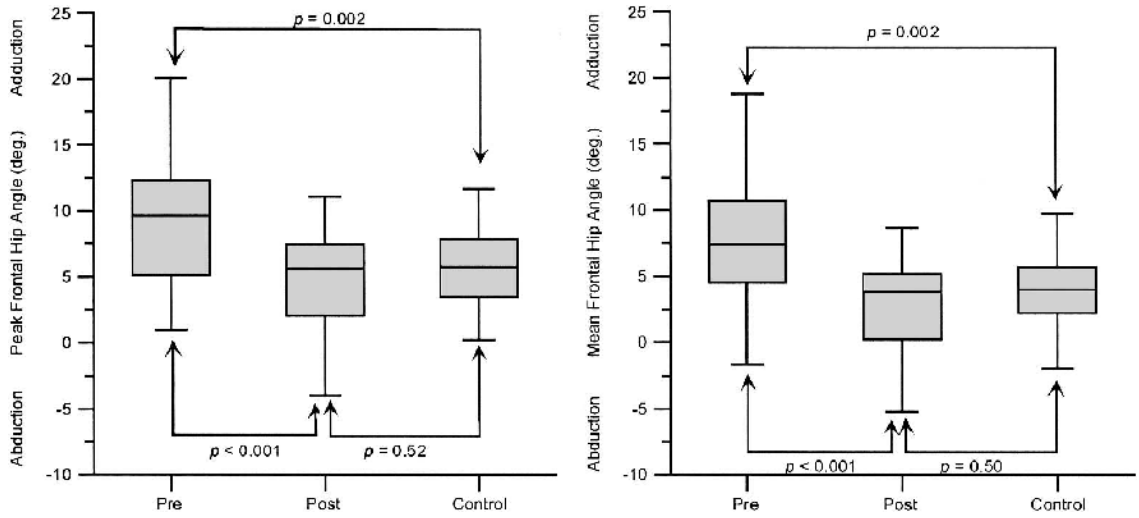

FIGURE 2. Comparisons of peak and mean single limb stance frontal hip angles. The presurgical group had significantly more adduction than the control group; after stapling, there was no difference.

gait. Preoperative gait analysis data revealed increased knee valgus (see Fig. 1) and increased hip adduction angle (see Fig. 2), combined with increased knee varus moment (see Fig. 3) and a medially shifted knee joint center (see Fig. 4). Comparison of preoperative data to postoperative data demonstrated that hemiphyseal stapling significantly changed these parameters, with changes resulting in values closer to the control population. In all of the parameters evaluated, with the exception of frontal knee moment, there were no statistically significant kinematic differences between the postoperative group and the age-matched controls. Sagittal plane parameters were grossly normal in all subjects. Some subjects did exhibit abnormal foot progression angles, with a mixture of both inward and outward deviations present, such that the group average was within the normal range. Postoperative measurements compared well with age-matched controls, indicating restoration of normal kinematics. Comparing postoperative measure to controls, we found significant differences only in mean and peak knee valgus moments, with a trend toward slight varus overcorrection (as desired). Analysis of pre- and postcorrection full-length weight-bearing radiographs showed similar improvement as the mechanical axis moved from lateral zone II or III to the middle of the knee (medial or lateral zone I) (Fig. 5).

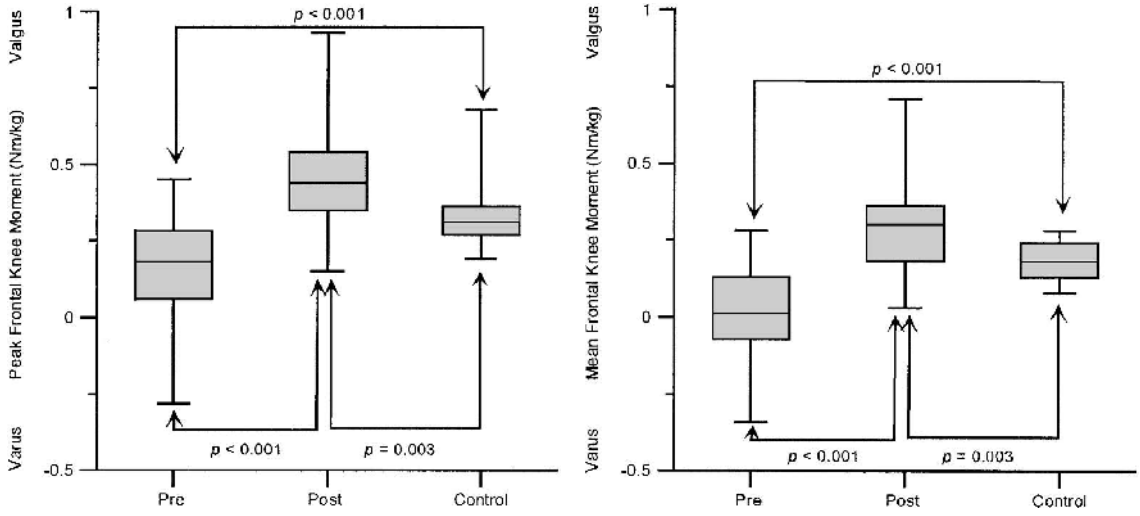

FIGURE 3. Comparisons of peak and mean single limb stance frontal knee moments. The presurgical group had significantly less valgus moment than the control group; the poststapling group had significantly more valgus moment than the control group.

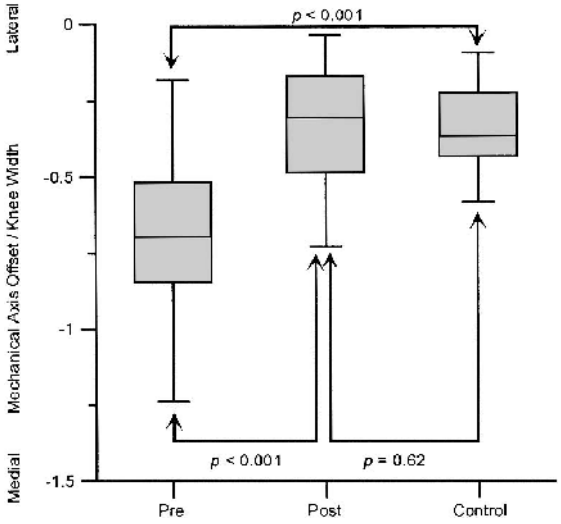

FIGURE 4. Comparisons of mean single limb stance knee joint center offset, representing the perpendicular distance from the mechanical axis (defined as the line between the hip joint center and ankle joint center) to the knee joint center. The presurgical group had significantly more medially displaced knee joint centers than the control group; after stapling, there was no difference.

DISCUSSION

It is widely recognized that juvenile genu valgum (age 2–6 years) is most often physiologic and will resolve spontaneously by age 6.[10,14] Therefore, parental education and expectant observation are the standard of care. However, by adolescence, straight legs and a neutral mechanical axis should be present. Persistent genu valgum has more than just cosmetic implications. With lateralization of the mechanical axis, patellofemoral tracking problems and eccentric loading of the lateral compartment may become relevant to the natural history. In the presence of genu valgum, patellofemoral realignment is illogical and, by itself, prone to failure. Varus-producing osteotomy may be considered, but this is a major undertaking and should be a last resort.[8,17] If recognized and treated in a timely fashion, complete resolution of the malalignment may be accomplished by hemiepiphysiodesis of the distal medial femur using staples. The actual amount of asymmetric growth needed to correct malalignment may be as little as 1 cm; this amount of correction can generally be anticipated within 6 to 16 months, depending on the rate of growth following surgery. We recommend hemiphyseal stapling to normalize the mechanical axis because it is logical, simple, and reproducible. It is well tolerated by this patient population, and the recovery is quite rapid. The advantage of stapling over percutaneous or open epiphysiodesis relates to issues of timing. By consensus, estimation of skeletal maturity is approximate at best.[1,6,11] Therefore, permanent epiphysiodesis poses the risk of over- or undercorrection and is limited to adolescent patients. Stapling, which is reversible, permits neutralization of the mechanical axis at any

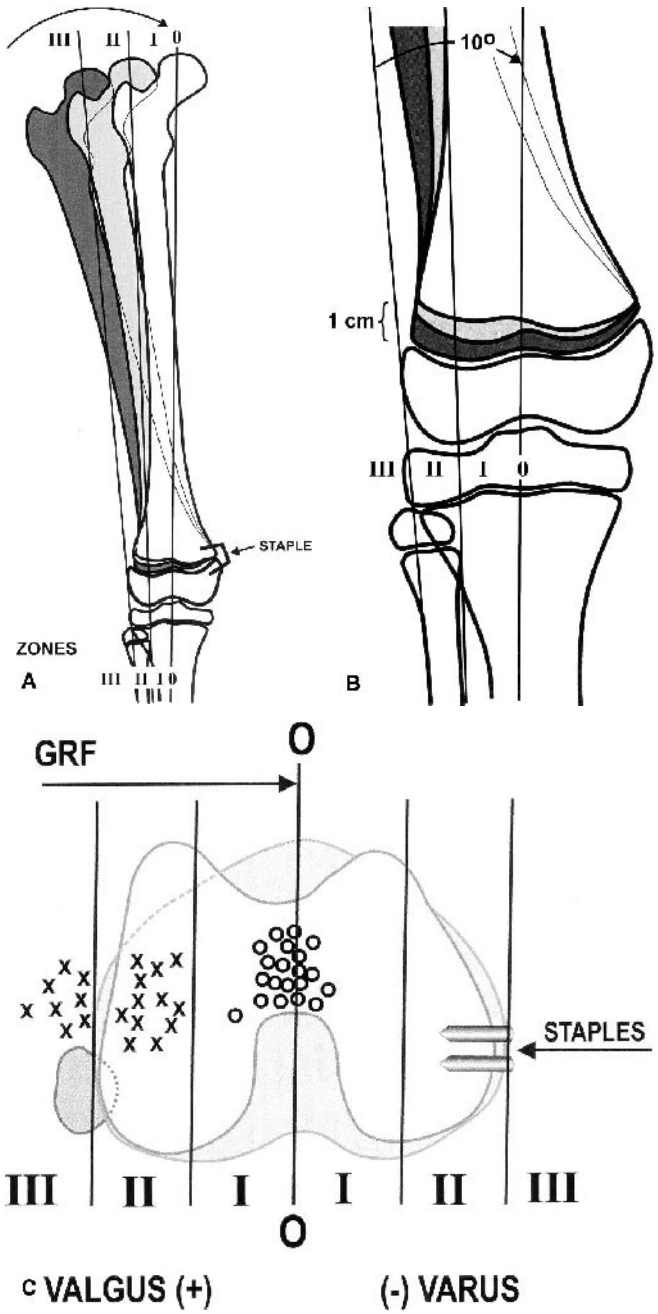

FIGURE 5. (**A**) For correction of femoral valgus, staples are placed medially around the distal physis with subsequent lateral growth. The femoral head is centered over the knee and the axis shifts to bisect the knee; circumduction gait and anterior/medial knee pain resolve accordingly. (**B**) One centimeter of lateral growth following stapling may be sufficient to normalize the axis, changing the anatomic (femoral-tibial) valgus by 10°. This takes approximately 1 year. (**C**) Preoperatively (x) the ground reaction force (GRF) was in lateral zone II or III due to genu valgum. Postoperatively (o), following stapling, the GRF shifted to neutral (medial or lateral zone I), at which point the staples were removed.

age without "burning any bridges" and may be repeated if the deformity recurs.[4,12,15,16]

This study has demonstrated that several potentially adverse kinematic and kinetic consequences of genu valgum are present during gait. Not only were knee valgus angles significantly greater in this population compared with age-matched controls, but hip adduction and frontal moments about the knee were also significantly different. The statistically significant differences present in frontal knee moment when comparing the postoperative group to age-matched normal subjects may occur because this group of patients presents more like adults in physique than their age-matched counterparts. The average weight of the patient group at their initial analysis was 56 ± 20 kg, while the age-matched group averaged just 36 ± 10 kg. When the postoperative hip and knee data are compared to published adult data, there appears to be little difference, although statistical comparison is not possible. Also concerning this parameter, it may seem counterintuitive that moments are increased by correction of the deformity. This likely reflects some of the inaccuracy of the gait model that determines the moments about the knee center. A more accurate assessment would compute frontal moments about the medial condyle, where the mechanical axis passes in normally aligned individuals. This would have the effect of shifting the data in Figure 3 such that the control values would be approximately zero, the postoperative values would be slightly valgus, and the preoperative values would reflect a varus moment.

Given the correlation of body habitus with slipped capital femoral epiphysis and Blount's disease, it is a matter of speculation that rapid growth in height or weight may pose an excessive load on a physis; in the series we noted growth disturbance of the lateral femoral condyle and its physis. A strong correlation was found in this patient cohort to link genu valgum with abnormal growth in the form of rapid skeletal growth, decreased skeletal growth, or increased weight or body mass index. Eleven of the 16 subjects fell below the 5th or above the 95th percentile according to the Centers for Disease Control and Prevention growth charts in weight, stature, or body mass index (10 at the time of the study; 1, who had suffered from malnutrition, previously). Of the remaining six subjects, five reported an immediate family member with genu valgum. Overall, seven of the patients reported a possible hereditary link, suggesting that family diet or genetic growth traits may play a role.

While sagittal plane kinematics and kinetics were not significantly affected by hemiphyseal stapling, one subject did present with a worsened unilateral recurvatum pattern. This occurred in one of the two patients who had a history of unilateral, late-onset Perthes and had undergone two prior varus rotational osteotomies at the hip. Recurvatum of the Perthes limb was noted at her initial study and was somewhat worsened after her genu valgum was corrected. We attribute this recurvatum to a persistent leg length discrepancy, although this discrepancy did not change over the period of the study, and it is unclear why it may have worsened. It is possible that the increased recurvatum was a result of a slight difference in marker placement between studies.

CONCLUSIONS

The kinematics of gait is adversely affected by persistent genu valgum. Our data document differences when compared with a control population not only at the knee, but at the hip as well. The mechanical overload caused by malalignment may prove deleterious to the growing epiphyses and the ligamentous structures and eventually to the articular cartilage of the joints themselves. These problems are insidious but cumulative, resulting in a self-sustaining vicious cycle. The benefits of normalizing the mechanical axis and redirecting the ground reaction forces should be appreciated and were corroborated by our study. Perhaps this should be taken into account when considering the timing of surgery. Rather than arbitrarily waiting until near skeletal maturity before intervention, judicious stapling in early adolescence should be offered to symptomatic patients. In addition to the obvious cosmetic and functional improvement afforded by this treatment, we believe that the improved hip and knee mechanics that we observed will serve to protect the major weight-bearing joints indefinitely.

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