Malunion in the lower limb

A NOMOGRAM TO PREDICT THE EFFECTS OF OSTEOTOMY

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Nomograms derived from mathematical analysis indicate that the level of malunion is the most important determinant of changes in the moment arm of the knee, the plane of the ankle and alterations in limb length. Testing in five patients undergoing reconstruction showed a mean error of postoperative limb length of 2.2 mm (SD 0.8 mm), knee moment arm of 4.7 mm (SD 3.3 mm) and ankle angle of 2.6° (SD 2.3°). These nomograms provide the information required when assessing whether a particular degree of angulation may be accepted.

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Malunion in the lower limb impairs function by altering the effective limb length and disturbing joint mechanics. Abnormal joint loading induced by the deformity may result in early osteoarthritis. This has been demonstrated in animal models¹ and in retrospective clinical studies.² Both the angle and the level of the malunion are important. In cadaver studies, Tarr et al³ found that distal tibial deformity had significantly more effect on the tibiotalar contact area than proximal deformity. In the knee, similar studies by McKellop, Llinás and Sarmiento⁴ found that varus and valgus angulation of 20° in proximal tibial fractures doubled contact pressures, whereas those in the distal third increased the pressure by only 25%.

Puno et al⁵ developed a mathematical model which predicted knee and ankle malalignment for a given tibial angular malunion and presented this in tabular form. Paley et al⁶ described a comprehensive technique for analysing malalignment and planning corrective surgery. These analyses have shown a relationship between the level of the

fracture and the effects of angulation on the direction of the axis of the ankle,^{5,7,8} but there appears to be no consensus on how much angulation is clinically acceptable. Russell⁹ states that malalignment of more than 15° may require corrective osteotomy, whereas Apley and Solomon¹⁰ consider angulation of more than 7° or any rotation to be unacceptable. Van der Schoot et al² suggest simply that angular deformity should be minimised.

The increasing use of one-stage lengthening over nailing in reconstruction of the lower limb¹¹ requires a reliable predictor of the result of the correction of length. We have constructed a nomogram which determines the effects of the level of a fracture and angulation at the fracture site, on leg length, ankle angle and knee moment arm. We tested the model in patients undergoing reconstruction of the lower limb.

Patients and Methods

Mathematical analysis. We used a Cartesian co-ordinate system to represent the lower limb. The nomograms were derived from this analysis.¹²

Patients. We studied five patients undergoing correction of malalignment (Table I). All had full-length anteroposterior radiographs to assess the mechanical axis and the degree of deformity in the coronal plane, and lateral radiographs to assess deformity in the sagittal plane. CT scanograms allowed for more accurate assessment of the length of the unaffected limb. Nomograms generated using the calculations above were used in preoperative planning to determine the predicted changes in length, knee moment and ankle axis. After correction the actual changes achieved were measured, taking into account errors due to magnification on the plain radiographs, the additional changes in length after osteotomy and any callotasis following correction of angulation. The accuracy of the system was assessed by comparing the predicted and actual changes for all three measurements in both planes.

Figure 1 shows the steps involved in preoperative planning and postoperative measurement. A radiograph of the whole limb allows the length to be measured and the level of the deformity calculated as a percentage of the distance from the centre of the femoral head to the ankle mortice. The deformity in both planes is measured on the radio-

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Fig. 2

Nomograms of the effects of fracture level and angulation in the frontal plane on knee moment (left), ankle angle (centre) and leg length (right). The lines from the centre out represent 5° steps of the deformity in either the valgus or varus plane (vertical axis - percentage of limb length as 10% steps horizontal axis determines effect of deformity).

Fig. 3

Nomograms of the effects of fracture level and angulation in the sagittal plane on knee moment arm (left), ankle angle (centre) and leg length (right). The lines from the centre out represent 5° steps of the deformity (vertical axis - percentage of limb length as 10% steps; horizontal axis determines effect of deformity).

The relationship between shortening of the mechanical axis and the level of the fracture was non-linear in both planes. In the coronal plane varus deformity changed limb length more than valgus deformity for all fractures in the femur, with varus malunion close to the greater trochanter having the greatest effect. A varus deformity always led to

shortening, whereas some valgus deformities in the proximal femur actually increased length. A neutral point was identified in the femur where no change in length occurred.

In the tibia, varus and valgus deformities had identical effects on limb length. Deformities close to the knee led to the greatest changes in knee moment arm and deformities

Table II. Comparison of predicted and actual changes for the five patients having correction of malalignment

Case	Length change (mm)		Knee moment arm in coronal plane (mm)		Ankle angle in coronal plane (°)	
	Predicted	Actual	Predicted	Actual	Predicted	Actual
1	1	2	14	18	6	9
2	10	13	22.5	20	3	3
3	10	13	40	31	25	31
4	9	11	63	56	12	9
5	26	24	35	34	7	6
Mean error		2.2		4.7		2.6
SD		0.84		3.3		2.3

close to the ankle led to the greatest changes in ankle angle.

In the sagittal plane shortening was greatest for deformity near the knee. Deformities in this plane can be accommodated to some degree by the hip, knee and ankle within their normal range of movement.

The predicted and measured changes in five clinical cases are given in Table II. Mean errors of 2.2 mm (SD 0.84) for length change, 4.7 mm (SD 3.3), for knee moment arm and 2.6 mm (SD 2.3) for ankle angle were observed between predicted and actual measurements.

Discussion

We have produced comprehensive nomograms for the rapid assessment of the relative effects of angle and level on the function of the lower limb as measured by length, ankle angle and knee moment. Of particular note is the evident importance of the level of a malunion within the lower limb (Figs 1 and 2).

Normal function requires equal leg lengths with normal ankle angles and knee moments. Malunion can affect all three in a complex manner. A malunion nomogram allows rapid analysis of the complex effect of level on length. Ankle angle is linearly related to the level and degree of malunion, being greatest as malunion approaches the ankle. The knee moment is most affected by fractures nearest the knee.

A standard model of the lower limb was used with fixed proportions for the femoral neck, femoral shaft and tibia. By expressing shortening and knee moment arm as percentages of true leg length, differences between patients were taken into account. In reality, there are differences in the proportions of these limb segments and the angles between them which are not accounted for simply by scaling the model in this way. Errors in the addition method are an order of magnitude less than the errors in the measurement of the radiograph. Accepting these errors, the predictions from the nomograms are sufficiently accurate for preoperative planning, as seen in the five patients used to test the predictions (Tables I and II). Full preoperative planning requires the effects of translations and many other factors to be taken into account, as Paley et al⁶ show in their comprehensive approach to reconstruction of the lower limb.

McKellop et al⁴ showed that maximum contact pressures in the knee were doubled when there was 20° of angulation in the proximal tibia but increased only by 25% for similar angulation in the distal tibia. The knee moment arm calculated here agrees qualitatively with these observations, although in vivo the relationships between knee moment and peak contact pressure are not likely to be simple. Our results correlate with the ankle angles as a function of fracture angulation and fracture height in the tibia found by Puno et al.⁵ Here fractures throughout the lower limb have been considered and presented in a useful form. Nomograms allow the combination of the effects of deformity in both the sagittal and coronal planes to be taken into consideration.

There are complex interactions when considering reconstructive surgery. For instance, the patient in Figure 3 suffered this malunion at an early age when there was sufficient time for growth and remodelling to correct the plane of the knee. Reconstruction so far has restored length and alignment, but a further procedure is required to correct the plane of the knee. We have also noted effects on arrest of the growth plate in younger patients such that a simple correction of pure angular deformity may fail fully to restore length. The nomogram allows this discrepancy to be predicted and indicates when further lengthening is required.

Lack of consensus on acceptable deformity^{2,9,10} can be explained by our findings, where the importance of level has been identified. No angle, singly, can be used to define an acceptable degree of malunion. Combining effects of level and angle should allow a better correlation of malunion with subsequent osteoarthritis.

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