OSTEOTOMY FOR DEFORMITY OF THE RADIUS

COMPUTER-ASSISTED THREE-DIMENSIONAL MODELLING

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A computer-assisted method of preoperative planning was used to create virtual models of the deformed distal end of the radius after malunion of a fracture. By comparison with a similar model of the uninjured wrist, values were calculated for the angles and lengths to be corrected by osteotomy. Shifts of the distal fragment were analysed for 33 deformed wrists, 27 of which underwent corrective osteotomy and bone grafting. In more than half the cases there was dorsal or volar shift of 3 mm or more.

The accuracy of the correction was measured by comparing the three-dimensional models before and after osteotomy with the model of the normal wrist. The volar and ulnar inclination angles of the articular surface of the radius and the radial length were regularly restored to normal.

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Colles' and Smith's fractures of the distal radius often heal in malposition and sometimes require corrective osteotomy, especially in young people (Fernandez 1982).

Many authors have reported a clear correlation between the accuracy of reconstruction of the anatomy of the wrist and its eventual function (Cooney, Dobyns and Linscheid 1980; Fernandez 1982; Forgon and Mammel 1983; Ekenstam et al 1985; Villar et al 1987; Jenkins and Mintowt-Czyz 1988; McQueen and Caspers 1988; Solgaard 1988). This is particularly true of the relationships at the distal radio-ulnar joint (Forstner 1987).

After fracture, several anatomical deformities may be present: the normal volar tilt of the distal articular surface of the radius may be lost, or reversed (Fig. 1a); the normal ulnar tilt of the articular surface may be lost

or reversed (Fig. 1b); the radius may be shortened relative to the ulna (Fig. 1b); and the distal fragment may be displaced relative to the long axis of the radius (dorsal/volar shift or radial/ulnar shift; Fig. 1c).

A corrective osteotomy should correct all components of the malunion, not only the angular deformities and the shortening but also the distal fragment shifts (Fig. 2).

Two-dimensional preoperative planning of corrective osteotomies of the distal radius can lead to errors and failure to achieve anatomical reconstruction (Bilić and Zdravković 1988a). BIZCAD (Bilić and Zdravković 1988b) is a computer-aided preoperative planning method which provides three-dimensional 'wire' models (Fig. 3). From these the dimensions of the required bone graft and the amount and direction of angulation and translation at the osteotomy can be deduced. We present the results of 27 corrective osteotomies of the radius planned by this method.

PATIENTS AND METHODS

The phenomenon of shift was analysed preoperatively using the BIZCAD method in 33 patients who had malunited extra-articular fractures of the distal radius. The principles of this technique of computer-assisted planning for corrective osteotomies have already been published (Bilić and Zdravković 1988b; Zdravković and Bilić 1990) but to aid in the understanding of this paper, the method will be briefly described.

For the generation of a 'wire' computer model, two orthogonal radiographs of the wrist are obtained. The axis of the radius is defined, several bony landmarks are identified and their co-ordinates are measured using a grid on a transparent sheet or a digitising tablet. The most important anatomical landmarks are the volar and dorsal edges of the ulnar notch and the tip of the radial styloid process (points 1, 3 and 5 in Figure 3). The co-ordinates of each point are entered into the computer and stored in the data file.

Computer simulation is then made of the corrective osteotomy on the model of the deformed bone. The model of the normal radius is used as a reference. The two models are optionally visible from the three standard projections. Simulation can be done interactively or automatically. Automatic simulation gives the plan that

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Fig. 1

Fig. 2

Possible translations of the distal fragment of the radius after fracture: a = change of volar tilt; b = change of ulnar tilt; c = displacement in distal radio-ulnar joint (axial view). I = normal radius; II = radius healed in malposition.

I—An osteotomy performed without correction of shift results in malposition despite good correction of the angle of the distal radial joint surface (interrupted line = ideal anatomical position). II—Reposition with correction of dorsal shift (a), and correction of radial shift (b) results in a normal radio-ulnar relationship (c). DE = dorsal edge; RM = radial marker; RE = radial edge; DM = dorsal marker.

Fig. 3

		PLAN	INITIALLY
RADIUS:	UT (degrees)	22.7	0
	VT (degrees)	13.5	-10.4
	RLD (mm)	0	-6.5
GRAFT:	RU (mm)	25.5	
	DV (mm)	24.0	
	U (mm)	10.4	
	D (mm)	19.1	
	R (mm)	15.6	
	V (mm)	9.5	
SHIFTS:	RM (mm)	1.8	
	DE (mm)	1.8	
	DM (mm)	3.1	
	RE (mm)	2.6	

Anteroposterior (AP) and lateral views of the 'wire' model of the right distal radius from the preoperative BIZCAD plan: (a) AP view of the distal osteotomized part with reference points, (b) AP view of the proximal part with reference points, (c) AP view of the graft, (d) lateral view of the distal osteotomized part with reference points, (e) lateral view of proximal part with reference points, (f) lateral view of the graft. UT = ulnar tilt; VT = volar tilt; RLD = radius length difference between normal and deformed wrist; RU = width of the graft in radio-ulnar direction; DV = width of the graft in dorsovolar direction; U = ulnar; D = dorsal; R = radial; V = volar; RM = radial marker; DE = dorsal edge; DM = dorsal marker; RE = radial edge.

Fig. 4

Distribution of values of dorsal/volar shift in 33 patients with post-traumatic deformity of the distal radius.

Fig. 5

Distribution of values of radial/ulnar shift in 33 patients with post-traumatic deformity of the distal radius.

Fig. 6

Mean ulnar inclination angle (degrees; mean ± SD) for normal wrists and for deformed wrists before and after osteotomy. The differences are as follows: D1 = 15.6° ($p = 0.0000$); D2 = 1.9° ($p = 0.2894$) and D3 = 13.7° ($p = 0.0000$).

best remodels the injured radius to the shape of the normal one and generally needs no further manual corrections.

The precise dimensions of the bone graft are automatically calculated and printed out (Fig. 3). These measurements include values for the radial/ulnar shift

(controlled at the radial edge (RE) and the dorsal marker (DM)) and for the dorsal/volar shift, controlled at the dorsal edge (DE) and the radial marker (RM). These are the displacements which need to be achieved intraoperatively. They are presented at the site of the osteotomy as positive or negative radial, and positive or negative dorsal shifts of the bone graft relative to the diaphysis of the radius (Fig. 3). The shifts are controlled by marks placed on the graft and on the radius before performing the osteotomy (Fig. 2).

In the 33 patients measured, corrective osteotomy was found to be indicated in 27; 16 men and 11 women.

Three three-dimensional models were compared in each patient. The first was a model of the deformed wrist, the second a model of the contralateral normal wrist, and the third a model of the deformed wrist after correction. The preoperative and postoperative values for volar and ulnar tilt of the deformed wrists were compared with those of the normal wrist using the paired t -test. Those for radial shortening were similarly compared.

RESULTS

The distribution of values of dorsal/volar shift in the 33 patients with malunited fractures is given in Figure 4, and the distribution of values of radial/ulnar shift in Figure 5. One or other of these shifts was nearly always present, and in some cases the displacement was considerable. The dorsal/volar shift ranged from -10.4 to 8.2 mm (mean 3.3 mm) and the radial/ulnar shift from -8.6 to 7.9 mm (mean 2.3 mm). A dorsal/volar shift of 3 mm or more, and/or a radial/ulnar shift of 3 mm or more was present in more than half the patients (19 of 33).

The mean preoperative and postoperative values of ulnar tilt of the deformed wrists and those of the normal wrists in the 27 patients who underwent surgery are given in Figure 6, and the equivalent values for volar tilt in Figure 7.

Fig. 7

Mean volar inclination angle (degrees; mean ± SD) for normal wrists and for deformed wrists before and after osteotomy. The differences are as follows: D1 = 27.0° ($p = 0.0000$); D2 = 3.1° ($p = 0.0512$) and D3 = 23.9° ($p = 0.0000$).

Fig. 8a

Radiograph of a 37-year-old woman with deformities of the radius after fracture (a). Osteotomy plus bone grafting based on the three-dimensional computer-generated model resulted in good correction of all the components of the original deformity (b).

Fig. 8b

The mean preoperative radial shortening was 2.02 mm (SD = 2.20) and the average postoperative shortening was 0.24 mm (SD = 3.49). The difference of 1.78 mm is statistically significant ($p = 0.0061$).

A case example (Fig. 8) shows how the correction of tilt, shift and shortening enables the perfect anatomical reconstruction of the distal radiocarpal and radio-ulnar joints.

DISCUSSION

Some authors have already advocated preoperative planning with three-dimensional models of the bone graft (Fernandez 1982, 1988; Forstner 1987; Oestern and Laque 1990). It has proved difficult, however, to calculate the exact dimensions of the graft required, especially in the frontal plane (Sennwald 1987). Murphy et al (1986, 1988) described the use of three-dimensional reconstruction from CT images in a variety of orthopaedic surgical

applications. The BIZCAD method of three-dimensional preoperative planning was introduced from standard radiographs and the principles of computer-aided design (Bilić and Zdravković 1988a,b; Zdravković and Bilić 1990). Jupiter, Ruder and Roth (1992) used a method of preoperative planning on solid models in five cases of complex malunion of the distal radius. In their method, CT scans of the normal and the deformed wrists were reformatted and transferred to a computer-controlled milling machine, which created plastic models. Such models allowed the surgeon a true-to-life appreciation of the skeletal deformity, but their accuracy has not been confirmed. The exact dimensions of the required graft cannot be derived from these models nor values for the angles and lengths needed for correction. The solid model method is also expensive and time-consuming.

The BIZCAD method uses the minimum number of radiographs for construction of a computer model, reducing X-ray exposure and cost compared with CT.

The use of virtual rather than actual models allows their free manipulation and the simulation of several different osteotomy configurations.

Our data suggest that translations of the distal fragments are an important component of the deformity and that such shifts may persist despite correction of angulation and shortening. CT imaging can detect malrotations of the distal fragment of the radius, but it provides no guidance for their correction. Our method does not quantify the malrotations but gives exact data on how they can be corrected.

It is important to stress that the term 'shift' as used here, does not mean the translation of some particular point on the distal radius. Shifts are relative translations of the edges at the site of the osteotomy, and therefore

may be positive or negative, depending on where the osteotomy is performed with respect to the axis of rotation of the distal fragment. We found that both the graft dimensions and the shift corrections changed when the osteotomy site was shifted from a proximal to a more distal level.

On the basis of our sample of 33 cases we conclude that shifts do exist, and that they need to be corrected. Our experience suggests that computerised three-dimensional methods offer new possibilities for better preoperative planning of corrective osteotomy for deformities of the radius.

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