Distal radius fractures

Classification, function and recommendations to treatment

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The following papers constitute the basis of the present dissertation:

1) Solgaard S. Angle of inclination of the articular surface of the distal radius. Radiologe 1984; 24: 346-8.
2) Solgaard S. Classification of distal radius fractures. Acta Orthop Scand 1985; 56: 249-52.
3) Solgaard S, Petersen V S. Epidemiology of distal radius fractures. Acta Orthop Scand 1985; 56: 391-3.
4) Solgaard S, Kristiansen B, Jensen J S. Evaluation of instruments for measuring grip strength. Acta Orthop Scand 1984; 55: 569-72.
5) Solgaard S, Carlsen A, Kramhøft M, Petersen V S. Reproducibility of goniometry of the wrist. Scand J Rehab Med 1986; 18: 5-7.
6) Overgaard S, Solgaard S. Osteoarthritis after Colles' fracture. Orthopedics 1989; 12: 413-6.
7) Solgaard S. Function after distal radius fractures. Acta Orthop Scand 1988; 59: 39-43.
8) Solgaard S. Early displacement of distal radius fractures. Acta Orthop Scand 1986; 57: 229-31.
9) Solgaard S. External fixation or a cast for Colles' fracture. Acta Orthop Scand 1989; 60: 387-91.
10) Solgaard S, Bünger C, Sølund K. Displaced distal radius fractures. A comparative study of early results following external fixation, functional bracing in supination, or dorsal plaster immobilization. Arch Orthop Traum Surg 1989; 109: 34-38.

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CONTENTS

INTRODUCTION

In 1814 Dr. Abraham Colles stated in his paper: On the fracture of the carpal extremity of the radius: "One consolation only remains, that the limb at some remote period again enjoy perfect freedom in all its motions, and be completely exempt from pain: The deformity, however, will remain undiminished through life".

The present series of investigations support this statement, although as shall be shown, in some patients the results of treatment can be improved.

In spite of numerous reports no consensus has been obtained over the years about the handling of distal radius fractures. The issues of debate have been the influence of the initial displacement and treatment on the final functional outcome. Recommendations for treatment have ranged from immobilisation in plaster for various periods to more invasive methods, i.e. pins and plaster, external or internal fixation, primary bone transplantation or cementing to obtain perfect radiology. In recent decades, emphasizing early mobilization to prevent joint stiffness, functional bracing or even no splinting at all has been suggested.

Comparison of the results from different publications become difficult and incomplete because of the lack of definitions. Various fracture classification systems have been described, but have seldom been applied in the description of the results. Score systems, including the radiographic and functional evaluation, have been advocated, but a more detailed analysis of these score systems has not been performed.

In an attempt to further analyze some of these problems the present studies were undertaken.

The aim was first to evaluate the prognostic value for the radiographic outcome of the most commonly used fracture classifications. A prerequisite for this analysis was to define the radiographic parameters in a normal population by measuring the angles of the articular surface of the distal radius and the relative length of the radial styloid. Following that, different classification systems could be analyzed with respect to the radiographic prognosis in patient series treated by reduction and plaster.

Secondly the aim was to determine the age-specific incidences of distal radius fractures in a well-defined population, and to classify the fractures in order to determine the number of patients possibly needing other treatment than reduction and plaster.

Thirdly the aim was to evaluate the functional outcome considering the parameters most commonly included in a score system: 1) visible deformity, 2) pain, 3) range of motion, 4) grip strength and 5) the occurrence of complications. The range of motion and the grip strength can be given by objective measures, but the reliability and reproducibility of such measurements was not known. This required a study on the range of wrist motion with calculations of the *intra-* and *inter*observer variation. Furthermore, grip strength was tested by different dynamometers in order to determine their efficacy and table normal values for the correlation between the strength of the dominant and non-dominant hand. The influence of the different parameters could now be analyzed, and furthermore the influence of radiographic arthrosis on wrist function was evaluated.

The aim was next to analyze the correlation between the radiographic and functional result. It was demonstrated, that all parameters included in the score system were important, but the residual deformity after treatment was the most important factor for the functional result.

In consequence of the previous results the final aim of the study became an analysis of the radiographic and functional results after different alternatives of treatment. For this purpose three patient series were included: 1) treatment with plaster after reduction of severely displaced fractures, 2) functional bracing in supination versus plaster treatment, 3) external fixation.

CHAPTER 1
FRACTURE-CLASSIFICATION

The ideal classification system of fractures should imply useful information about the prognosis. The definition of the different fracture types should be unequivocal, and the number of types in the classification limited in order to facilitate the use.

A classification system is however only useful for comparison of different series, if the fracture types are related to the end result, and thus determinant for the choice of treatment.

Several classifications of distal radius fractures have been proposed, but over the last four decades only five classification systems have been in common use (Fig. 1). Investigations over the prognostic value of classification systems of distal radius fractures have not previously been performed.

A prerequisite for an analysis of the radiographic prognosis is a definition of an ideal or "anatomical" result of treatment, and this requires knowledge of the normal values and the variation of radiographic measurements of the wrist.

In 57 normal probands (for demographic variables, see appendix 1) the volar angulation was determined in the lateral plane, and in the AP-plane the radial angulation and the length of the radial styloid were measured (Fig. 2).

These parameters were recorded twice by the author with one week's interval and blindfolded. Average, standard deviation and variation coefficient of the first and second measurements were calculated to quantitate the reproducibility of the recordings (Table 1.1).

No significant difference between men and women was found, when measuring the volar tilt ($P = 0.513$) or radial angulation ($P = 0.313$), but men had significantly longer radial styloids (13 mm) than women (12 mm), ($P \leq 0.05$) (Mann-Whitney).

A high variation coefficient of 21 per cent when measuring volar angulation might be related to the radiographic technique directing the tube perpendicular to the wrist, whereas the direction of the tube is of minor importance for the measurements in the AP-plane.

In the AP-plane the direction of the tube is of minor importance. A high correlation between the radial angulation and the length of the radial styloid was found (Spearman rank-sum test, $r = 0.742$). The radial angulation is difficult to measure, especially when the articular surface is comminuted and displaced. In the subsequent studies only the length of the radial styloid has been used to describe the anatomy in the AP-plane before and after treatment of

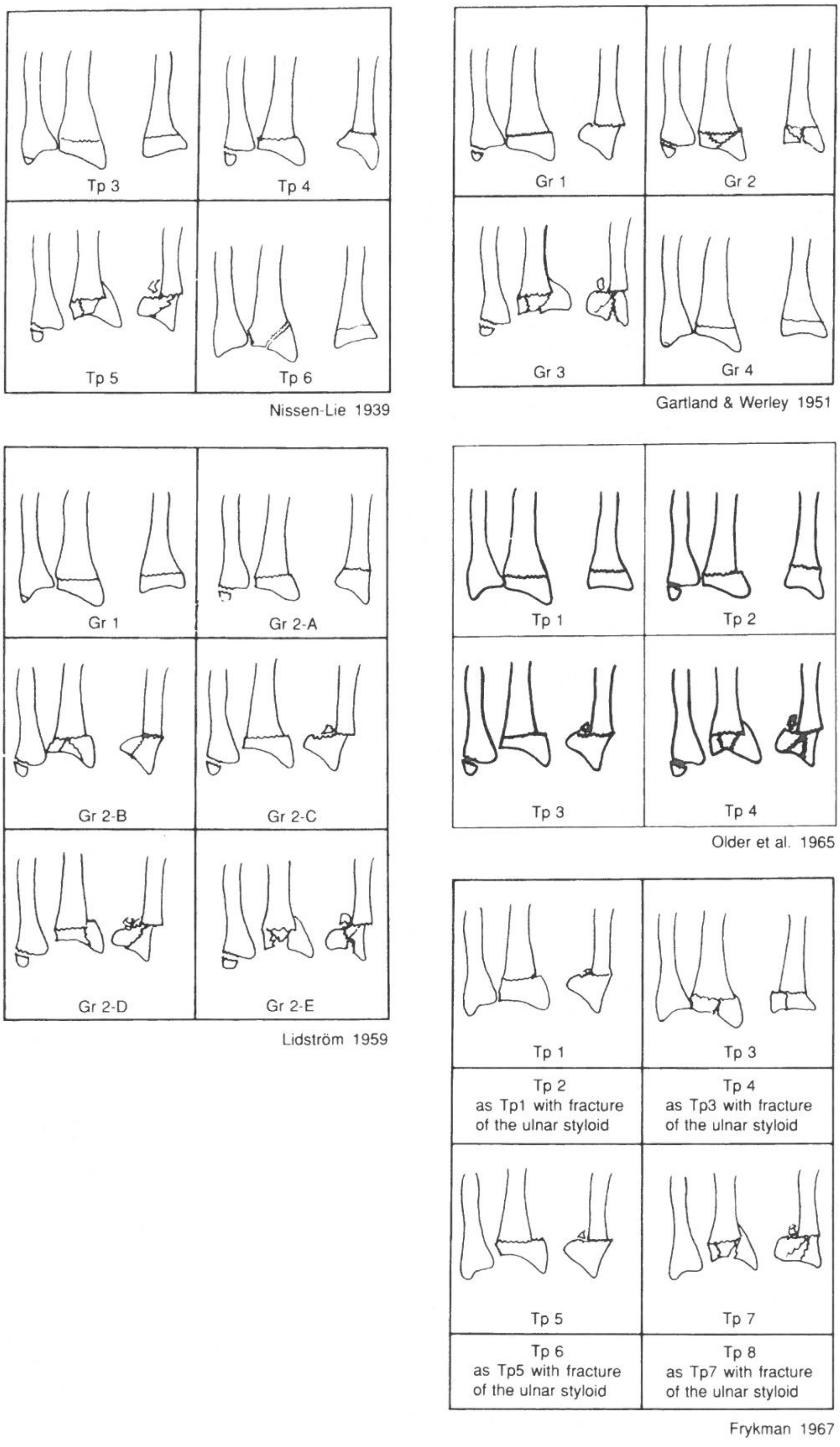

Fig. 1. *Schematic drawings of the five classification systems investigated.*

Nissen-Lie *(1939). Four fracture types with no grading of the displacement. Type 3: Minimal displacement; Type 4: Dorsal angulation, extra-articular, no comminution; Type 5: Intra-articular, comminuted; Type 6: Fractures of the radial styloid.*

Gartland & Werley *(1951). Three fracture types with no grading of the displacement. Group 1: Extra-articular, displaced; Group 2: Intra-articular, no displacement; Group 3: Intra-articular, displaced. To include all fractures in the present material, a fourth type, Group 4, of non-displaced extra-articular fractures was added.*

Lidström *(1959). Six fracture types. Group 1: Minimal displacement; Group 2-A: Extra-articular, dorsal angulation; Group 2-B: Intra-articular, dorsal angulation, joint surface not comminuted; Group 2-C: Extra-articular, dorsal angulation and dorsal displacement; Group 2-D: Intra-articular, dorsal angulation and displacement, joint surface not comminuted; Group 2-E: Intra-articular, dorsal angulation and displacement, joint surface comminuted.*

Older et al *(1965). Four fracture types. Type 1: Dorsal angulation up to five degrees, radial length distal to ulna at least 7 mm; Type 2: Dorsal angulation, radial length 1 to 7 mm, no comminution; Type 3: Dorsal radius comminuted, radial length less than 4 mm, distal fragment slightly comminuted; Type 4: Marked comminution, radial length usually negative.*

Frykman *(1967). Eight fracture types. Type 1: Extra-articular; Type 2: As Type 1 with fracture of the distal ulna; Type 3: Radio-carpal joint involved; Type 4: As Type 3 with fracture of the distal ulna; Type 5: Distal radio-ulnar joint involved; Type 6: As Type 5 with fracture of the distal ulna; Type 7: Radio-carpal and distal radio-ulnar joints both involved; Type 8: As Type 7 with fracture of the distal ulna.*

the fractures. This is in accordance with the recommendations by *Van der Linden & Ericson* (1981).

Based on the presented measurements normal anatomical ranges for the articular surface of the distal radius could be suggested, as 2 standard deviations on each side of the mean value will include approximately 95 per cent of a population. This means that a volar tilt of between 5 and 19 degrees is within the "normal" range. This range is further extended because of the variation coefficient of 21 per cent, implying that the normal range of volar tilt is from 3 to 22 degrees in radiographs taken with the tube perpendicular to the forearm. To facilitate the practical use a distal radius fracture reduced to 0 degrees of dorsal angulation was considered "anatomical".

In the AP-plane the average radial length was 12 $\pm$ 2.2 mm. Including two standard deviations and a variation coefficient of 6 per cent a reduction of a fracture to a radial length of at least 7 mm was thus considered "anatomical".

The daily clinical practice will not include comparative radio-

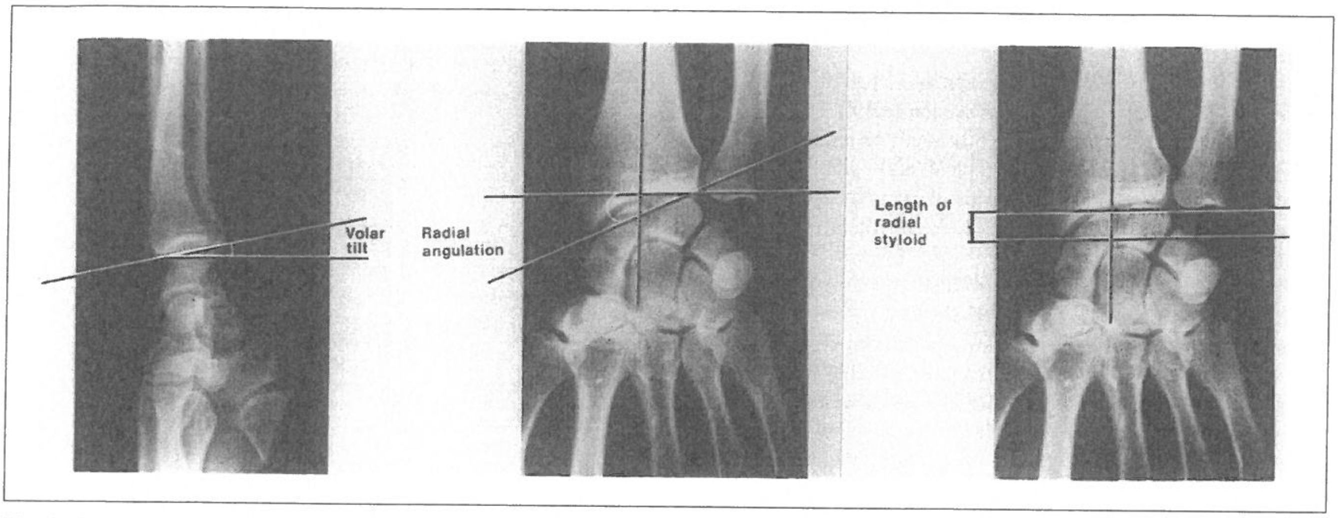

Fig. 2. *Radiographs of a normal wrist demonstrating the measurement of volar tilt (left), radial angulation (center) and length of radial styloid distal to ulna.*

Table 1.1 *The results of the measurements on the radiographs (average ± standard deviation) in 57 normal subjects.*

	volar tilt degrees	radial angulation degrees	length of radial styloid mm
1. measurement.......	12 ± 3.6	23 ± 3.5	12 ± 2.1
2. measurement.......	12 ± 3.3	23 ± 3.9	12 ± 2.3
average	12 ± 3.5	23 ± 3.7	12 ± 2.2
range	4-23	16-35	8-17
men	12 ± 3.3	22 ± 5.3	13 ± 2.2
women..............	12 ± 2.2	24 ± 2.9	12 ± 2.0
variation coefficient ...	21 percent	9 per cent	6 per cent

Table 1.2 *The result of the statistical screening in distal radius fractures as indicated by Goodman-Kruskall's marginal gamma values. Partial gamma values are the result of stratification to Older's classification.*

	anatomical reduction	anatomical position at fracture union	
	marginal gamma	marginal gamma	partial gamma
dorsal angulation.........	0.190*	0.710***	0.04
radial displacement.......	0.240*	0.465***	0.18
shortening	0.450***	0.657***	0.24
age	0.013	0.443***	0.50***
sex	0.003	0.359	
Nissen-Lie	0.309*	0.427**	0.03
Gartland & Werley	0.136	0.710***	0.36
Lidström	0.351*	0.734***	0.03
Older et al.	0.417***	0.852***	–
Frykman	0.007	0.276**	–0.418*
anatomical reduction......	–	0.881***	0.775***

* P ≤ 0.005 ** P ≤ 0.01 *** P ≤ 0.001.

graphs of the two forearms, as this would be economically unacceptable and involve unnecessary irradiation. Furthermore, the difference between the angles of the right and left joint has been shown to vary from 1 to 4 degrees (*Lidström* 1959, *Friberg & Lundström* 1976), and thus well within the ranges of the normality issue defined here.

Based on these definitions of an "anatomical" position of the fracture the analysis of the classification systems was performed.

The study included the radiographs of 269 patients (for demographic variables, see appendix 1). In all initial radiographs the fractures were classified by the author according to *Nissen-Lie* (1939), *Gartland & Werley* (1951), *Lidström* (1959), *Older and associates* (1965) and *Frykman* (1967) (Fig. 1).

The dorsal angulation, the length of the radial styloid distal to the ulna and the radial displacement (*Van der Linden & Ericson* 1981) were measured. The measurements were performed initially, after reduction and at fracture union. Furthermore, the age and sex of the patients were included in the statistical analysis using multiple contingency tables and a log-linear regression analysis (Chapter 7). This analysis has the advantage of quantification between the importance of different and interrelated parameters. Increasing numerical values of Goodman-Kruskall's gamma imply increasing importance of the parameter tested.

The possibility of obtaining an anatomical fracture reduction was the first problem to be analyzed (Table 1.2). This was primarily influenced by the length of the radial styloid. Accordingly, the classification system described by *Older and associates* (1965), grading in relation to radial length, proved to have the highest prognostic value. Age and sex did not significantly influence the result of reduction.

Secondly the possibility of obtaining fracture union in anatomical position was analyzed. Naturally, the quality of reduction was most important for the result, but the other radiographic parameters and age too significantly determined the result. Again the Older classification system had the highest prognostic value, as expressed by the highest marginal gamma values (Table 1.2).

Using the other four classification systems a significant distinction among the groups was also demonstrated. The analysis, however, showed, that if Older's system was compared directly with the other systems, only Frykman's classification had an independent prognostic value. This value was eliminated, when the age of the patient and the result after reduction were included in the analysis.

Of the radiographic parameters the dorsal angulation was most important, but again, when stratified after Older's system, this importance could be eliminated. Older's classification system was more informative on the prognosis than any other system.

After treatment of a distal radius fracture with reduction and plaster the prognosis is thus best predicted by the Older classification system. Type 1 and 2 have a good radiographic prognosis, whereas plaster treatment of fractures of type 3 and 4 never lead to a satisfactory radiographic result. The risk of obtaining non-anatomical union is increasing with age, especially in type 3 and 4, maybe because of the weak and comminuted dorsal cortex, which impedes maintenance of an anatomical reduction.

CHAPTER 2
EPIDEMIOLOGY

As shown in the previous chapter a number of patients might need another treatment than reduction and immobilisation in plaster. The number of potential patients, where this might be indicated was not known. Consequently an epidemiological study was performed to calculate the age-specific incidence of distal radius fractures, and to determine the distribution of the different fracture types in the population.

All cases of distal radius fractures defined as fractures within 4 cm of the wrist joint were recorded in the County of Frederiksborg in the calendar year 1981. The county is served by 5 hospitals, and 493 inhabitants had distal radius fracture. Patients treated in the county, but living outside were excluded, but inhabitants primarily treated outside the county were included. The age- and sex specific incidences were calculated on the basis of the population census January 1, 1981, and compared to similar studies in Oslo (*Falch* 1983) and Malmö (*Bengnér & Johnell* 1985) (Fig. 3 and Table 2.1).

A higher incidence in women in both the latter studies ($P \leq 0.00005$) was demonstrated. This difference could not be explained by seasonal variations, but could be caused by differences in the method of investigation. In Denmark treatment and radiographic control of fractures is only possible in hospitals, and in the present study all non-residents were excluded. Furthermore all radiographs were evaluated to secure, that only distal radius fractures were included.

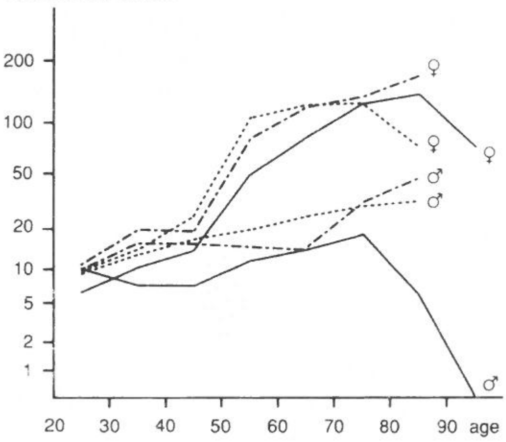

Fig. 3. *Age-specific incidence of distal radius fractures in men and women in Oslo (*Falch *1983), Malmö (*Bengnér & Johnell *1985) and Hillerød (present series).* ········· *Oslo* –·–·– *Malmö* ——— *Hillerød*

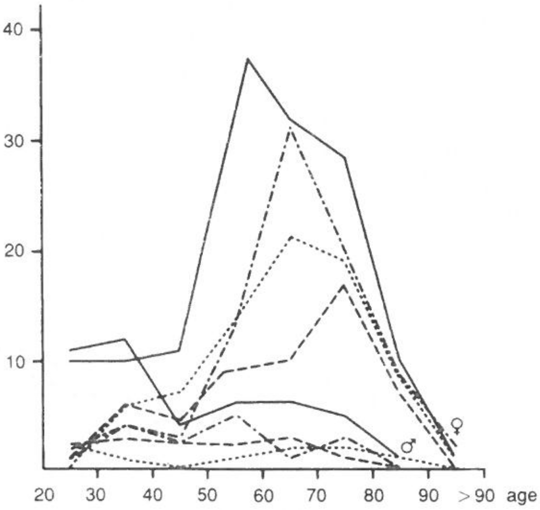

Fig. 4. *Number of fractures of each type (Older's classification system) in women (upper 4 curves) and men (lower 4 curves).*
——— *Type 1;* –·–·– *Type 2;* ········· *Type 3;* – – – – – *Type 4.*

Table 2.1 *The age-specific incidences of distal radius fractures in women and men over 20 years of age in the County of Frederiksborg, Denmark, 1981. Population at risk in thousands.*

	Women			Men		
Age	No. of fractures	Population at risk	Incidence pr. 10.000	No. of fractures	Population at risk	Incidence pr. 10.000
20–	13	21	6.2	21	21	10
30–	29	32	9.2	21	31	6.7
40–	27	21	13	15	22	6.8
50–	77	15	50	16	16	9.8
60–	101	12	81	14	12	12
70–	95	8.2	115	11	6.3	18
80–	47	3.5	133	1	1.8	6
90–	5	0.7	68	–	0.2	–
Total	394	114	35	99	111	9

Table 2.2 *Number of fractures of each type in women and men in the calendar year 1981.*

	Women	Men	Total
Type 1	139	45	184
Type 2	84	16	100
Type 3	77	9	86
Type 4	54	13	67
Total	354	83	437

Ninety-two per cent of the radiographs were available for review, and the fractures were classified according to Older (Fig. 4 and Table 2.2).

Reduction of the fracture had been performed in 46 per cent of the men and 58 per cent of the women ($P = 0.02$). The mechanism of injury was a fall on level ground in 87 per cent of the female and 64 per cent of the male patients ($P \leq 0.00005$).

Evaluation of the radiographs demonstrated, that the fractures were undisplaced in about 40 per cent of the women and 50 per cent of the men. Type 1 fractures were seen most frequently in the younger age group, and the number of more severely displaced fractures increased with age, at least in women. This was in accordance with the Malmö investigation (*Bengnér & Johnell* 1985), where the number of reduced fractures also increased with age. The finding may reflect the increasing fragility of bone. The incidence of falls increases with age (*Lucht* 1971), and the cause of fracture is a fall, but the severity of the fracture is caused by the bone fragility.

The population of Denmark includes a little more than 3½ million persons over 20 years of age. This implies, that between 8.000 and 9.000 distal radius fractures are treated each year. Furthermore, recent investigations have demonstrated a rising incidence of distal radius fractures (*Bengnér & Johnell* 1985).

CHAPTER 3
EVALUATION OF WRIST FUNCTION

Various score systems have been used for the evaluation of wrist function after distal radius fractures (*Gartland & Werley* 1951, *Lidström* 1959, *Frykman* 1967, *Sarmiento et al.* 1975, *Stewart et al.* 1984, *Porter & Stockley* 1984, *de Bruijn* 1987). Most of these score systems have been based on the original parameters used by Gartland & Werley, i.e. 1) the visible deformity, 2) pain, 3) range of motion and 4) the occurrence of complications. *Sarmiento and associates* included the grip strength. Several of the parameters can be assumed to be interrelated; e.g. severe pain with decreased motion or perhaps lack of normal finger mobility. An analysis of the interrelationship between the different parameters has not been found.

For the purpose of the present study the original functional score system described by *Gartland & Werley* was further modified, also to include the grip strength (Table 3.1).

Table 3.1 *Functional score system modified after* Gartland & Werley *(1951)*.

		points
Deformity	Prominent ulnar styloid	1
	Radial deviation	1-2
	Dinner-fork deformity	1-3
	Maximum	6
Subjective evaluation	No pain, no limitation of motion	0
	Slight pain, slight limitation of motion	2
	Occasional pain, some limitation of motion, weakness	4
	Pain, limitation of motion, activities restricted	6
	Maximum	6
Range of motion	Limitation of motion < 20 per cent	0
	Limitation of motion 20-50 per cent	2
	Limitation of motion > 50 per cent	6
	Stiffness of wrist	6
	Maximum	6
Grip strength	Normal (within 2 SD)	0
	2-4 SD	2
	4-6 SD	4
	< 6 SD	6
	Maximum	6
Complications	None or minimal	0
	Slight crepitation	1-2
	Severe crepitation	3-4
	Median nerve compression	1-3
	Pulp-palm distance 1 cm	3
	Pulp-palm distance > 2 cm	5
	Pain in distal radio-ulnar joint	1-3
	Maximum	15
Total score	Excellent	0-2
	Good	3-7
	Fair	8-18
	Poor	19-39

DEFORMITY

The recording of visible deformity included a registration of a prominent ulnar styloid, the occurrence of visible radial deviation, or persistance of the original dinner-fork deformity. If all deformities were present a maximum of 6 points was alloted. This registration of score was in accordance with the original description.

SUBJECTIVE EVALUATION

The subjective evaluation included the patient's own evaluation of pain, motion and strength, as reflected in the limitation of daily activities. No attempt was made to evaluate this parameter further, and as in the original score system this parameter was given a maximum of 6 points.

RANGE OF MOTION

One of the crucial points in evaluation of wrist function as described by *Gartland & Werley* (1951), or later modifications of this is the recording of the range of motion (ROM). Previous investigations on the reproducibility of goniometry of the wrist have only included one of the directions of motion. Complicated goniometers have been designed for such measurements, but the instruments are difficult to use in daily, clinical practice.

The accuracy in recording wrist motion was not known, and the relation between ROM for the right and left wrist was not known either. A study of ROM of normal, healthy probands was therefore performed with the intention of evaluating the *intra*-observer and *inter*-observer variation in all ranges of wrist motion, using a simple goniometer. Furthermore we intended to evaluate the influence of the skill of the observer, and to determine the relationship between the wrist motion of the right and the left wrist.

Thirty-one probands (for demographic variables, se appendix 1) were examined by 2 orthopedic specialists, and another 2 trainees with less than one years experience of orthopedics. Each observer examined the probands on three different occasions. Wrist flexion, extension, radial and ulnar deviation and forearm rotation were measured, and the standard deviation was used to calculate the variation coefficient (Table 3.2 and 3.3).

No difference between the specialists and the less experienced trainees could be disclosed. An accuracy of 10 degrees was obtained, and this seems adequate for clinical use. Changes in wrist motion less than that can thus hardly be regarded significant, though *Hellebrandt and associates* (1949) reported, that a well trained physiotherapist could increase the reliability of goniometric measurements. The difference between the right and left wrist, when including the total range of motion in the three directions was insignificant, and the opposite wrist has been used as a reference in the subsequent studies of disability after wrist fracture.

The average range of motion recorded in the present study (Table 3.2) was of the same magnitude as reported by others (*American Academy of Orthopaedic Surgeons* 1965, *Boone & Azen* 1979).

In the score system (Table 3.1) used for the evaluation of disability after distal radius fracture, the range of motion was given a maximum score of 6 points. Normal daily activities can be accomplished within 10 degrees of flexion and 35 degrees of extension (*Brumfield & Champoux* 1984) and within 100 degrees of forearm rotation (*Morrey et al.* 1981). Considering a total range of motion of the wrist of about 400 degrees (Table 3.2), this corresponds to a range of about 50 per cent of the normal range. Arbitrarily we defined a limitation of motion of less than 20 per cent as normal, whereas a limitation of between 20 to 50 per cent was alloted 2 points, and a limitation of motion of more than 50 per cent was considered just as disabling as a stiff wrist and alloted 6 points.

GRIP STRENGTH

Another quantificable parameter in the score system was the grip strength. In most previous studies on wrist fractures the grip strength has only been included as a recording of a reduced strength. The grip strength is suitable for quantitative measurements, and various dynamometers for the registration of grip

Table 3.2 *Standard deviation (SD) within observers calculated as the result of three measurements and between observers (4 observers each performing three measurements). Calculation of average range of motion based on 744 measurements in 31 probands.*

	same observer SD	different observer SD	right / left		average range of motion (degrees)
flexion	5.2	6.0	1.01	NS	77
extension	5.8	6.2	0.98	*	73
ulnar deviation	6.4	8.8	1.01	NS	40
radial deviation	5.2	5.4	0.93	**	26
pronation	5.3	6.8	0.98	***	86
supination	8.0	10.1	1.01	*	93

NS: P > 0.05 *: P ≤ 0.05 **: P ≤ 0.01 ***: P ≤ 0.001.

Table 3.3 *Variation coefficient (SD/average x 100) for each of the four observers (A and B: orthopedic specialists, C and D: residents).*

	variationcoefficient (per cent)				
	A	B	C	D	
flexion	5.7	7.6	5.7	6.4	NS
extension	6.5	8.6	5.6	7.2	*
ulnar dev.	15.9	12.3	13.5	18.8	**
radial dev.	24.3	21.3	19.8	18.0	NS
pronation	7.5	4.7	5.1	7.6	**
supination	8.4	7.0	4.5	5.6	***

NS: P > 0.05 *: P ≤ 0.05 **: P ≤ 0.01 ***: P ≤ 0.001.

strength have been designed. The ideal dynamometer should meet the following requirements: 1) Reproducibility and a high degree of linearity. 2) Measurements independent of hand size. 3) The instrument should be comfortable for the patient. 4) The instrument should be small and easy to carry around.

In insurance-medicine in Scandinavia the frequently used dynamometers when evaluating disability are the steel spring dynamometer and the Martin Vigorimeter. The steel spring dynamometer (Fig. 5) is very uncomfortable to use, and the accuracy of the measurements was not known. The Martin Vigorimeter (Fig. 6) has been investigated by *Thorngren & Werner* (1979), and is known to be an accurate instrument. The accuracy of these two instruments were compared to a new product, the My-Gripper (Fig. 7), which is small and handy, comfortable for the patient and requires no adjustment for different hand sizes.

The 3 dynamometers were investigated in a universal testing machine (1441 Zwick, Gmhb. & Co, W. Germany) with electronic measurement of force and deflection, and the regression lines calculated after 5 repeated measurements (Fig. 8).

The recordings for the My-Gripper and the Martin Vigorimeter with the medium balloon were almost linear, whereas the other instruments measured a lower force than expected.

A clinical study of 100 healthy probands (for demographic variables, see appendix 1) was also performed, and to determine and compare the precision of the instruments, the variation coefficients were calculated (Table 3.4). The results obtained with the testing machine were confirmed. The Martin Vigorimeter with the medium balloon and the My-Gripper had the highest degree of precision as indicated by the lowest variation coefficients. Both the machine testing and the clinical study demonstrated, that the steel spring dynamometer had a low precision and thus was unfit for clinical use.

The grip strength of the probands decreased with age and increased with height and weight. A statistical analysis was performed with multiple linear regression analysis to determine the relationship between the grip strength of the dominant (D) and non-dominant (ND) hand. Due to the applicability of the My-Gripper a nomogram (Fig. 9) describing the relationship between the grip strength of the dominant and non-dominant hand was developed, and a statistical analysis demonstrated, that the difference $\sqrt{D} - \sqrt{ND}$ did not correlate with age, sex, height and weight of the probands.

The grip strength was alloted maximally 6 points, as the other parameters in the functional score system. If the grip strength was within 2 standard deviations (SD) of the expected grip strength, it was defined as normal. Arbitrarily we regarded a grip strength within 2-4 SD as slightly decreased, and alloted this 2 points, a grip strength within 4-6 SD was given 4 points, whereas a deviation of more than 6 SD from the expected was given the maximum of 6 points.

The grip strength has by others been found to have a high correlation to the final functional result after Colles' fractures (*Scheck* 1962, *Bünger et al.* 1982), and grip strength is also in insurance medicine given a high priority, when evaluating disability. Consequently we found it justified to give the grip strength the same priority in the functional score system as the other parameters.

Table 3.4 *Variation coefficients in per cent for the Martin Vigori-meter, the steel spring dynamometer and the My-Gripper. Calculations based on 100 probands, each having five trials with each instrument.*

	V_{right}	V_{left}	$V_{average}$
Large balloon	8.0	7.7	7.9
Medium balloon	6.1	6.8	6.5
Small balloon	6.8	8.2	7.5
Steel spring	12.6	12.8	12.7
My-Gripper	6.5	6.7	6.6

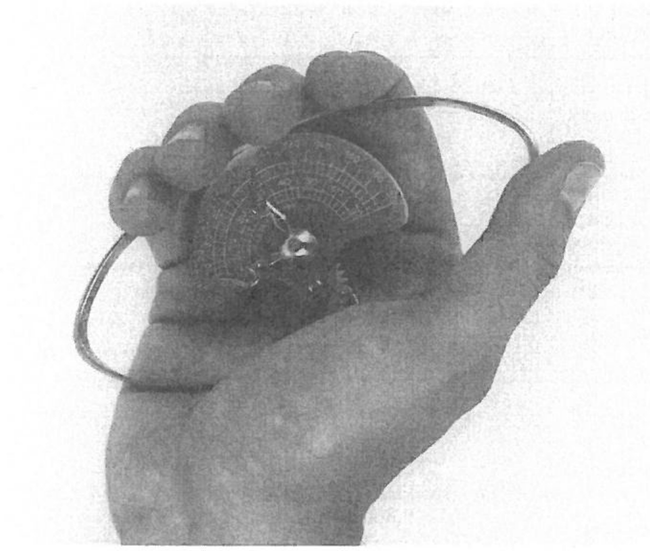

Fig. 5. *The steel spring vigorimeter.*

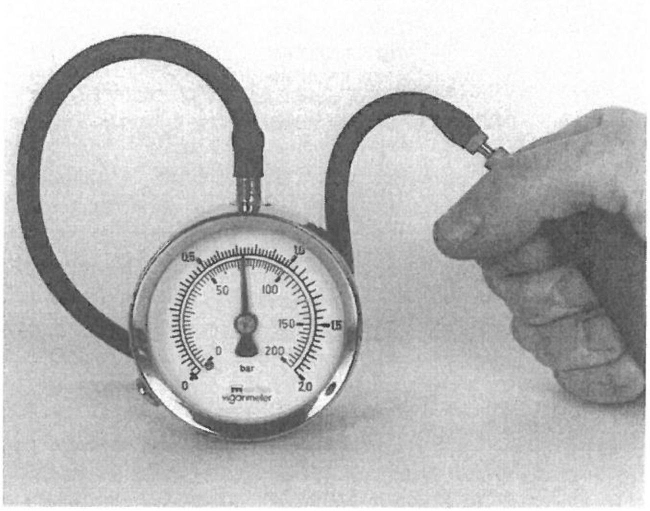

Fig. 6. *The Martin dynamometer.*

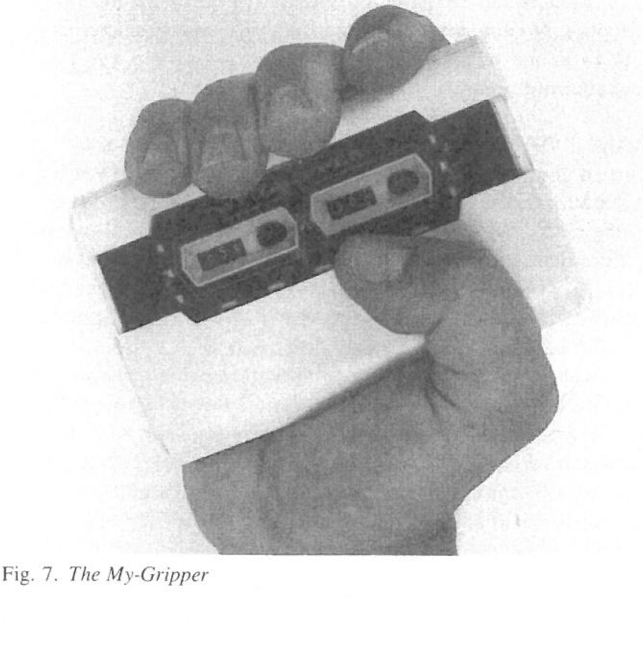

Fig. 7. *The My-Gripper*

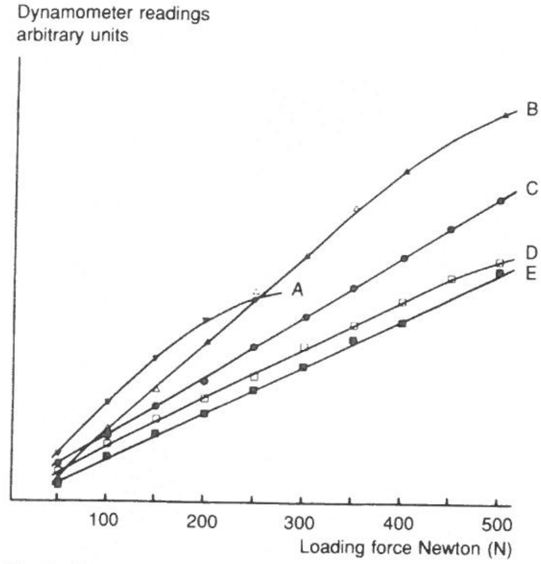

Fig. 8. *Dynamometer readings in arbitrary units following increasing force load in the universal testing machine. (A: Martin Vigorimeter, small balloon; B: Steel spring dynamometer; C: Martin Vigorimeter, medium balloon; D: Martin Vigorimeter, large balloon; E: My-Gripper).*

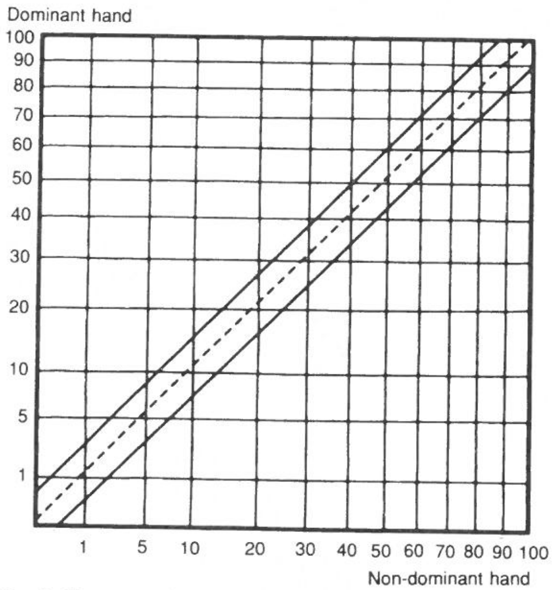

Fig. 9. *Nomogram for the grip strength of 100 probands. The units in the diagram are plotted as the square root, so that the expected force of one hand can be read directly knowing the force of the contralateral hand (average of three trials ± 2 SD, dynamometer: the My-Gripper).*

COMPLICATIONS

The last parameter registrated was the occurrence of late complications. Joint crepitation with passive movements of the wrist, median nerve symptoms and pain and instability of the distal radio-ulnar joint were registered. Late complications are often deleterious to the wrist function (*Frykman* 1967, *Cooney et al.* 1980), and were given a maximum of 15 points.

ANALYSIS OF THE FUNCTIONAL SCORE SYSTEM

The purpose of the further study was evaluate the different parameters in functional score systems and their mutual correlation and to disclose the relationships between the radiographic and clinical measures.

One-hundred and fifty-four patients (for demographic variables, see appendix 1) with distal radius fracture were analyzed. Reduction, if needed, had been performed followed by plaster immobilisation. All patients had been radiographed initially, after reduction, at union and at follow-up, and all fractures were classified according to Older. At the follow-up examination after 3½ years the functional score was determined using the score system presented above. All data were analyzed using multidimensional contingency tables and the statistical analysis performed with the Mann-Whitney test, the Chi-square test, and the Goodmann-Kruskall's gamma test (marginal and partial) (Chapter 7).

The result of the functional evaluation can be seen from Table 3.5. No patient had a poor result, but a close correlation between the fracture type and the functional result 3½ years later could be demonstrated with the best results in less displaced fractures.

There was also a correlation between function and the radiographic result at follow-up. The number of patients with only a fair result increased with increasing residual dorsal angulation and decreasing length of the radial styloid (Tables 3.6 and 3.7).

A more detailed analysis of the different parameters in the functional score system is described in Tables 3.8 and 3.9. All parameters showed a correlation to the initial fracture type. The more

Table 3.5 *Functional result in 154 patients with a distal radius fracture. Score system modified after* Gartland & Werley *(1951) (Table 3.1); fracture classification according to* Older et al. *(1965).*

Type	Number	Reduction required	Excellent	Good	Fair
1	63	5	43	18	2
2	50	39	26	17	7
3	22	22	8	10	4
4	19	18	3	11	5

Table 3.6 *Relation between dorsal angulation at follow-up and functional score in 154 patients with distal radius fracture.*

	Dorsal angulation (degrees)			
	≤ 0	1-10	11-25	≥ 25
Excellent or good	63	35	30	8
Fair	2	2	9	5

Mann-Whitney test, $P \leq 0.001$.

Table 3.7 *Relation between length of the radial styloid distal to the ulna at follow-up and functional result in 154 patients with distal radius fracture.*

	Length of radial styloid (mm)			
	> 12	12-8	7-5	≤ 5
Excellent or good	22	56	24	34
Fair	0	4	7	7

Mann-Whitney test, $P \leq 0.05$.

Table 3.8 *Functional score in 154 patients with distal radius fracture. Fracture type according to* Older et al. *(1965); functional score modified after* Gartland & Werley *(1951). Values are mean (SD).*

Type	n	Total score	Deformity	Subjective evaluation	Range of motion	Grip strength	Complications
1	63	1.7 (2.3)	0.3 (0.6)	0.8 (1.2)	0.0 (0.3)	0.3 (0.9)	0.3 (0.6)
2	50	3.3 (3.4)	0.9 (0.9)	1.3 (1.6)	0.2 (0.5)	0.4 (1.0)	0.6 (0.8)
3	22	4.0 (3.0)	1.4 (1.0)	1.4 (1.5)	0.3 (0.7)	0.4 (0.8)	0.5 (0.5)
4	19	6.2 (4.5)	1.9 (1.2)	1.5 (1.6)	0.9 (0.9)	0.6 (1.5)	1.3 (1.9)

Table 3.9 *Goodman-Kruskall's partial gamma values as the result of the statistical analysis. Increasing values imply increasing correlation between variables.*

	Deformity	Subjective evaluation	Range of motion	Grip strength	Complications
Deformity	–	−0.72***	0.43*	0.12	−0.10
Subjective evaluation	−0.72***	–	−0.05	−0.09	−0.60***
Range of motion	0.43*	−0.05	–	0.15	0.14
Grip strength	0.12	−0.09	0.15	–	0.22
Complications	−0.10	−0.60***	−0.14	0.22	–

*: $P \leq 0.05$ **: $P \leq 0.01$ ***: $P \leq 0.001$.

comminuted and displaced the fracture, the worse the result. All the parameters investigated showed an increasing score (i.e. an inferior result), as the fractures became more displaced and comminuted.

The analysis of the interrelationship between the different parameters showed, that the subjective evaluation of the patient was closely correlated to the occurrence of deformity and complications (Table 3.9). The range of motion was also correlated to deformity, whereas the grip strength was unrelated to the other parameters. The statistical analysis demonstrated, that all parameters were of importance for the final functional score, but that deformity had the highest influence. Furthermore, the influence of the initial fracture type was also mediated through a higher frequency of residual deformity after treatment in these patients.

In conclusion it was found, that the presented score system for the evaluation of wrist function is applicable. All the parameters included in the score system are separately important for the functional result, but several of the parameters are interrelated. The total score is related to the late radiographic result, but also to the initial fracture type according to *Older and associates* (1965). The occurrence of residual deformity seems to have a high influence on the final functional score, and a rational way to improve function would therefore be to diminish the residual deformity.

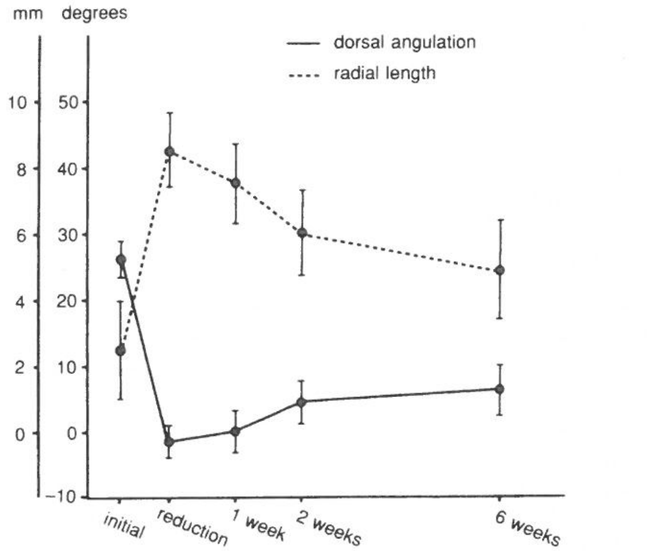

Fig. 10. *Radiographic evaluation of 47 patients with distal radius fracture measured initially, after reduction and at one, two, and six weeks respectively. Values are mean ± 2 SD.*

CHAPTER 4
ARTHROSIS

Radiographic arthrosis is not included in the functional score system. With the purpose of elucidating the influence of radiographical arthrosis on wrist function a long-time follow-up was undertaken.

Fifty-six patients (for demographic variables, see appendix 1), with displaced distal radius fractures of type 2, 3 and 4, were examined after median 86 months. The patients were radiographed, and a functional evaluation as previously described was performed. Radiographic arthrosis was defined according to *Lidström* (1959).

All patients had initially been randomized to treatment with reduction and either a low cast or functional bracing in supination (*Bünger et al.* 1984). The statistical analysis (Chapter 7) demonstrated no difference between the radiographic and functional result after the two treatments, neither at the primary follow-up, nor at the present long-time follow-up. The patients were therefore pooled into one series. Table 4.1 demonstrates for each fracture type the number of patients with arthrosis.

In this long-time follow-up series 25/56 patients demonstrated radiographic signs of arthrosis. This frequency is higher than reported by *Gartland and Werley* (1951) (22 per cent), *Lidström* (1959) (25 per cent) or *Smaill* (1965) (25 per cent). The observation time in the present series, however, was much longer, and only displaced fractures were included. *Gartland & Werley* (1951) ascribed the arthrosis to radiographic malposition of the fracture at union. In the present study the occurrence of arthrosis was not related to the residual dorsal angulation nor to the length of the radial styloid. The statistical analysis (Chapter 7, Fig. 11) demonstrated, that arthrosis was correlated to the age of the patient ($P \leq 0.001$) and to the fracture type, i.e. the initial displacement ($P \leq 0.01$). Arthrosis only influenced the function of the wrist in the older patients having a higher frequency of visible deformity ($P \leq 0.0001$). None of the other parameters in the score system could be related to arthrosis (Fig. 11). *Frykman* (1967) found a high frequency of arthrosis in the distal radio-ulnar joint (19 per cent), often associated with pain and laxity. This could not be demonstrated in the present series.

Table 4.1 *Number of patients with radiographic arthrosis* (Lidström *1959); functional score is average (Table 3.1).*

	No	None	Slight	Moderate	Severe
Type 2	21	15	6	0	0
score		3.9	6.2	–	–
Type 3	22	10	5	7	0
score		4.6	2.2	4.6	–
Type 4	13	6	6	0	1
score		3.8	5.2	–	13

CHAPTER 5
RADIOGRAPHIC AND FUNCTIONAL RESULT AFTER TREATMENT WITH REDUCTION AND PLASTER

The patients in the previous analyses had all been treated by the standard method usually applied in the Scandinavian countries. Reduction, if considered necessary, was performed in local analgesia by manual traction or suspension in Chinese fingertraps. The wrist was immobilised with dorsal and volar plaster slabs or with a low circular cast for 5 to 6 weeks. The position of the hand was neutral or with slight volar flexion, ulnar deviation and pronation. Previous investigations have demonstrated, that the position of the hand is of no importance for the final result (*Van der Linden & Ericson* 1981), and this was consequently not recorded.

In this chapter the radiographic and functional result in patients with distal radius fractures treated by reduction and a low cast for 5-6 weeks will be reported.

Table 5.1 demonstrates the late result after treatment of 154 patients, with a distal radius fracture (for demographic variables, see appendix 1). The dorsal angulation and length of the radial styloid were evaluated radiographically initially, after reduction (if performed), at union and at follow-up (after median 40 months). The latter examination also included a functional score reported in chapter 3. Radiographic arthrosis was registered using the definition described by *Lidström* (1959).

Table 5.1 *The radiographic and functional result in 154 patients with distal radius fracture 3½ years earlier. Values are median (range). Dorsal angulation in degrees, radial length in mm.*

		Type 1	Type 2	Type 3	Type 4
Number		63	50	22	19
Initially	dorsal	−6 (−21-12)	16 (7-45)	30 (12-45)	28 (0-45)
	length	11 (5-12)	7 (4-12)	3 (2-9)	−2 (−12-3)
Reduction	dorsal	–	0 (−10-35)	4 (−12-22)	3 (−18-21)
	length	–	10 (6-18)	9 (2-13)	8 (3-14)
Union	dorsal	−2 (−21-17)	10 (−10-36)	11 (−8-35)	12 (−8-40)
	length	11 (6-15)	7 (1-12)	4 (−4-13)	2 (−4-10)
Follow-up	dorsal	0 (−21-17)	10 (−13-40)	10 (−10-35)	14 (−8-40)
	length	11 (6-19)	7 (1-14)	3 (−5-13)	4 (−4-11)
Functional score		1 (0-11)	2 (0-12)	3 (0-10)	5 (1-18)
Arthrosis No.		3	10	6	9

In 47 patients (type 2: 12 cases, type 3: 28 cases, type 4: 7 cases), who had intermediary radiographic controls performed after 1 and 2 weeks, it was demonstrated, that secondary displacement predominantly occurred within the first 2 weeks after fracture (Fig. 10). In only 4 cases the secondary displacement took place after the second week, and no further displacement occurred after the 6th week.

The radiographic evaluation in both the present study and in the classification analysis (Chapter 1) has confirmed, that a fracture classification with quantification of the displacement is useful for the description of the radiographic end result. In the present series (154 patients) a highly significant correlation between radiographic and functional outcome was found (Chapter 3, p. 29). It can thus be stated, that undisplaced fractures of type 1 have a good prognosis, both regarding the radiographic and functional result. Fractures of type 2, which are usually extra-articular, can most often be reduced to a satisfactory position (no dorsal angulation and length of radial styloid 7 mm or more). The median functional result in these patients is good. Patients with an unsatisfactory radiographic result have an inferior functional result, compared to patients with a better radiographic position. It seems therefore justified to try to reduce and treat these patients with plaster in order to get a satisfactory function. Radiographic control should be performed after 10-14 days. Rereduction is still possible, and is claimed to give better results than re-reduction after the first week (*Collert & Isakson* 1978), though the indication for re-reduction has been doubted by *McQueen and associates* (1986). In the author's opinion other methods of treatment should be considered, if a satisfactory radiographic result of reduction is not achieved, or if secondary displacement occurs.

No significant difference could be demonstrated between fractures of type 3 and type 4. Both fracture types are difficult to reduce, and all fractures show secondary displacement, when treated with reduction and plaster. Still, the median functional result after 3½ years was in most cases acceptable, but the range was wide, with several patients having a less satisfactory function. The radiographs in these patients showed rather severe dorsal angulation and considerable radial shortening. The central point in the treatment is to prevent secondary displacement and subsequent deformity. Several studies have emphasized the application of other methods of treatment. In the next chapter the results of treatment with functional bracing and external fixation will be discussed.

CHAPTER 6
REDUCTION AND PLASTER, FUNCTIONAL BRACING OR EXTERNAL FIXATION?

A number of other possibilities than treatment with reduction and plaster immobilisation have been advocated: In undisplaced fractures, with a good prognosis, no treatment at all has been suggested (*de Bruijn* 1987, *Abbaszadegan et al.* 1989). In displaced fractures functional bracing has been recommended (*Sarmiento et al.* 1975, *Sarmiento et al.* 1980, *Bünger et al.* 1984), but found of limited value in other series (*Stewart et al.* 1984, *de Bruijn* 1987, *Ferris et al.* 1989).

With the purpose of improving the radiographic result plaster immobilisation in combination with internal fixation (ulnar pinning) (*DePalma* 1952 and *Dowling & Sawyer* 1961) or percutaneous pinning with Kirschner wires (*Scheck* 1962, *Cole & Obletz* 1966 and *Green* 1975) has been suggested. Rush-pins have been used by *Lucas & Sachtjen* (1981), and *Kofoed* (1983) and *Schmalholz* (1989) advocated primary filling of the dorsal cortical defect with bone-cement. More recent reports have concentrated on external fixation.

The purpose of this part of the study was to compare the short and long term results obtained with external fixation (A) to functional bracing in supination (B) or conventional treatment with reduction and plaster immobilisation (C).

A: EXTERNAL FIXATION:

Forty-five consecutive patients (for demographic variables, see appendix 1) with Older type 2, 3 and 4 fractures were treated. Three parallel threaded pins were inserted in general or regional anaesthesia through stab-wounds in the distal radius and two further pins in the proximal part of the second metacarpal. The pins were fixed by a single bar after reduction of the fracture in Chinese fingertraps. No pre-drilling or soft tissue protection was used. The median time in hospital was 3 (1-14) days. After 5 weeks the fixator was replaced by a dorsal plaster slab for one additional week. No patient was re-reduced.

Evaluation of the radiographic and functional result was performed after 3, 6, 12 and 29 months.

B: FUNCTIONAL BRACING IN SUPINATION OR DORSAL PLASTER IMMOBILISATION:

These patients were extracted from a previously published randomized study of 136 patients (*Bünger et al.* 1984). All radiographs were re-evaluated, and the fractures classified according to *Older and associates* (1965), excluding undisplaced fractures of Type 1.

Thirty-six patients (appendix 1) had been treated with functional bracing in supination. After reduction in local anaesthesia an above elbow splint was applied with the forearm in 60 degrees of supination and ulnar deviation. After one week the splint was replaced by a pre-fabricated PVC orthosis, allowing only volar flexion of the wrist. The brace was removed after 5 weeks. Four patients were re-reduced during the treatment. No patient was hospitalised.

Fourty-nine patients, (appendix 1) were treated as out-patients by reduction in local anaesthesia and an above elbow splint with ulnar deviation and pronation. After 12 days this bandage was replaced by a low cast with the wrist in neutral position for another 4 weeks. In 7 cases the fracture was rereduced.

In both series follow-up had been performed after 3 and 6 months. In the surviving 56 patients a late follow-up after 86 months (Chapter 4) was done to evaluate the occurrence of arthrosis (for demographic variables, see appendix 1).

C: LOW CAST:

This patient series has been described in Chapter 3 (Table 3.5) and 5. All undisplaced fractures of Type 1 were excluded, leaving 91 patients (appendix 1) for investigation 40 months after fracture. All patients were reduced in local anaesthesia and immobilised in a low cast for 5 to 6 weeks. No patient was reduced more than once, and no patient was hospitalised.

Comparison of the three patient series A, B and C was performed in the following way: The early results were evaluated comparing series A and B, the late results comparing series A and C. Statistical analysis was performed using multivariate recursive graphic and log linear regression models (*Wermuth & Lauritzen* 1983) (See Chapter 7).

EARLY RESULTS

The radiographic result after functional bracing in supination and dorsal plaster immobilisation (series B) were similar to series C, but external fixation (series A) resulted in superior radiographic results (Table 6.3). This was, however, not reflected in the early functional outcome, which was equivalent after all three treatments (Table 6.1).

Sarmiento and associates (1975) suggested, that functional bracing in supination prevented secondary displacement by eliminating the deforming force of the brachioradialis muscle and permitting early mobilization of the wrist. A superior functional result was demonstrated. This was confirmed by *Bünger and associates* (1984), but only for the follow-up at 3 months – not at 6 months. In the present investigation the fractures primarily reported by Bünger and associates were re-classified using Olders classification. Now no significant difference, when comparing 3 and 6 months functional results after external fixation, functional bracing in supination and dorsal plaster immobilisation, could be demonstrated. However, function after distal radius fracture is not completely stationary until one year after treatment (Table 6.2). A significant improvement for all fracture types in series A occurred during the first year of observation, after which function was stationary.

De Bruijn (1987) investigated the results after functional bracing after one year and showed, that the result to a higher degree depended on the initial displacement of the fracture, than on the choice of treatment. This was confirmed in the present investigation, but only when the observation time was short.

LATE RESULTS

When comparing the result after 29 months following external fixation (series A) with the series of patients treated with reduction and plaster and followed for 40 months (series C) the superior radiographic results were obvious. The dorsal angulation was significantly smaller, and the length of the radial styloid significantly greater following external fixation (Table 6.3).

Supporters of external fixation have all reported a superior radiographic result. Wrist function has also been claimed to be better after external fixation, but only in the study by *Kongsholm* (1987) a fracture classification and a control group have been included. In the present study a comprehensive statistical analysis (Chapter 7) has been used, making it possible to quantitate the influence of the different parameters evaluated. The interrelation-ship between the different parameters was, however, complicated, and is illustrated in Fig. 11. It was demonstrated, that the choice of treatment significantly influenced the radiographic result, both in the AP-plane and in the lateral plane. As can be seen the better functional result after external fixation was caused by a smaller dorsal angulation (C-A), whereas the length of the radial styloid had no direct influence on the function.

The final functional score, however, was also influenced by the initial displacement (Fig. 11: D), and by the occurrence of radiographic arthrosis (Fig. 11: B). The frequency of arthrosis after 3 years was equivalent in patients treated by external fixation and plaster immobilisation (Table 6.4).

Thus in spite of an almost anatomical radiographic end-result, treatment by external fixation seems not to prevent secondary arthrosis. An explanation might be, that the congruity of the radiocarpal joint probably never is completely restored (cfr. the influence of the fracture type on the occurrence of arthrosis (Fig. 11)).

When comparing the rate of complications a significant difference between series A and B was registered (Table 6.5). Median nerve symptoms and shoulder-hand syndrome occurred by the same frequency after all three treatments. Infection occurred in 4 of the patients, leading to premature removal of the fixator in three patients. An equivalent number of infections have been described in other studies (*Forgon & Mammel* 1981, *Cooney* 1983, *Vaughan et al.* 1985, *Kongsholm* 1987).

Twelve patients with injury to the cutaneous branch of the superficial radial nerve were recorded. At the latest follow-up after 29 months, three patients had symptoms from the neuropathy. Five further patients, though un-noticed had a decreased 2-point-discrimination on the dorsal aspect of the thumb and index fingers. In the present study no pre-drilling or soft tissue protection was applied. *Kongsholm* (1987) suggested a more proximal approach, when inserting the pins in the radius, and also used surgical exposure of the bone as also recommended by *Cooney* (1983). The complication might probably be avoided by using blunt dissection and soft tissue protection, when inserting the proximal pins. Consequently I do not find that this complication should preclude the use of external fixation.

Treatment by external fixation was more expensive than conventional treatment, as the patients had to be admitted to the hospital.

Table 6.1 *Average functional score ± SD in the three fracture types and treatment groups B (plaster and functional bracing) and A (external fixation) after 3 and 6 months.*

	Plaster	Functional bracing	External fixation
3 months			
Type 2	6.6 ± 4.3	6.9 ± 4.5	9.1 ± 4.5
Type 3	8.6 ± 3.7	6.6 ± 3.8	8.2 ± 4.8
Type 4	9.4 ± 4.6	11.8 ± 6.1	9.9 ± 5.4
6 months			
Type 2	5.3 ± 3.6	4.3 ± 3.2	4.6 ± 5.1
Type 3	8.1 ± 4.1	4.6 ± 3.0	6.9 ± 5.4
Type 4	7.5 ± 3.3	8.0 ± 3.9	6.9 ± 4.3

Table 6.2 *Median functional score (range) after 3, 6, 12 and 29 months in 40 patients treated by external fixation (group A).*

	3 months	6 months	12 months	29 months
Type 2	8 (3-19)	4 (0-17)	2 (0-7)	1 (0-11)
Type 3	7 (1-18)	4 (0-17)	1 (0-11)	3 (0-12)
Type 4	9 (3-18)	7 (0-17)	4 (0-10)	3 (0-7)

Table 6.3 *The results of the radiographic and functional evaluation of 40 patients treated by external fixation (EF) (series A) and 91 patients treated by cast (series C). Observation time 29 months respect. 40 months. Dorsal angulation given in degrees, radial length in mm. Values are median (range).*

		Type 2	Type 3	Type 4
Fracture type	EF	8	15	17
	cast	50	22	19
Dorsal angulation initially	EF	29 (0-40)	20 (7-60)	30 (0-55)
	cast	16 (7-45)	30 (12-45)	28 (0-45)
Dorsal angulation after reduction	EF	−13 (−19-0)	0 (−15-20)	0 (−11-6)
	cast	0 (−10-35)	4 (−12-22)	3 (−18-21)
Dorsal angulation follow-up	EF	−5 (−8-17)	−7 (−12-32)	0 (−15-25)
	cast	10 (−13-40)	10 (−10-35)	14 (−8-40)
Radial length initially	EF	8 (6-10)	4 (0-11)	−1 (−15-0)
	cast	7 (4-12)	3 (2-9)	−2 (−12-3)
Radial length after reduction	EF	13 (10-15)	11 (8-17)	11 (5-16)
	cast	10 (6-18)	9 (2-13)	8 (3-14)
Radial length follow-up	EF	11 (5-22)	10 (6-12)	8 (3-15)
	cast	7 (1-14)	3 (−5-13)	4 (−4-11)
Functional score	EF	1 (0-11)	3 (0-12)	3 (0-7)
	cast	2 (0-12)	3 (0-10)	5 (1-18)

Table 6.4 *Frequency of arthrosis in the four fracture types (*Older et al. *1965) in the different patient series.*

Follow-up	29 months	40 months	86 months
Treatment	external fixation	plaster	plaster or functional bracing
Type 2	3/8	10/50	6/21
Type 3	5/15	6/22	12/22
Type 4	6/17	9/19	7/13
Total	14/40	25/91	25/56

Table 6.5 *Early complications in the three treatment groups.*

No.	Plaster 49	Functional bracing 36	External fixation 41
Median nerve symptoms	2	2	2
Shoulder-hand syndrome	2	3	3
Radial neuropathy	3	3	12
Infection	–	–	4

However, no re-reductions had to be performed after external fixation.

In conclusion, external fixation seems justified in patients with severely displaced distal radius fracture of type 3 and 4. It is probably also useful, when secondary displacement occurs in type 2 fractures. The dorsal angulation can be significantly reduced. Thereby function is also improved. Secondary arthrosis is not prevented.

CHAPTER 7
STATISTICAL METHODS

The statistical analysis included use of standard statistical methods. Calculations of standard deviation, variation coefficients and regression lines were performed, and calculations of age-specific incidences with confidence limits were used in the epidemiological study.

Comparison of the results was performed using non-parametric statistical tests such as the Mann-Whitney test and the Spearman rank-sum test. For the evaluation of the goniometric measurements analysis of variance was used, and when constructing the nomogram for the evaluation of grip strength, multiple linear regression analysis was included.

The more sophisticated analysis of the classification systems, the functional score system and the results of treatment necessitated the use of a more comprehensive statistical approach. The software for this analysis was developed by cand.stat. *Svend Kreiner*, and as the theory for these methods of analysis is relatively new, the method will be explained in detail below.

The basis for the analysis is the use of graphical models for multidimensional contingency tables (*Edwards & Kreiner* 1983). A graphic model may be regarded as a set of assumptions concerning conditional independence of pairs of variables given the rest of the variables of the study. If additional assumptions are imposed concerning causal or recursive structures, we have what is known as a recursive graphical model. The model may conveniently be represented by an interaction graph (Fig. 11), where the squares represent variables, which may be connected by lines, if these variables are conditionally dependent. Squares, which are not connected by lines, represent variables, which are conditionally independent, given the rest. The interaction graph may be treated as a mathematical model, where graph theoretical methods for the analysis can be used to derive properties of the statistical or probabilistic model of importance for the interpretation of the results.

The analysis included a large number of different variables: demographic variables such as age and sex, radiographic parameters such as fracture type, radial length and dorsal angulation, measured at different times during the period of observation, and furthermore, the analysis included the result of the functional evaluation and the different parameters included in the functional score system. Finally, the occurrence of complications and arthrosis were included.

In the search for interaction between the variables all parameters were compared in a screening procedure, using two-way tables. The next step was an analysis of three-way tables to disclose hidden interactions, and to check for conditional independence of variables, for which interactions were implied by the first two phases. A graphic base model could now be constructed and defined by conditional independence of pairs of variables, for which no evidence had been found against conditional independence in at least one three-way table.

The graphic models constitute a subset of the class of log linear models for contingency tables (*Bishop et al.* 1975). This means, that a large number of methods and standard programmes, developed for the log linear models, are available for the graphic models as well.

The so-called cliques of the interaction graph (subsets of completely connected squares) defined the generating set and the parameters for the log linear structure of the graphic model. Variables, which are not connected in the interaction graph, are not only conditional independent, given the rest of the variables, but also given the smaller subset of variables, which actually separate the variables in the interaction graph. In Fig. 11 functional score and treatment are not connected, and therefore assumed to be conditional independent given the remaining seven variables. One may, however, cut all paths from treatment to functional score by removing the vertices corresponding to dorsal angulation and fracture type. It follows, therefore, that treatment and functional score are conditionally independent, given these two variables only. This property, closely connected to the so-called collapsibility of contingency tables, provided the justification for analyzing marginal tables in the course of the analysis, rather than always considering the technical and demanding problem of analyzing a large nine-dimensional table.

The statistical tests used in the course of the analysis were the standard Chi-square and likelihood-ratio tests always considered, when analyzing multidimensional tables and – when ordinal variables were considered- the Goodman-Kruskall gamma (marginal and partial), which is known to have much greater power against ordinal alternatives, than the Chi-square test (*Kreiner* 1986 and 1987). Another advantage of the method is, that the P-values are exact figures rather than asymptotic.

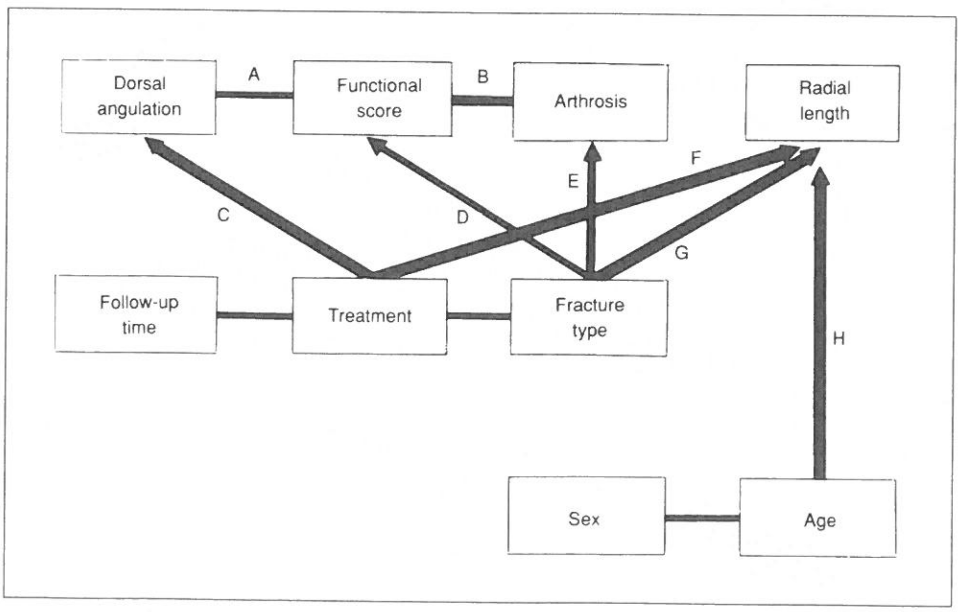

Fig. 11. *The interaction graph showing the variables included in the analysis (the squares of the graph),the conditional dependencies (the lines between the squares) and independencies (where no line is present) and the recursive or causal structure, presumed in the analysis (the arrows). The letters A-H demonstrate the result of the Goodman-Kruskall partial gamma test. P-values are exact according to the methods described by* Kreiner *(1987).*

A: gamma = 0.31 ; P = 0.006
B: gamma = 0.45 ; P = 0.004
C: gamma = 0.64 ; P $\leq$ 0.0005
D: gamma = 0.31 ; P = 0.018
E: gamma = 0.30 ; P = 0.04
F: gamma = 0.65 ; P $\leq$ 0.0005
G: gamma = 0.59 ; P $\leq$ 0.0005
H: gamma = –0.49 ; P $\leq$ 0.0005

CHAPTER 8
GENERAL DISCUSSION AND CONCLUSIONS

The theoretical fundament for the analyses in most of the papers included in the present survey is the statistical method. The use of graphic models and a log linear regression analysis made it possible to evaluate the influence of several interrelated parameters and not least to quantify their relative importance. This was used in the analysis of the classification systems.

A fracture classification should always be included, when reporting the results of fracture treatment. An undisplaced fracture does not imply the same prognosis as a severely displaced, comminuted and intraarticular fracture. Results of the treatment must be given separately for each fracture type.

Previous investigators have also classified the fractures, but an attempt to evaluate the prognostic value of the commonly used classification systems has not been performed before. *Older's classification* (1965) is the only system with a grading of the displacement, and the radiographic prognosis can be read·from the fracture type.

Older's classification system (1965) also proved valuable when describing the functional prognosis. There was a clear correlation between the fracture type and the functional outcome several years later, in spite of attempts to modify function by alternative treatments. This has been confirmed by *de Bruijn* (1987).

The description of wrist function also implied the use of a score system, where the score for the different parameters evaluated were added to give a total score. One might argue, that such an addition is invalid, but that is what is being done in daily clinical practice, when evaluating disability. Furthermore, the statistical analysis demonstrated, that each of the parameters tested (deformity, pain, range of motion, grip strength and complications) influenced wrist function. Other score systems have also been proposed (*Lidström* 1959, *Porter & Stockley* 1984, *de Bruijn* 1987), but most later studies have used various modifications of *Gartland & Werley's system* (1951). I have found the original registration of decreased range of motion difficult to apply, and also found it necessary to include the grip strength.

The allocation of points to each parameter included in the score systems has in all investigations been arbitrary. This might possibly influence the evaluation of the functional result. No indication of one parameter being more important than others was found in the literature. Consequently all parameters were given the same maximal score, except the occurrence of late complications. Due to its deleterious effect on wrist function, this finding was given a high priority (*Frykman* 1967, *Cooney et al.* 1980). The statistical analysis demonstrated no evidence against this distribution of points; neither did the interrelationship of some of the parameters included.

The analysis of the radiographic and functional result in patients with undisplaced fractures of Type 1 demonstrated a satisfying result after treatment with plaster for 5 to 6 weeks. This period is probably unnecessarily long. *De Bruijn* (1987) and *Abbaszadegan and associates* 1989) used no splinting at all with good results. I agree with *McAuliffe and associates* (1987), that a short dorsal plaster slab for three weeks is in its place to relieve pain and protect the wrist from swelling. Type 1 fractures included 42 per cent of patients with distal radius fractures.

In Type 2 fractures (23 per cent of the patients), reduction is often indicated. Secondary displacement frequently occurs. Radiographic control should be performed after 10 to 14 days, where re-reduction still is possible. The value of re-reduction has been doubted by *McQueen and associates* (1986). *Fenyö & Johansson* (1974) and *Collert & Isacson* (1978), however, advocated re-manipulation and continued plaster treatment. Alternatively *Jonsson* (1983) recommended re-dislocated fractures treated with external fixation. In my opinion Type 2 fractures should be treated by manipulation after suspension in Chinese fingertraps followed by a low circular cast for 5 weeks. If secondary displacement with dorsal angulation and radial shortening of more than 5 mm occurs, external fixation should be considered in the young patient. In the older patient a moderate secondary displacement of the fracture is probably better left (*McQueen et al.* 1986). A visible deformity will be the result, but in the long term the functional result will be acceptable, and the risk of secondary arthrosis is not influenced by the radiographic position of the fracture.

Type 3 and Type 4 fractures (35 per cent) have almost identical prognoses. Secondary displacement after plaster treatment will always occur. In the present study functional bracing offered no advantage over plaster treatment, and the promising results by *Sarmiento and associates* (1975) could not be confirmed, neither in this study, nor by *Stewart and associates* (1984) or by *de Bruijn* (1987).

Operative treatment with internal or external fixation has been recommended in numerous studies. These studies, except from *Jenkins and associates'* (1987) and *Kongsholm's* (1987), have been un-controlled without a fracture classification, and the methods of evaluating the end result have been difficult to assess. All investigations have demonstrated superior radiographic results. This was also the case in the present series, but the functional result after 3 and 6 months, was not better after external fixation than after treatment with brace or plaster. After one year, however, when wrist function is stationary (*de Bruijn* 1987, present series) a superior functional result can be expected.

Treatment of thirty-five per cent of patients with distal radius fractures with external fixation implies higher economical expenses than conventional plaster treatment. The patients have to be hospitalised, and investments in fixators have to be made. However, re-reductions are avoided, and radiographic examinations during the treatment can be reduced to a minimum. External fixation can therefore be recommended in patients with Older type 3 and 4 fractures. The application of the fixator must be performed meticulously to avoid neurological complications, and be followed by careful instruction of the patient. In the author's opinion no other alternative exists at present. Primary bone grafting, internal fixation with plate and screws or even filling of the cortical defect with bone cement has no place in the treatment of this common fracture, and combination of external fixation and functional treatment (*Clyburn* 1987) must still be regarded as experimental.

APPENDIX 1

The different patient series used for the investigations in the present survey. Ref. No. refers to the papers listed in the introduction. Age is median except ref. No. 1, which is mean.

subject	ref.No.	total	men	women	age	range	follow-up	range
radiograph. norm.wrist	1	57	32	25	43	17-82	–	–
classifi-	2	269	41		58	20-85	–	–
cation				228	64	26-101	–	–
goniometry	5	31	8	23	37	24-65	–	–
grip strength ...	4	100	45	55	45	20-87		
wrist funct.	7	154	35	118	58	23-86	40 months	35-54
arthrosis	6	56	5	51	71	37-92	86 months	75-94
ext. fixation	9	40	7	33	59	27-82	29 months	26-32
funct. bracing ..	10	36	4	32	68	31-91	3 and 6 months	
dorsal plaster...	9	49	5	44	65	31-92	3 and 6 months	
low cast	7+9	91	18	73	63	23-68	42 months	31-54

RESUMÉ

Afhandlingen omhandler problemerne vedrørende klassifikation og behandling af håndledsbrud hos voksne. Efter udmåling af fejlstilling på røntgenbilleder på ulykkestidspunktet og efter heling af bruddet klassificeredes bruddene efter 5 almindeligt anvendte klassifikationssystemer. Ved hjælp af en logistisk regressionsanalyse fandtes det system, der har den bedste prognostiske værdi. For de enkelte typer beskrives det røntgenologiske resultat efter gipsbehandling.

Endvidere undersøgtes betydningen af de parametre, der anvendes til beskrivelse af det funktionelle resultat (fejlstilling, smerter, bevægeindskrænkning, kraftnedsættelse og komplikationer). Der fandtes god korrelation mellem brudtype og funktionelt slutresultat.

Resultaterne efter påpladssætning og gipsbehandling blev sammenlignet med funktionel bandagering og med fastholdelse med ydre apparatur (Hoffmann apparatur). Der fandtes ingen forskel med kort observationstid (3 og 6 måneder), men med lang observationstid var resultatet efter Hoffmann-apparatur bedst. Hoffmann-apparaturet forhindrede, at bruddet atter forskubbede sig efter påpladssætningen. Det bedre funktionelle resultat var specielt korreleret til forhindring af bagoverbøjning af ledfladen. Der var også andre faktorer, der påvirkede resultatet specielt havde brudtype, høj alder og slidgigtudvikling en negativ effekt på resultatet. Disse forhold kunne ikke påvirkes ved hjælp af det ydre apparatur. Påpladssætning og fastholdelse af håndledsbrud med ydre apparatur kan anbefales hos yngre patienter med svært forskudte brud.

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