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Trochanteric Fractures

An Epidemiological, Clinical and Biomechanical Study

BY

J. STEEN JENSEN

MUNKSGAARD . COPENHAGEN

Denne afhandling er af det Lægevidenskabelige Fakultet ved Københavns Universitet antaget til offentligt at forsvares for den medicinske doktorgrad.

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VIII. J. Steen Jensen (198o) Mechanical strength of McLaughlin hip nail plates manufactured from 316 LVM stainless steel. Acta orthop. scand. 51, 439-444

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XII. J. Steen Jensen, S. Sonne-Holm & E. Tøndevold (198o) Unstable trochanteric fractures. A comparative analysis of four methods of internal fixation. Acta orthop. scand. 51, 949-962

Preface

The studies presented were performed at the Biomechanics Laboratory and Department of Orthopaedic Surgery T-2, Gentofte Hospital, University of Copenhagen, Denmark during my appointment as a senior registrar. I am grateful to the heads of the department, Knud F. Jansen and especially Poul S. Rasmussen, for their keen interest and qualified hand guiding through all stages of my investigations.

I am indebted to the heads of the Departments of Orthopaedic Surgery at Rigshospitalet, Frederiksberg Hospital, Frederiksborg County Hospital in Hillerød and Gentofte Hospital for letting me use their patients for the clinical studies. To my associates, N. Mossing, S. Sonne-Holm and E. Tøndevold, I owe great thanks for their profound interest in participating in the radiological and clinical surveyes. The statistics of the large patient series were conducted by Sv. Kreiner-Møller (cand. stat.) who took great interest in the profound analysis of the results and even consented to write the last chapter of this book.

A study like this would not have been possible without understanding colleagues, N. Mossing, O. Buhl and J. Boss Nielsen, who made the daily work smoother and less oppressive.

The biomechanical investigations were made possible through a primary understanding of the involved problems by the national dealer, Simonsen & Weel Ltd. The engineers, E. Glube, M. Sc. and C. Vogel, M. Sc. from the Copenhagen Engineering College demonstrated a comprehensive and unselfish curiosity in the implant testing programme. Even J. Scanlan and P. Lowes of Howmedica International Inc. added important suggestions to the experimental set-up. The testing equipment was built in collaboration with the Machine Work Shop and Laboratory of Electronics, Gentofte Hospital with essential contributions from Otto F. Hansen and J. P.

Thorngaard, M. Sc. in particular. One of the corner stones for the laboratory testing was a free supply of implants, as offered from Howmedica International Inc., N.C. Nielsen Ltd., Zimmer-USA International and Simonsen & Weel Ltd.

An essential condition for the accomplishment of the entire study was extensive financial aid provided by the Danish Medical Research Council, the Medical Research Foundation for Copenhagen etc., Nordisk Gjenforsikrings Jubilæumsfond and the Guildal Foundation.

This study could not have been conducted without an unselfish family. I wish therefore to dedicate this book to my wife, Birthe, and daughters, Christina and Michala, who have shown great patience, understanding and acceptance of the many hours of sparetime offered at the communion table of research.

Copenhagen, November 198o

J. Steen Jensen.

Contents

Chapter 1
Introduction

The relative number of elderly people in the population has been increasing over the years (Boucher 1959, Buhr & Cooke 1959, Jensen & TØndevold 198o, Mårtenson 1962). According to Boucher (1959) about one third of all beds in accident wards of hospitals were occupied by old people. Lucht (1971) found that about 2o % of the elderly admitted to hospital after domestic falls had sustained hip fractures.Hip fractures are one of the main diseases of geriatric medicine.

The treatment of hip fractures requires an increasing part of the total number of hospital days (Gylling 196o, Jensen & TØndevold 198o) and approximately every fifth bed in an ordinary orthopaedic ward nowadays is occupied by a patient with hip fracture (Jensen & TØndevold 198o).

The total number of hip fractures has doubled for every 17 year increment (Alffram 1964, Buhr & Cooke 1959, Jensen & TØndevold 198o, Mårtenson 1962), but a more active program applying operative treatment followed by early mobilization with full weight-bearing has reduced the average hospitalization time to about 21 days (Jensen & TØndevold 198o). Non-operative treatment of hip fractures is known to be followed by high mortality rates (Arlt et al 1973, Clawson 1957, Cleveland et al 1947, 1948).

In accordance with these considerations a need was found for a re-evaluation of the epidemiology of hip fractures and themortality rates. This survey was to be based on a series of patients treated according to modern principles of internal fixation and mobilization.

The results of treatment of femoral neck fractures have been well described in the literature,biomechanically by Frankel (196o) and clinically by Barnes et al (1976).

In the internal fixation of trochanteric fractures

3 main types of implants have been widely used, namely a one-piece, fixed angle nail-plate (Jewett 1941), a two-piece, free angle nail-plate (Thornton 1937, McLaughlin 1947) and a telescoping screw-plate device (Pugh 1955, Clawson 1964).

Throughout the years numerous publications have considered technical failures following the internal fixation of trochanteric fractures. Only a few of these were comparative studies of the different methods (Friedenberg et al 1972, Jacobs et al 1976, Kyle et al 1979, Laros & Moore 1974, Massie 1962, Wade et al 1959, Wynn Jones et al 1977). These studies have, however, only compared two methods at a time.

With the increasing number of hip fractures it is for economical reasons at least, of utmost importance to improve the fracture treatment and apply the safest possible methods (Gallanaugh et al 1976, Jensen & Tøndevold 198o).

The aims of the present studies were thus to evaluate the 3 types of implants mentioned biomechanically and to evaluate the results of internal fixation in a comparative study. An additional purpose was to convey an understanding for the importance of biomechanical considerations in fracture treatment.

Chapter 2

Epidemiology and Mortality

Former studies of the mortality following hip fractures were based on series including a large number of patients treated non-operatively and with late mobilization of the operated patients (Alffram 1964, Clark & Wainwright 1966, Manpel et al 1961, McGoey & Evans 196o, Mikkelsen & Langholm 1964, Weeden et al 1957). The mortality rate has been claimed to be higher in patients with trochanteric fractures than among those sustaining femoral neck fractures (Colbert & O´Muircheartaign 1976, Cleveland et al 1951, Dolk & Westerborn 1977, McGoey & Evans 196o, Mikkelsen & Langholm 1964, Riska 197o, Weeden et al 1957).

An investigation of the incidence of hip fractures during the beginning of the 197o´ties was undertaken (Jensen 198o (I)). Simultaneously the influence of age, sex, social environment and fracture type on the mortality in series of patients treated according to modern principles was analyzed (Jensen & Tøndevold 1979 (II), Jensen et al 1979 (III)).

Patients

During the years 1971 - 1976 a total of 1,592 patients over the age of 5o years were admitted to hospital with hip fracture.

In Table 2.1 the age and sex distribution is listed in relation to the fracture type. The mean-age of the entire series was 77 years, which is consistent with recent reports (Beals 1972, Gordon 1972, Riska 197o), but 3 - 5 years older than stated in earlier publications (Alffram 1964, Fitts et al 1959, Miller 1978, Sweet et al 1967, Öhman et al 1968). The percentage of female patients of about 75 % is largely unchanged (Alffram 1964, Gordon 1972, Manpel et al 1961, McNeill 1975, Miller 1978, Weeden et al 1957). Female patientspatients had a higher mean-age than males. In accordance with others (Alffram 1964, Beals 1972, Gordon 1972) females sustaining trochanteric fractures were older than those sustaining femoral neck fractures.

Table 2.1 : Age and sex distribution related to fracture type in 1,592 patients.

		Troch. fract.	Fem.neck fract.
Total Series :			
Number		836/1592 (52%)	756/1592 (48%)
Age	mean	78 ± 1o	76 ± 1o
	median	79	77
	range	51 - 98	51 - 99
Females :			
Number		631/836 (76%)	593/756 (78%)
Age	mean	79 ± 9	76 ± 1o
	median	81	77
	range	52 - 98	51 - 97
Males :			
Number		2o5/836 (24%)	163/756 (22%)
Age	mean	73 ± 1o	75 ± 11
	median	75	76
	range	51 - 95	51 - 99

Trochanteric fractures were internally fixed with Jewett, McLaughlin or sliding screw-plates in 96 % (799/836), whereas non-operative treatment was applied in the remainder. In femoral neck fractures, 44 % (333/756) were treated with primary hemiarthroplasty and 29 % (221/756) by internal fixation with a sliding nail. The remaining 27 % (2o2/756) were treated non-operatively for impacted fractures with early weight-bearing mobilization.

Table 2.2 : The assessment of social function.

Social function groups		Definition
I	Independent	Manages everything Possibly working
II	Slightly dependent	Manages household,Meals-on-wheels Home-help ≤ 4 hours/week
III	Moderately dependent	Manages personal needs Home-help ≥ 5 hours/week Possibly Distrect Nurse
IV	Totally dependent	Living in nursing home or long-term nursing at home

Table 2.3 : Assignment to social function groups on admission to hospital.

Social function group	I	II	III	IV
Number	148	128	1o6	136
Percentage	29%	25%	21%	26%
Median age	69	79	81	84

Another study was made in 1977 on a prospective series of 518 patients with hip fractures (Jensen et al 1979 (III)). The median-age in that series was 78 years (range 26 - 96), and the mean-age 76 $\pm$ 12 years. 81 % (417/518) of the patients were females.The distribution of fracture types and methods of treatment were fairly similar to the retrospective series presented above. The 518 patients were assessed and classified into four groups according to their dependence on the social welfare system, as defined in Table 2.2. The distribution of the patients according to social function is presented in Table 2.3 together with the median-ages observed.

Methods

Information about the composition of the background population in the area of admission for the years 1971 - 1976 was obtained from the Danish Central Bureau of Statistics.

Both the patients and the background population of the area were subdivided into sex and age groups with 5 year increments. The fracture types were listed for the patients.

From these data the incidence of hip fractures was calculated and analysed by a multiplicative Poisson model (Andersen 1977).

Life tables were calculated by decrement analysis and compared by Gehan's modified Wilcoxon test.From information about date of admission and date of death the life tables were calculated. In the analysis of the mortality in hospital even the dates of discharge were included. Survival rates for a comparable cohort from the population in the area of admission of similar age and sex distribution were calculated from data obtained from the Danish Central Bureau of Statistics.

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The patients in the prospective series had a follow-up examination after 6 months and were re-assessed in the social function groups. In case of death the date was obtained from the Danish Central Bureau of Personal Registration and the survival time calculated.No patients were lost to follow-up.

A Cox regression analysis was used for the study of the dependence between mortality and age, sex or social function.

Results and Discussion

The occurence of femoral neck fractures and trochanteric fractures in relation to age and sex is shown in Figure 2.1. The percentage of femoral neck fractures was found to be fairly constant and independent of age in males. The percentage decreased constantly with the age in females, thus nearly being halved from the 5th to the 9th decade. In another series (Jensen et al 198o (XII)) a multiple contingency table analysis revealed that the number of unstable trochanteric fractures increased with the age (P < o.oooo5), especially in females.

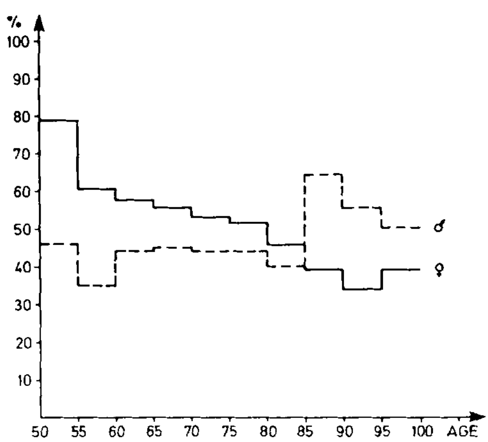


Figure 2.1 : Percentage of femoral neck fractures related to age and sex.

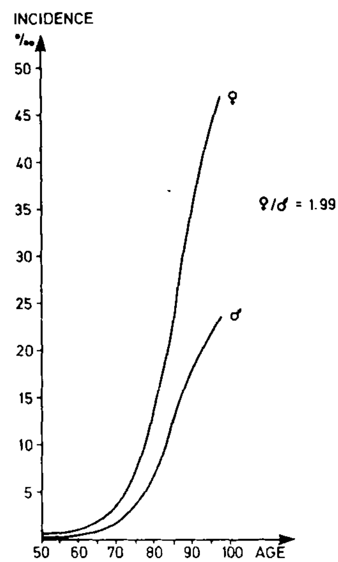


Figure 2.2 : Incidence of hip fractures.

As seen from Figure 2.2 the incidence of hip fractures in the retrospective series increased exponentially with age from the 7th decade and doubled with each 5 year increment of age. The sex ratio females/males was 1.99. These findings confirmed reports from Bauer (196o), Gallanaugh et al (1976) and Knowelden et al (1964).

The incidence of hip fractures above the age of 5o years was 3 per thousand, which is in accordance with recent studies (Gallanaugh et al 1976, Gordon 1972). It is, however, approximately twice the incidence reported in the 195o´ties (Buhr & Cooke 1959, Stewart 1955, 1958).

In comparison with Alffram´s series (1964) a similar incidence was found for patients until the age of 75 years. A considerable increase for the oldest age groups was, however, encountered. Nilsson & Obrant (1978) claimed that the incidence has not changed since the late 196o´ies, but this can not be confirmed by this study. As about half of the patients sustaining hip fractures are over the age of 8o years an adjustment of the age distribution of the population and a re-evaluation of the incidence is considered important every lo years for the future planning of hospital care of patients with hip fractures.

The average hospitalization time was 24 days (range 2o - 28 days for each year of the period). No significant difference in hospitalization time was found between trochanteric and femoral neck fractures.

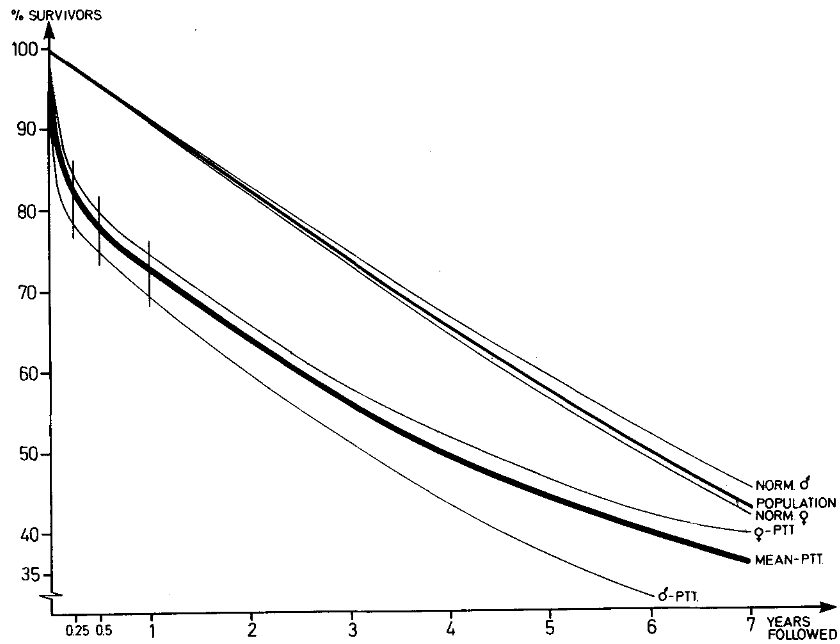
The hospital mortality was 8.6 % (137/1,592), being 9.8 % (82/836) after trochanteric fractures and 7.3 % (55/756) following femoral neck fractures. A multivariate logistic analysis revealed, that age alone was responsible for the difference ($\underline{P}$ < o.o2), whereas the fracture type as such was of minor importance. This is in contrast to those who claimed a higher mortality rate in trochanteric fractures (Colbert & O´Muircheartaign 1976, Cleveland et al 1951, Dolk & Westerborn 1977, McGoey & Evans 196o, Mikkelsen & Langholm 1964, Riska 197o, Weeden et al 1957). It is shown, however, in the present series that female patients sustaining trochanteric fractures are older. It must be emphasised that age and sex exclusively determine the hospital mortality rates (Alffram 1964, Beals 1972, Clark & Wainwright 1966, Eddy 1972, Fitts et al 1959, Gordon 1972, Jensen & Tøndevold 1979 (II), Manpel et al 1961, Miller 1978, Reno & Burlington 1958, Schenk et al 1956). Severe somatic complications post-operatively result in a higher mortality rate (Reno & Burlington 1958). This is confirmed by the present series in which 63 % (122/194) of patients sustaining serious somatic complications died. Schenk et al (1956) found as many as 85 % however.

Figure 2.3 : Estimated probability of death during hospitalization after hip fracture, related to age.

By means of a multivariate logistic analysis the probability of death after hip fracture could be estimated according to age and sex, as shown in Figure 2.3. The probability of death increased exponentially with the age and was higher for males in any age group.

The life tables for the entire series and for males and females separately are presented in Figure 2.4. The expected survival rates for the population cohort of same age was slightly higher for males than for females, because the male patients were younger in the present series. There was, however, a higher mortality among male patients with hip fractures during the entire period of observation. The curves for male patients became parallel 1.8 years after the fracture with an excess mortality of 23 %, and 3.6 years after the fracture the survival rate of male patients was slightly higher than expected. By comparison, female patients obtained the expected survival rate 1.6 years after the fracture and the excess mortality was 17 %. After 2.6 years the survival rate after hip fracture became higher than expected.

Figure 2.4 : Life Tables for 1,592 patients with hip fractures.



These results are in contrast to others (Alffram 1964, Colbert & O'Muircheartaign 1976, Fitts et al 1959, Miller 1978), who claimed the survival rate to parallel the expected after 3 - 8 months, respectively, but their series were smaller and their patients younger.

In the prospective study of 518 patients all patients with hip fractures were included. This resulted in a slightly lower mean-age of 76 years compared to 77 years in the former study (Jensen & Tøndevold 1979 (II)). The median-age was also one year lower.

Table 2.4 : Risk of death or social deterioration 6 months after hip fracture.

Pre-fracture assessment		Died	Social deterioration	Total risk
I :	148	4 (3%)	52/144 (36%)	56/148 (38%)
II :	128	12 (9%)	5o/116 (43%)	62/128 (49%)
III :	1o6	27 (26%)	39/ 79 (49%)	66/1o6 (62%)
IV :	136	38 (28%)	-	38/136 (28%)
Total	518	81 (16%)	141/339 (42%)	222/518 (43%)

At follow-up examination 6 months later the mortality was calculated to about 16 %. This is slightly lower than the about 2o % stated in previous studies (Alffram 1964, McCown & Miller 1976, Miller 1978, Jensen & Tøndevold 1979 (II)), but might be explained by the lower age.

As seen from Table 2.4 the mortality rates increased with increasing social dependence, as assessed on admittance to hospital. A Cox regression analysis revealed the 6 months mortality to depend more on the pre-fracture social function than on the age and sex of the patients (P < o.ool).

The table also demonstrates that the total risk of social deterioration 6 months after the fracture increased significantly with a higher level of dependence as assessed on admission to hospital (P < o.o5, Chi-square test). A multivariate logistic analysis revealed that the pre-fracture social dependence determined the total risk of death or social deterioration to a greater extent than the age at the time of fracture (P < o.o5).

The pattern of mortality following hip fractures as compared to the population might thus be discussed.

It was observed that the number of somatic complications increased with age. The lethality among patients suffering from somatic complications also increased with age. In comparison with the population the old and weak patients were thus dying during hospitalization. During the following period an excess mortality was observed among the socially more dependent patients, who might also be considered as physically more frail. About one and a half year after the fracture the survival rates for the patients might thus be influenced by a higher percentage of somatically stronger and socially more independent patients compared to the cohort of the population.

A total clarification of the mortality patterns, however, demands a pro-spective study with a long-term follow-up of patients matched according to age, sex, physical condition and social dependence.

Conclusions

The incidence of hip fractures increases exponentially with age from the 7th decade of life and is approximately doubled with each 5 year increment of age. The sex ratio females / males is 1.99.

The incidence among persons above the age of 75 years has increased during the past twenty years. An adjustment of the incidence for the old age groups is recommended every lo years.

The mean-age of patients sustaining hip fractures is 77 years, the median-age 78 years, and about 75 % of pateints are females.

Trochanteric fractures are encountered in about 5o % of patients. The percentage of trochanteric fractures is constant and independent of age in males, but increases with age in females. Unstable trochanteric fractures are increasing with age.

The hospital mortality is 9 % with an average hospitalization time of 24 days. The fracture type does not influence the mortality rate.

The 6 months mortality is about 2o %.

The mortality after hip fracture is primarily determined by pre-fracture social dependence on the social welfare system and secondarily by the age and sex of the patients.

Chapter 3
Classification of Trochanteric Fractures

The results of the internal fixation of trochanteric fractures by different methods have been the subject of numerous publications. The deeper understanding of the results presupposes knowledge about the fractures treated.

A need for a uniform classification of trochanteric fractures was therefore found.

Primarily a classification system must contain valid information about the possibility of obtaining fracture reduction with bony contact. A stable weight transmission system for the load at the hip is thereby established. In case of diastasis over the fracture line, parts of, or the entire, hip joint load must be transmitted through the implant.

Another demand is a prediction of the risk of secondary fracture dislocation following internal fixation.

In the literature 5 different systems of fracture classification have been described. These are presented in Table 3.1.

The most simple classification divides the fractures into displaced and undisplaced (Hafner 1951, Bang Rasmussen 1953, Wade et al 1959).

The mechanical importance of the femoral arch has been pointed out in numerous publications leading to a classification based on the medial comminution (Harrington 1975, Jacobs et al 1976, Johnson et al 1968, Kumar 1973, Laros & Moore 1974, Massie 1962, 1964, Murray & Frew 1949, Niemann & Mankin 1968, Rennie & Mitchell 1976, Sarmiento 1967, Sarmiento & Williams 197o, Scott 1951).

Ender (197o) in connection with the introduction of his condylocephalic nailing described a system based on the fracture mechanism. The system, however, has only been applied in publications about this particular method of internal fixation (Ender 197o, Ender & Simon-Weidner 197o, Hult & Nilsson 1978, Kapral 1976, Poigenfürst & Schnabl 1977).

Table 3.1 : Classification systems for trochanteric fractures.

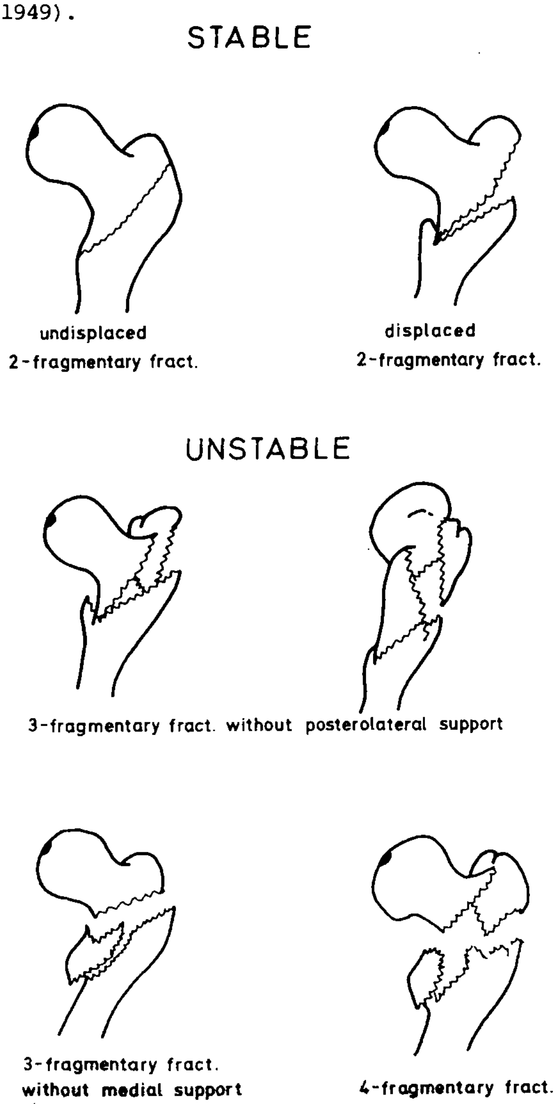
PRIMARY DISLOCATION :	
Type 1 :	undisplaced
Type 2 :	displaced
PRESENCE OF MEDIAL COMMINUTION :	
Type 1 :	stable,i.e. no medial comminution
Type 2 :	unstable,i.e. displaced lesser trochanter or larger femoral arch fragment
ENDER´s SYSTEM (197o) :	
Type 1 :	eversion fracture,i.e. posteromedial rotation wedge
Type 2 :	impaction fracture,i.e. inversion and adduction of neck fragment with varus collapse of the fracture
Type 3 :	diatrochanteric fracture,i.e. fracture line extending subtrochanterically or being reversed
TRONZO´s SYSTEM (1973) :	
Type 1 :	incomplete fracture only involving greater trochanter
Type 2 :	uncomminuted fracture,with or without slight displacement intact posterior wall and relatively small lesser trochanter fragment
Type 3 :	comminuted posterior wall with telescoping of neck spike into shaft fragment.Lesser trochanter fragment large
Type 4 :	like Type 3,but greater trochanter totally broken off
Type 5 :	comminuted posterior wall without telescoping of the 2 major fragments.Neck spike displaced outside shaft.Most posterior wall lost medially
Type 6 :	reversed oblique fracture with medial displacement of shaft.Greater trochanter attached or not to neck fragment
EVANS´ SYSTEM (1949) :	
Type 1 :	undisplaced 2-fragmentary fracture
Type 2 :	displaced 2-fragmentary fracture
Type 3 :	3-fragmentary fracture without postero-lateral support due to displaced greater trochanter fragment
Type 4 :	3-fragmentary fracture without medial support due to displaced lesser trochanter or femoral arch fragment
Type 5 :	4-fragmentary fracture without medial and postero-lateral support.Combination of Type 3 and Type 4

Apart from the medial comminution leading to unstable reduction in the AP-plane, detachment from the posterior aspect of the greater trochanter might lead to reduction with fracture diastasis in the lateral plane. Boyd & Griffin (1949) described a system which took into consideration both the mechanical and postero-lateral instability. This system was modified by Tronzo (1973), but has only been used in few publications (Bosacco et al 1973, Boyd & Andersson 1961, Ecker et al 1975), maybe because it is rather complex in its construction.

A rather simple classification system was described by Evans (1949). This system was slightly modified by

Jensen & Michaelsen (1975), who classified the fractures from the pre-operative X-rays alone, and included only 5 types. The system, as shown in Figure 3.1, combines displacement with detachment from the lesser or greater trochanter. Numerous publications have adopted Evans' classification (Bremner & Graham 1958, Clawson 1957, 1964, Cram 1955, Cuthbert & Howat 1976, Dimon 1973, Dimon & Hughston 1967, Evans 1951, Foster 1958, Friedenberg et al 1972, Harrington & Johnston 1973, Horn & Wang 1964, Jensen 198o (IV), Jensen et al 1978 (X), Jensen et al 198o (XI), Jensen et al 198o (XII), Jensen & Sonne-Holm 198o, Kuderna et al 1976, Kyle et al 1979, Lowell 1966, Morrison et al 1978, Parker 1955, Robey 1956).

Figure 3.1 : Classification of trochanteric fractures according to Evans (1949).



The purpose of the present study (Jensen 198o (IV)) was to select the classification system most predictive for the prognosis of the fracture treatment as related to fracture reduction and secondary dislocation. It was decided to consider only fractures treated with the sliding screw-plate system (Clawson 1964), because this fixation method allows secondary impaction of the fracture. In all cases of diastasis the fracture thus dislocates until bony contact between the main fragments is established. In other methods of internal fixation a secondary fracture dislocation would always involve either failure of the osteoporotic bone of the femoral head or neck OR technical failure of the implant.

Patients

234 patients with trochanteric fractures were treated with the sliding screw-plate implant in the period January, 1st 1978 to June, 3oth 1979. The fractures were followed to bone union or technical failure.

Methods

The fracture types were assessed according to the 5 classification systems from the pre-operative X-rays.

The fracture reduction was evaluated from the immediate post-operative X-rays. Anatomical reduction was defined as a maximum diastasis of 4 mm over the fracture line in the AP- or lateral projection. The fractures were X-rayed by regular intervals. Technical failure was defined as bending or loosening of the implant and cutting or penetration of the screw within or through the femoral head or neck confinements. Secondary dislocation was defined as impaction or varus displacement due to technical failure, or impaction due to telescoping of the implant.

An information analysis was performed by multidimensional contingency tables adding variables in steps and compared in relation to Kullbach´s information measure (1959). For each step of the analysis the significance of the information contained was calculated. In addition a multiple contingency table analysis was performed with successive testing, as described by Madsen (1976).

Results and Discussion

The fractures were assessed according to the different classification systems in types as listed in Table 3.2, which also shows the fracture reductions obtained.

Table 3.2 : Classification of trochanteric fractures in relation to the quality of reduction.

Type	Number	Anatomical reduction in both planes	Fracture diastasis in lateral plane	Fracture diastasis in AP-plane	Fracture diastasis in both planes
Primary Dislocation :					
1 :	41 (18%)	3o (73%)	7	4	-
2 :	193 (82%)	45 (23%)	43	18	87 (45%)
Medial Comminution :					
1 :	139 (59%)	63 (45%)	39	6	31 (22%)
2 :	95 (41%)	12 (13%)	11	16	56 (59%)
Ender´s System :					
1 :	114 (49%)	49 (43%)	18	13	34 (3o%)
2 :	1o6 (45%)	23 (22%)	31	6	46 (43%)
3 :	14 (6%)	3 (21%)	1	3	7 (5o%)
Tronzo´s System :					
1 :	2 (<1%)	1 (5o%)	1	-	-
2 :	1o6 (45%)	59 (56%)	23	1o	14 (13%)
3 :	33 (14%)	4 (12%)	4	4	21 (64%)
4 :	52 (22%)	6 (12%)	18	5	23 (44%)
5 :	4o (17%)	5 (13%)	4	3	28 (7o%)
6 :	1 (<1%)	-	-	-	1
Evans´ System :					
1 :	25 (11%)	24 (96%)	1	-	-
2 :	9 (4%)	8 (89%)	1	-	-
3 :	95 (41%)	31 (33%)	34	3	27 (28%)
4 :	28 (12%)	6 (21%)	4	11	7 (25%)
5 :	77 (33%)	6 (8%)	1o	8	53 (69%)

The first step of the information analysis revealed the Evans´ system to contain the most reliable information about the possibility of achieving anatomical reduction for the 5 different fracture types (P < o.oooo5). The gradings in the system included an increasing risk of reduction with diastasis in one or both planes (P < o.ol, Sperman-test). In the next step of the analysis the Evans´ system was excluded and the second best system was found to be that based on the primary dislocation of the fracture (P < o.oooo5). The remaining 3 systems did not give any significant information in the following steps of the analysis (P = o.3539). A multiple contingency table analysis applied to the Evans' system revealed, that the fracture type determined the quality of reduction (P < o.oooo5).

Table 3.3 : Classification of trochanteric fractures in relation to secondary fracture dislocation.

Type	Secondary Dislocation in Relation to Reduction: Anatomical reduction both planes	Diastasis lateral plane	Diastasis AP-plane	Diastasis both planes	Telescoping	Technical Failure	Secondary Dislocation Total
Primary Dislocation :							
1 : 41	1 (3%)	5 (71%)	4 (1oo%)	o	9	1	1o (24%)
2 : 193	5 (11%)	27 (63%)	12 (67%)	81 (93%)	118	13	125 (65%)
Medial Comminution :							
1 : 139	3 (5%)	28 (72%)	5 (83%)	29 (94%)	61	7	65 (47%)
2 : 95	3 (25%)	4 (36%)	11 (69%)	52 (93%)	66	7	7o (74%)
Ender system :							
1 : 114	4 (8%)	1o (56%)	1o (77%)	31 (91%)	5o	8	55 (48%)
2 : 1o6	o	21 (68%)	4 (67%)	44 (96%)	66	6	69 (65%)
3 : 14	2 (67%)	1	2 (67%)	6 (86%)	11	o	11 (79%)
Tronzo system :							
1 : 2	-	1	-	-	1	-	1 (5o%)
2 : 1o6	5 (8%)	16 (7o%)	9 (9o%)	13 (93%)	41	4	43 (41%)
3 : 33	1 (25%)	1 (25%)	3 (75%)	19 (9o%)	23	2	24 (73%)
4 : 52	-	11 (61%)	3 (6o%)	22 (96%)	32	5	36 (69%)
5 : 4o	-	3 (75%)	1 (33%)	26 (93%)	29	3	3o (75%)
6 : 1	-	-	-	1	1	-	1 (1oo%)
Evans system :							
1 : 25	1 (4%)	1 (1oo%)	-	-	1	1	2 (8%)
2 : 9	-	1 (1oo%)	-	-	1	-	1 (11%)
3 : 95	2 (6%)	24 (71%)	3 (1oo%)	26 (96%)	51	7	55 (56%)
4 : 28	1 (17%)	1 (25%)	8 (73%)	7 (1oo%)	16	1	17 (61%)
5 : 77	2 (33%)	5 (63%)	5 (63%)	48 (91%)	58	5	6o (78%)

In Table 3.3 the pre-operative classification of the fractures is related to the secondary fracture dislocation. The information analysis was repeated and confirmed that the Evans system also in this respect was the most informative (P < o.o18). In the next step of the analysis the second best system was again that based on the primary dislocation of the fractures (P < o.oooo5). No additional information was contained in the remaining systems (P = o.14) according to the following steps of the analysis.

This means, that the classification system according to Evans was highly superior to any other systems. The second best system was, in respect of reduction as well as risk of secondary dislocation, that based on primary dislocation. The gradings in that system were, however, not differentiated enough, as more than 8o % of fractures were assessed in the risk group.

The gradings in the Evans system showed also an increasing risk of secondary fracture dislocation ($\underline{P}$ < o.ol, Spearman test) and a multiple contingency table analysis revealed that secondary dislocation was determined by the quality of reduction ($\underline{P}$ < o.oooo5).

This means, that the fracture type is determining the quality of reduction, as the more comminuted fractures are more difficult to reduce with bony contact. The appearance of fracture diastasis in one or both planes was connected with a high risk of secondary dislocation.

The different types in the Evans system can be further analysed.

Type 1 fractures are undisplaced primarily and only consist of a shaft and a femoral neck fragment. In all fractures but one the bony contact between the fragments was preserved. In the latter case telescoping was encountered. One of the anatomically reduced fractures was followed by a technical failure.

Type 2 fractures consist of two displaced fragments. All these fractures were reduced anatomically except one with anterior diastasis. This resulted in secondary impaction due to telescoping of the screw.

Type 3 fractures with detachment of a posterior fragment from the greater trochanter could be anatomically reduced only in every third case. The problem is the reduction in the lateral plane, as for 36 % (34/95), or bi-plane diastasis, as for 28 % (27/95). Secondary dislocation occurred in 56 % (55/95) of cases. Bi-plane diastasis was the cause in 96 % (26/27) of cases and anterior or posterior diastasis in 71 % (24/34).

Type 4 fractures with detachment of the lesser trochanter from the femoral arch could be anatomically reduced in only 21 % (6/28) of cases. Diastasis medially was encountered in 39 % (11/28), leading to secondary dislocation in 73 % (8/11). Bi-plane diastasis was encountered in 25 % (7/28), which all dislocated secondarily.

Type 5 fractures have a combination of the mechanical problems involved in Type 3 and Type 4, respectively. Anatomical reduction was achieved in only 8 % (6/77). Bi-plane diastasis was encountered in 69 % (53/77). Secondary dislocation was observed in 78 % (6o/77). This was most often due to bi-plane diastasis, as for 8o % (48/6o), or one-plane diastasis, as for 17 % (1o/6o) of cases.

In the total series secondary dislocation was found in 8 % (6/75) of anatomically reduced cases, but this is to some extent due to the definition of anatomical reduction, allowing a fracture diastasis of 4 mm.

In the present series the modification of the Evans´ system (Jensen & Michaelsen 1975) was used. Evans (1949) originally assessed the stability of the fractures from the primary and the immediate post-operative X-rays. In the present series the fractures were assessed solely from the primary X-ray. This assessment is very easy to apply, as just the number of fragments is counted. The simplification seems justified from the results obtained here and comprises a satisfactory prediction of the prognosis for the internal fixation.

Conclusions

The Evans´ classification for trochanteric fractures is highly superior ro any other existing system concerning the prediction of the possibility of achieving anatomical fracture reduction and the risk of secondary fracture dislocation. These two factors should be the corner stones of any classification system, because the comminution of the fracture is determining the quality of reduction, and the existence of fracture diastasis is leading to secondary dislocation.

The Evans classification system should thus be mandatory in any publication on the results of treatment of trochanteric fractures.

Chapter 4

Methods of Internal Fixation

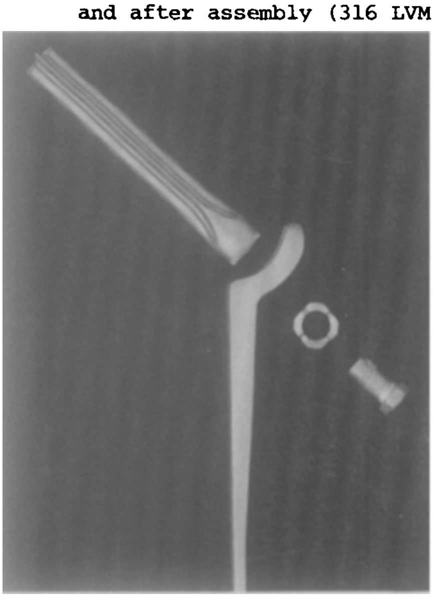
A comprehensive historical review of the development of hip implants has been given by Tronzo (1974).

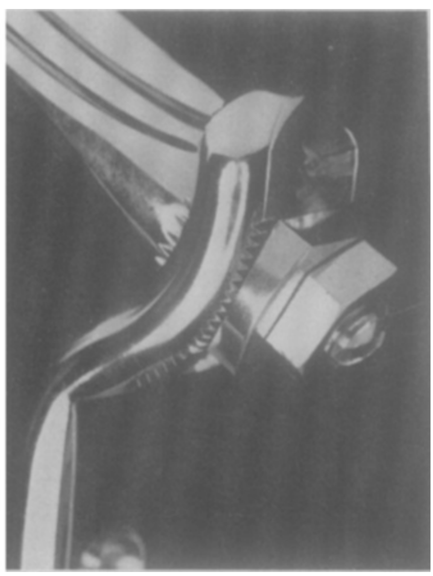
The three most widely used methods of internal fixation for trochanteric fractures in Nothern Europe will be described.

McLaughlin Nail-Plate

Thornton (1937) was the first to describe a succesful case of internal fixation of a trochanteric fracture with to-days equipment. He used a Smith-Petersen nail mounted to a side-plate by a bolt. This method was further developed by McLaughlin (1947). From Scandinavia the first reports on the use of McLaughlin implants were published around 195o (Svend Hansen 1949, Bang Rasmussen 1953).

Figure 4.1 and 4.2 : McLaughlin nail-plate, before (Co-Cr-Mo) and after assembly (316 LVM steel).





As seen in Figure 4.1 the implant consists of a nail, which has a trifin shaped cross-section. The base of the trifin nail is plane with a circular cross-section and equipped with small notches. The plate has a curved extension, which is equipped with serrations to secure rotational stability. The shape of the curved extension is hemispherical. The nail and the plate is assembled by a top bolt with a thin washer interposed between the back of the curved plate extension and the bolt. The washer has 2 knobs fitting with correspon-ding notches at the back of the plate extension. The implant can be assembled in angles with 6^{o} increments from 114^{o} to $15o^{o}$, and is thus a free angle device. The described implant is manufactured from Cobalt-Chromium-Molybdenum alloy (How-medica International Inc., USA and Ireland). In 1955 McLaugh-lin & Garcia described a modification with a diamond shaped nail with a base extension into a threaded stud. The implant was assembled by a nut with an enclosed elastic washer with the purpose of avoiding unwinding. This implant was also manufactured from Cobalt-Chromium-Molybdenum alloy.

With the same purpose Zimmer-USA has altered the nail-plate connection by increasing the thickness of the washer and locked the top bolt by an additional thin, cen-trally placed bolt with left turned threads (Figure 4.2). This implant is manufactured from 316 LVM stainless steel. The dimensions of the implant are otherwise identical with the Cobalt-Chromium-Molybdenum implant, but the increments between the netches of the plate extension are 2^{o}.

Jewett Nail-Plate

In 1941 Jewett described an implant with a fixed angle between the nail and the plate. Newell (1947), Cleveland et al (1948) and Jewett et al (1953) were the first to describe the clinical experiences with this device.

Attempts have been made to improve the strength of the nail part by using a thick, round nail (Holt 1963) or a I-beam nail (Sarmiento 1967, Sarmiento & Williams 197o). The trifin nail cross-section has, however, gained the wi-dest popularity.

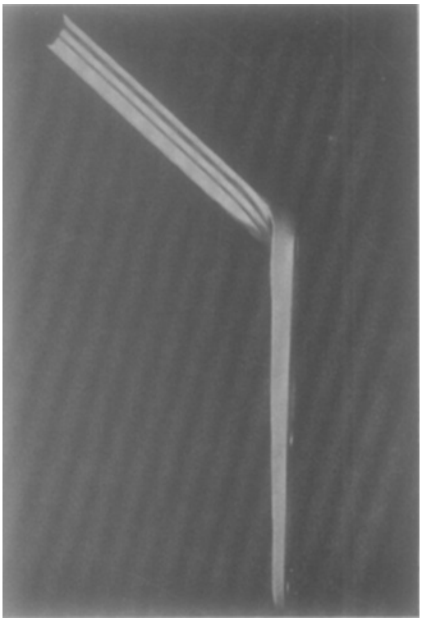


Figure 4.3 : The Jewett nail-plate manufactured from Co-Cr-Mo alloy.

The implant is available in different nail and plate lengths with 5^{o} increments of the nail-plate angle between $12o^{o}$ and $16o^{o}$.

The implant is cast as a one-piece device from Cobalt-Chromium-Molybdenum alloy (Howmedica International Inc., USA and Ireland).

Sliding Screw-Plate

In the beginning of the 195o´ies implants with telescoping nails were introduced by Pugh (1955) and von Pohl (Böttger & Dahlke 1963, Ehlers & May 1964, Kirschke 197o). These original implants were modified by Massie (1962, 1964), and in 1964 Clawson described the sliding screw-plate, which is the most widely used telescoping device in Western Europe to-day.

As seen from Figure 4.4 the implant consists of a lag screw threaded on the proximal 2 cm. The remaining part of the screw is hexagonal in shape. The screw is assembled with the barrel of the side plate. Rotational stability of the implant is secured by a stud in the lower medial part of the round barrel. This implant is manufactured from Cobalt-Chromium-Molybdenum alloy and supplied in barrel-plate angles of 135^{o} and 15o^{o} (Howmedica International Inc., USA and Ireland).

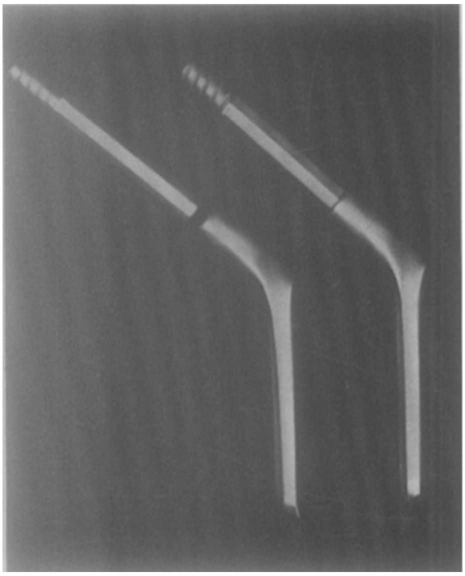


Figure 4.4 : Sliding screw-plate implant manufactured from Co-Cr-Mo alloy, before and after assembly.

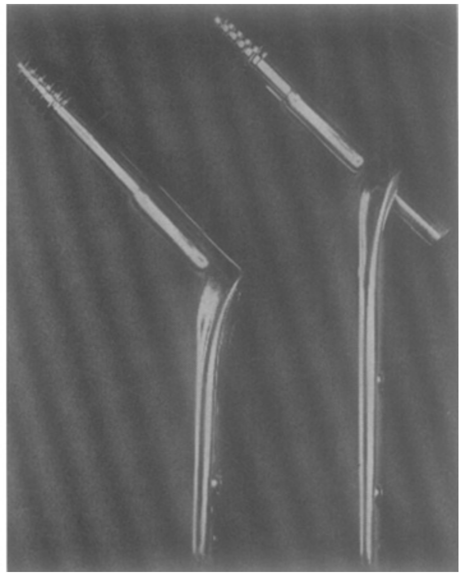


Figure 4.5 : Sliding screw-plate implant manufactured from 316 LVM stainless steel, demonstrating telescoping.

Another modification of the sliding screw-plate implant is shown in Figure 4.5. The difference to the type mentioned above is, that the rotational stability is secured by an inferiorly placed, longitudinal slot in the round screw fitting with a brim in the barrel. The implant is manufactured from 316 LVM stainless steel and supplied in barrel-plate angles with 5^{o} increments from 12o^{o} to 15o^{o} (Zimmer-USA International, USA and France).

Besides that a third modification (the original) by Richards Manufacturing Compahy Inc., USA exists, being identical with the afore-mentioned implant apart from the slot in the screw being placed superiorly. This implant is manufactured from 316 LVM stainless steel and supplied in barrel-plate angles with 5^{o} increments from 13o^{o} to 15o^{o}.

Chapter 5

Determination of Hip Joint Force, Abductor Muscle Force and Femoral Shaft Inclination

The internal architecture of the femoral neck was proved to be in accordance with the mathematical stress trajectories by Wolff (187o). This was confirmed by others (Backman 1957, Inman 1947, Koch 1917, Tobin 1955, Williams & Svensson 1971).

Conflicting results have been stated concerning the relationship between the magnitude and direction of the hip joint force and the abductor muscle force as well as the inclination angle of the femoral shaft. Calculated ratios of abductor muscle force in relation to hip joint force has varied from o.4 - o.6 (McLeish & Charnley 197o, Pauwels 1935, Rydell 1966, Williams & Svensson 1968) up to o.65 - o.75 (Amtmann & Kummer 1968, Denham 1959, Hamacher & Roesler 1972, Inman 1947). In the same publications the joint force inclination was reported as between 6^{o} and 17^{o}, the abductor pull direction between $1o^{o}$ and 21^{o} and the femoral shaft inclination between 5^{o} and 15^{o}.

In an experimental situation there is a need for a standardized arrangement regarding these parameters. For static experiments on surgical implants the vectors and the femoral shaft inclination is for simplification considered in the frontal plane only.

The photoelastic technique, which is based on transparent, isotropic solids becoming bi-refringent under mechanical loading (Föppl & Mönch 1972), has been widely used by engineers in the analysis of constructions which are difficult to describe in mathematical terms. Although the anisotropy of bone can not be taken into account Brekelmans et al (1972) found the method useful in determining the mechanical behavior of bone. The photoelastic technique has been used for studies of 2-dimensional hip models (Fessler 1957, Milch 194o, Ruszkowski & Muftic 1972), showing stress patterns corresponding with the stress trajectories in the femoral neck (Wolff 187o, Koch 1917, Pauwels 1935, 1973).

The purpose of the present study (Jensen 1978 (V)) was thus by use of the photoelastic technique to determine the relationship between the force vectors and femoral shaft inclination in order to find a standardized arrangement for further laboratory experiments.

Hip Models

Based on measurements on X-rays of normal hip joints from 5 persons, 2-dimensional models of the proximal femur were manufactured from lo mm thick polyester plates (Araldite-B). Idealized models with femoral neck angles of 13o$^{\circ}$ and 14o$^{\circ}$, respectively, were made.

Theoretical Background

When the hip model (Araldite-B) is loaded and illuminated with polarized light in a polariscope the difference between the principal stresses at any point in the model is proportional to the relative retardation of the two component rays of polarized light that pass through the point. When the relative retardations are equal to an integral multiple of wavelengths of the light used, no light is transmitted. In monochromatic polarized light the lines of constant shear stresses appear as black bands, the isochromates. In white polarized light the neutral axis, which is stress-free, is seen as a dark band, while the isochromates appear in colours of the spectrum. The isochromates are numbered from the neutral axis, which is called the zero-isochromate. The number of isochromates increases with increasing mechanical stress (Föppl & Mönch 1972).

Experimental Arrangement

The hip model was mounted to a steel socket and placed in a polariscope (Tiedemann A 159, W.Germany). A vertical load was applied and the abductor muscle pull simulated by weights over a system of pulleys to the greater trochanter of the model.

The parameters considered are demonstrated in Figure 5.1. The femoral inclination was varied between 5°, 1o° and 15°, the hip joint force inclination between 6°, 11° and 16° and the abductor pull direction between 1o°, 15° and 2o°. The abductor muscle force/hip joint force ratio (M/J) was varied between o.55, o.6o and o.65.

The model was viewed in polarized light and the picture on the analyser screen photographed and compared to the stress trajectories reconstructed from Koch (1917) and Pauwels (1935, 1973).

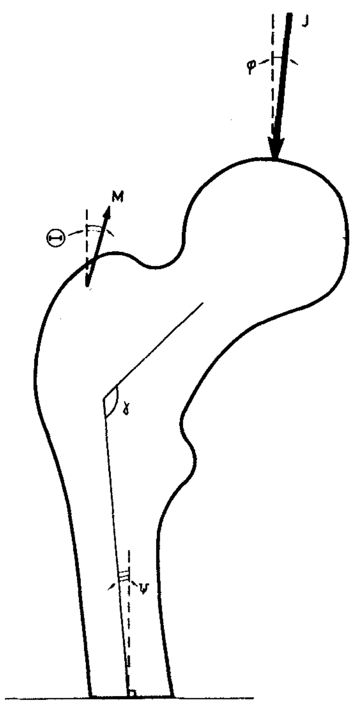


Figure 5.1 : Forces at the proximal femur.

J = RESULTANT HIP JOINT FORCE
M = ABDUCTOR MUSCLE FORCE
γ = FEMORAL NECK ANGLE
φ = JOINT FORCE INCLINATION
Θ = ABDUCTOR PULL INCLINATION
ψ = FEMORAL SHAFT INCLINATION
DOTTED LINES INDICATES VERTICAL

Results and Discussion

A total of 142 experiments in different combinations were performed (Jensen 1978 (V)), leading to a standardized experimental arrangement with a femoral shaft inclination of 5^{o}, a hip joint force inclination of 6^{o}, and an abductor pull inclination of 15^{o}. The magnitude of the abductor pull was 55 % of the hip joint force. In that situation the patterns of isochromates in the models accorded best with the stress trajectories shown by Koch (1917) and Pauwels (1973).

The femoral shaft inclination of 5^{o} accorded with Pauwels (1935), while the two force inclinations were in accordance with McLeish & Charnley (197o). The ratio between the abductor pull and the hip joint force corresponded also with former studies (McLeish & Charnley 197o, Pauwels 1935, Rydell 1966, Williams & Svensson 1968).

The limitations of the experiments were, that the eccentric position of the center of gravity, the thigh muscle pull, the forces of the ligaments and the anteversion of the femoral neck experienced in the human body as well as the anisotropicity of the bone could not be taken into account. Besides that, the study was purely 2-dimensional and deformations of the model and probable shear forces from torque were assumed not to alter the stress patterns.

As the experiments were performed with the aim of standardizing an experimental arrangement for further laboratory testing the results obtained were found acceptable although not directly applicable to a clinical situation.

Conclusions

The optimal experimental arrangement for further laboratory testing includes a femoral shaft inclination of 5^{o}, a hip joint force inclination of 6^{o} and an abductor pull inclination of 15^{o} to the vertical, respectively. The ratio between the abductor muscle pull and the hip joint force should be o.55.

Chapter 6

Biomechanical Experimental Arrangement and Equations for Calculations

Brettle (197o) and Martz (1956) pointed out the necessity of examining the strength of implant designs.

In clinical series on plate fixations of unstable trochanteric fractures mechanical failures such as bending or breakage of Jewett nail plates have been reported in 5 - 3o % of cases (Boyd & Griffin 1949, Cleveland et al 1959, Dimon & Hughston 1967, Evans 1951, Fielding 1973, Jacobs et al 1976, Johnson et al 1968, Kyle et al 1979, Laros & Moore 1974, Moritz & Scheuba 197o, Morrison et al 1978, Parker 1955, Robey 1956, Sarmiento 1967). Following internal fixation with McLaughlin implants additional problems are encountered with failure of the nail-plate junction leading to a reported failure rate of 6 - 46 % (Bremner & Graham 1958, Clawson 1957, Cram 1955, Foster 1958, Friedenberg et al 1972, Jensen & Michaelsen 1975, Laros & Moore 1974, McLaughlin & Garcia 1955, Sarmiento 1963).

In the internal fixation of unstable trochanteric fractures reliable bony support is in most cases not achieved. Consequently the hip joint load must be transmitted through the implant to the femoral shaft (Dimon 1973, Fielding 1973, Frankel 1963, Johnston 1973, Jensen 1978 (VI), Jensen et al 1978 (X), Massie 1962, Scheuba 197o, Sonstegard et al 1974). The hip joint load during normal level walking has been reported to 3 - 5 times the body weight (Paul 1967, 1971, 1976, Rydell 1966).

Stress-coating with brittle lacquer has been used to a certain extent in studies of the proximal femur (Evans 1961, Evans et al 1951, Evans et al 1953, Evans & Goff 1957, Spears & Owen 1949, Williams & Svensson 1971), but was by Brekelmans et al (1972) stated to be rather inaccurate. Bearing the recommendations of Haboush (1952, 1953) in mind the photoelastic technique was chosen to get a primary impression of the stress patterns inside the hip nails (Jensen 1978 (VI)). This study was performed as for the hip models described in Chapter 5 and revealed the maximum shear forces to be situated in the nails and the plates of Jewett hip nail-plate models manufactured from polyester (Araldite-B) about 2.5 - 3 cm from the nail-plate junction. The 2-dimensional models did not take the engineering design of the implants into account and consequently the additional conclusions of this study are <u>not</u> valid (Jensen 1980 (VII)). The results obtained did, however, give a lead for the positioning of strain-gauges in the following implant testing.

Experimental Arrangement

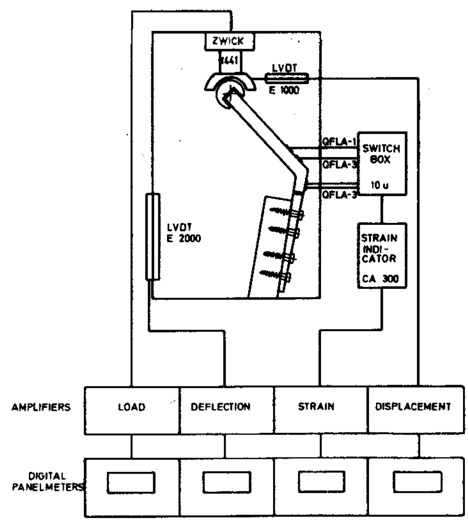


Figure 6.1 : Diagram of experimental arrangement.

The implant was fixed by screws to a heavy steel bar and mounted in a base clamp inclined 11^{o} to the vertical. The steel bar did not support the proximal 25 mm of the plate.

The nail was mounted with a strain gauge 25 mm from the nail-plate junction (QFLA-3, TML, Japan) and an additional strain gauge proximal to that (QFLA-1, TML, Japan), as seen from Figure 6.2.

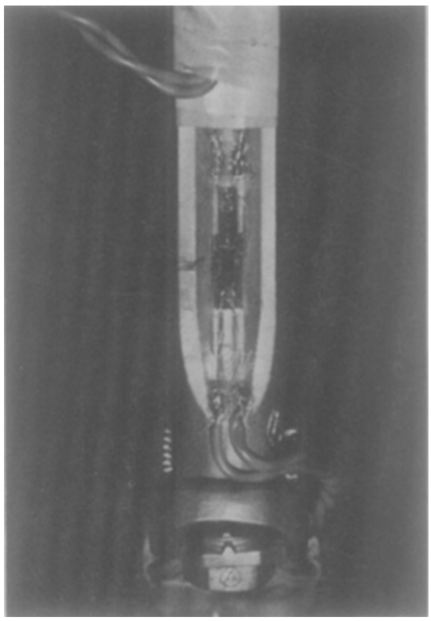


Figure 6.2 : Positioning of strain gauges at McLaughlin nail.

In the same fashion the plate was mounted with 2 strain gauges 25 mm distal to the nail-plate junction. The strain gauges were bonded to the metal surface with a cyanoacrylate cement (Eastman 91o, Kodak, USA). In case of sliding screw-plates the telescoping effect was eliminated by gluing the screw to the barrel with a slightly expanding 2-component polyurethan glue (Foss-Than 2 K 235o, Sadofoss, Denmark). The strain gauges were mounted at the screw 3 mm from the medial edge of the barrel, at the barrel 2o mm from the lateral border and at the plate just distal to the counter bore designed for operation tools and telescoping.

The strain gauges were connected to a switch box (1o U, Automation Industries,Peekel Division,Holland) and a strain indicator (CA 3oo, Automation Industries, Peekel Division, Holland) measuring the strain signals by Wheatston bridges. The strain gauges were temperature compensated for steel and the experiments performed over short time intervals. The strain signals were amplified (W-lol, C.Worsøe, Denmark) and converted into microvolts by digital volt meters (Intersil Inc., USA and KAS Elektroniklab.,Denmark).

The strain gauge mounted nail-plate arrangement was placed in a universal testing machine (1441 Zwick GmbH & Co, W.Germany) with electronic force measurement (o - lo kN).

The deflection of the implant, which is equivalent to the movement of the cross head of the testing machine, was measured by a linear displacement transducer (LVDT E 2ooo, Schaevitz Engineering, USA). The electronic signals were amplified (KAS Elektroniklab., Denmark and W-lol, C.Worsøe, Denmark) and converted into microvolts (Intersil Inc., USA and KAS Elektroniklab., Denmark).

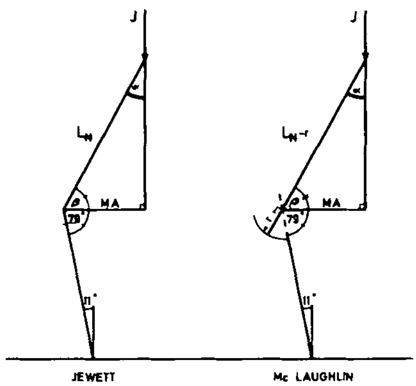
At the tip of the implant a polished Vitallium head from a total hip prosthesis was mounted and the force applied through a high-density-polyethylene acetabular cup by a polished steel bar at the cross head of the testing machine. A thin layer of grease was applied between the steel bar and the acetabular cup to reduce frictional forces further. As bending of the implant involves elongation of the moment arm the displacement of the implant tip medially was measured with a linear displacement transducer (LVDT E loo, Schaevitz Engineering, USA), which was mounted to the acetabular cup. This signal was also amplified and converted into microvolts as described above.

Load was applied to the nail tip by advancing the cross head of the testing machine at a rate of 12 mm per minute. Recordings of all measurements were done at static loads for every o.5 mm deflection of the implant. The testing was completed, when 15 mm of deflection was obtained.

The microvolt recordings were converted into Newton, millimeters and microstrain, respectively. Load-deflection diagrams and load-strain diagrams were constructed. The yield point, where the metal undergoes a permanent plastic deformation, was defined as the point, where the straight line of the graph was transformed into a curved line.

In each series of testing 5 experiments were performed and mean-curves calculated.

Equations for Calculations



α = 169° ÷ nail-plate angle

β = nail-plate angle ÷ 79°

J = applied force perpendicular to moment arm

MA = moment arm

L_N = nail length

r = radius of plate extension

Figure 6.3 : Mathematical calculation of nail length.

The purpose of the study was to test the Jewett, McLaughlin and sliding screw-plate implants in different nail-plate angles. In order to obtain comparable results the moment arm (MA) about the intersection between the back of the plate and the center-line of the nail was to be kept constant. According to Figure 6.3 the nail length (L_N) could thus be calculated to :

(1) $L_N = \frac{MA}{\sin \alpha}$, for Jewett and sliding screw plate implants, and to

(2) $L_N = \frac{MA}{\sin \alpha} + r$, for McLaughlin implants.

(r = 13.7 mm and 14.3 mm, respectively for Cobalt-Chromium-Molybdenum and 316 LVM stainless steel implants).

The nail lengths corresponding to a moment arm of 41.4 mm are shown in Table 6.1.

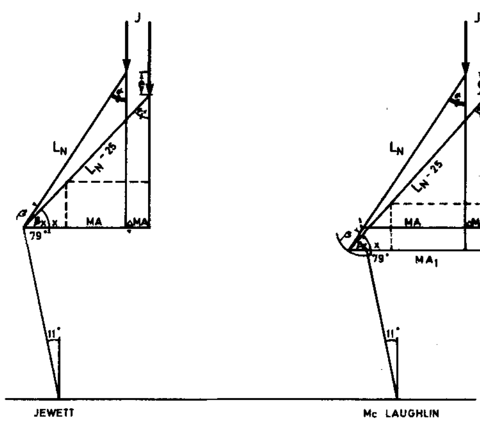
Table 6.1 : Applied nail plate angles and nail lengths.

Nail plate angle (degr.)	Nail lengths, mm Jewett	McLaughlin (Co-Cr-MO)	McLaughlin (316 LVM)	Sliding screw plate
125	59.5			
126		74.4	74.9	
132		82.6	83.o	
135	74.o			74.o
138		94.o	94.6	
14o	85.3			
15o	127.o	14o.7	141.3	127.o

The bending moment (M_B) applied to different parts of the implant can be calculated according to the equation :

$$(3) \qquad M_B = J \times (MA_x + \Delta MA_x)$$

(MA_x = moment arm about chosen point, ΔMA_x = elongation of moment arm, recorded in experiments). The moment arm about the intersection between the back of the plate and the centerline of the nail or screw is in any situation 41.4 mm.



α = 169° × nail-plate angle

β = nail-plate angle × 79°

$\beta \times \beta_x$ = varus angulation

B = perpendicular distance between tip of nail and moment arm about junction

e = deflection of implant

J = applied force

L_N = nail length

MA = moment arm about intersection

MA_1 = moment arm about junction in McLaughlin implants

ΔMA = elongation of moment arm

X = reduction of moment arm about strain gauge center at nail

The suffix "x" indicates the angles at the yield point.

Figure 6.4 : Mathematical calculations of moment arms, bending moments and varus angulations.

For the McLaughlin implants the moment arm about the nail-plate junction can be calculated according to the equation :

$$(4) \qquad MA_1 = L_N \times \sin \alpha$$

The varus angulation, i.e. degrees of bending, at the yield loads for the implants can be calculated from Figure 6.4 according to the equations :

$$\sin \beta_x = \frac{B \times e}{L_N}$$

$$\sin \beta = \frac{B}{L_N}$$

$$(5) \qquad \sin \beta_x = \sin \beta \times \frac{e}{L_N}$$

For simplification the varus angulation is calculated in relation to the original nail-plate angle and in relation to the nail-plate junction.

For any experiment the bending moment about the strain gauge center at the nail can be calculated for the Jewett and McLaughlin nails from Figure 6.4 according to the following equations :

$$\sin \alpha_x = \frac{MA_1 + \Delta MA \times X}{L_N \times 25} = \frac{MA_1 + \Delta MA}{L_N}$$

$$(6) \qquad X = 25 \times \sin \alpha_x$$

$$(7) \qquad M_B = J \times (MA_1 + \Delta MA \times X)$$

For the Jewett experiments MA_1 is identical with MA.

In the experiments with the sliding screw-plates the strain gauges were placed at the screws with the center 3 mm from the medial barrel edge. The bending moment can still be calculated according to the above mentioned equation (7), but the equation (6) has to be altered to :

$$(8) \qquad X = (D + 3) \sin \alpha_x$$

The distance D is equivalent to the medial extension of the barrel from the intersection between the back of the plate and the centerline of the screw. The distance D varies with the different designs, as listed in Table 6.2.

Table 6.2 : Measures from different sliding screw-plates.

Implant	Angle (degr.)	Barrel length mm	D = medial extension of barrel, mm
Co-Cr-Mo	135	38.1	28.5
Co-Cr-Mo	15o	38.1	26.5
316 LVM	135	37.5	24.8
316 LVM	15o	36.o	23.o

Chapter 7
Implant Testing

A number of investigations have been made previously on different hip implants (Foster 1958, Frankel 1963, Holt 1963, Kaufer et al 1974, Martinek et al 1976, Martz 1956, Richter & Peter 1975, Sauer et al 1977, Schöttle et al 1977, Sonstegard et al 1974, Sunami et al 1977). The majority of the German papers, however, report on experiments with AO-angle plates or intramedullary rods and Holt´s series (1963) deals with his own nail and previous designs, which are not used in Western Europe.

The purpose of the present studies (Jensen 198o (VII, VIII, IX)) was thus to investigate the failure modes under loading of the Jewett, McLaughlin and sliding screw-plate implants manufactured from either Cobalt-Chromium-Molybdenum alloy or 316 LVM stainless steel.

The static experimental arrangement described in Chapter 6 does not take into account the muscle traction and the repetitive loading of the hip joint encountered in the clinical service of the implants. The static study does, however, reveal the mode of failure for different components of the implants and the corresponding loads. Information about how the implants act in vivo and about the risk of fatigue failure is also obtained (Dumbleton & Black 1975, Frankel & Burstein 1971, Martz 1956, Swanson & Freeman 1977).

Biomechanical studies have been performed on a model of unstable, 4-fragmentary trochanteric fractures with modifications of reduction and fixation by hip implants (Kaufer et al 1974, Sonstegard et al 1974). In such experiments the conceivable movement of the implant within the femoral head and the holding power of the screws in the femoral shaft can not be considered. Consequently only the ultimate compressive strength of the implants was reported. It is, however, more important to define the yield point, where permanent plastic deformation is beginning. Considerable bending can take place before the ultimate strength of the implant is exceeded (Brettle et al 1971, Dumbleton & Black 1977), resulting in dislocation of an internally fixed fracture.

A standardized load-deflection diagram demonstrates this clearly. Consequently the present study considers the points, where different parts of the implants undergo yielding. In the description of the results the term, yield point, will be used, although a metal as such has only one yield point, determined from a stress-strain diagram.

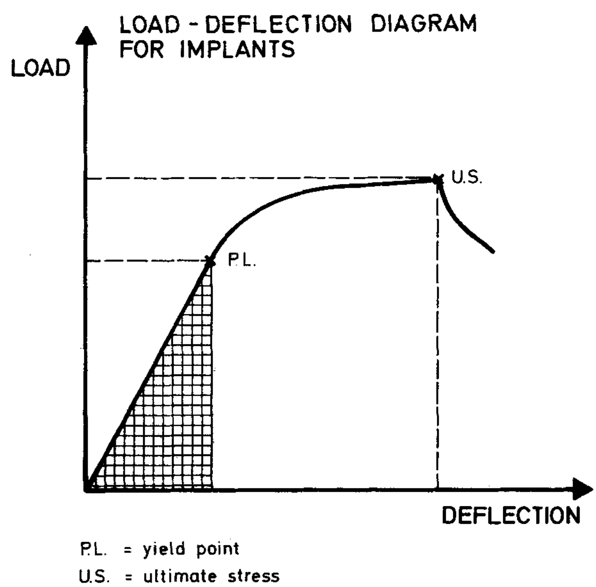


Figure 7.1 : Standardized load-deflection diagram.

Results and Discussion

McLAUGHLIN NAIL-PLATES.

Loading experiments were performed with implants manufactured either from Cobalt-Chromium-Molybdenum alloy or 316 LVM stainless steel.

The diagrams in Figure 7.2 demonstrate three yield points for McLaughlin implants manufactured from Cobalt-

Chromium-Molybdenum alloy. Only two yield points were encountered in McLaughlin implants manufactured from 316 LVM stainless steel (Figure 7.3).

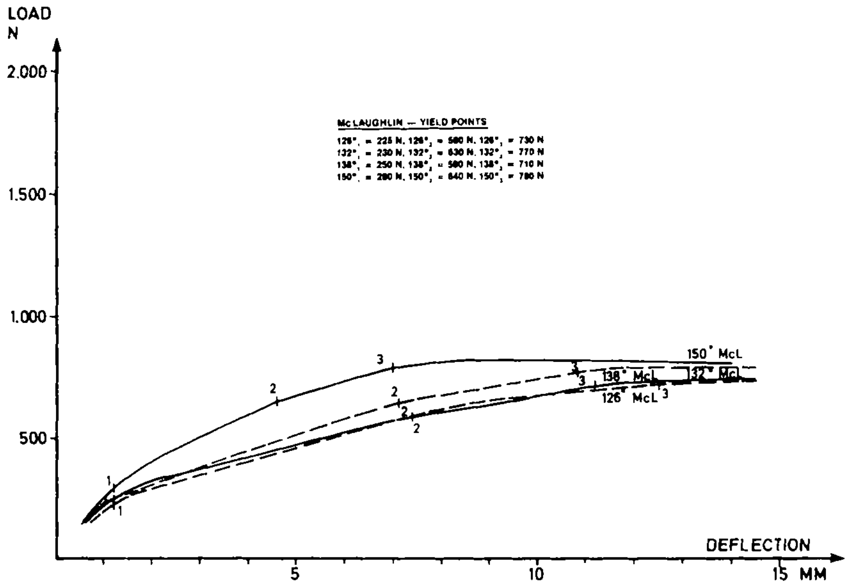


Figure 7.2 : Load-deflection diagrams for trifin McLaughlin nail-plates manufactured from Cobalt-Chromium-Molybdenum alloy.

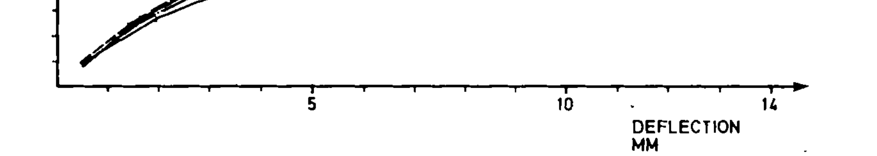


Figure 7.3 : Load-deflection diagrams for trifin McLaughlin nail-plates manufactured from 316 LVM stainless steel.

The lowest yield point occured in Cobalt-Chromium-Molybdenum implants at loads of 225 - 28o Newton, increasing slightly with the nail-plate angle. The corresponding deflections of the implants were 1.o5 - 1.25 mm, as seen from Table 7.1. For 316 LVM stainless steel implants the lowest yield points occured at loads of 245 - 26o N with corresponding deflections of 1.5o - 1.95 mm.

Table 7.1 : Deflection and varus angulation of McLaughlin hip nail-plates at mechanical loading.

Implant McLaughlin	Nail-plate angle degr.	β degr.	Nail length L_N,mm	Deflection e_1,mm	β_1 degr.	Varus angulation $\beta-\beta_1$	Deflection e_2,mm	β_2 degr.	Varus angulation $\beta-\beta_2$	Deflection e_3,mm	β_3 degr.	Varus angulation $\beta-\beta_3$
Co-Cr-Mo	126°	47°	74.4	1.20	45.7°	1.3°	7.40	39.2°	7.8°	12.60	34.2°	12.8°
	132°	53°	82.6	1.05	51.8°	1.2°	7.10	45.5°	7.6°	10.75	41.9°	11.1°
	138°	59°	94.0	1.25	57.6°	1.5°	7.40	51.1°	7.9°	11.15	47.6°	11.4°
	150°	71°	140.7	1.20	69.6°	1.5°	4.55	66.0°	5.1°	7.00	63.6°	7.4°
316 LVM	126°	47°	74.9	1.60	45.2°	1.8°	5.65	41.0°	6.0°			
	132°	53°	83.0	1.50	51.3°	1.7°	5.50	47.1°	5.9°			
	138°	59°	94.6	1.55	57.2°	1.8°	6.00	52.5°	6.5°			
	150°	71°	141.3	1.95	68.7°	2.3°	6.85	52.5°	7.2°			

The lowest yield point was in all cases due to failure of the nail-plate junction. The small knobs of the serrations of the plate portion were flattened at the lower contact point (Figure 7.4), as well as the corresponding area at the nail base (Figure 7.5).

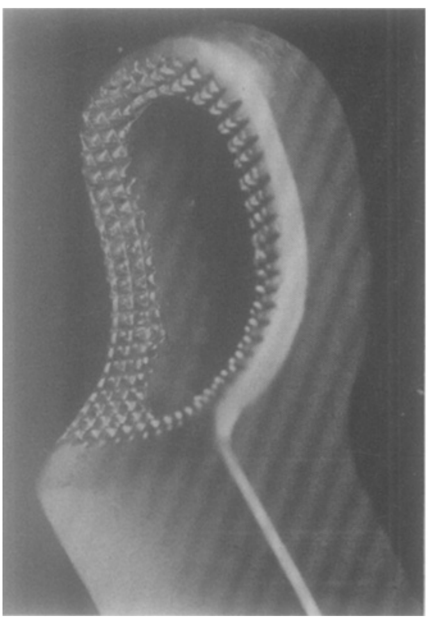


Figure 7.4 : Curved plate extension after testing.

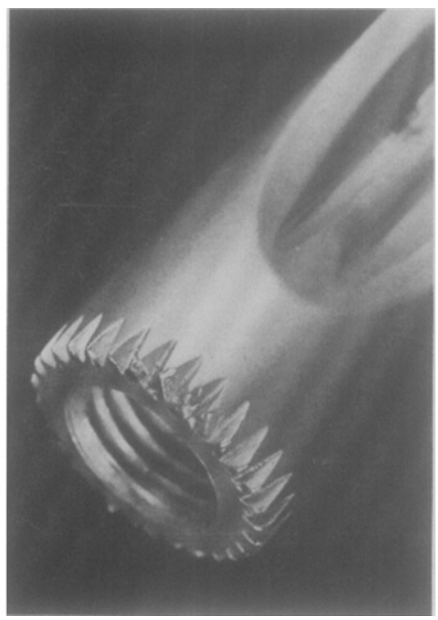


Figure 7.5 : Base of nail after testing.

Further the washer of the Cobalt-Chromium-Molybdenum implants bended successively and became gradually more concave and thinner (Figure 7.6).

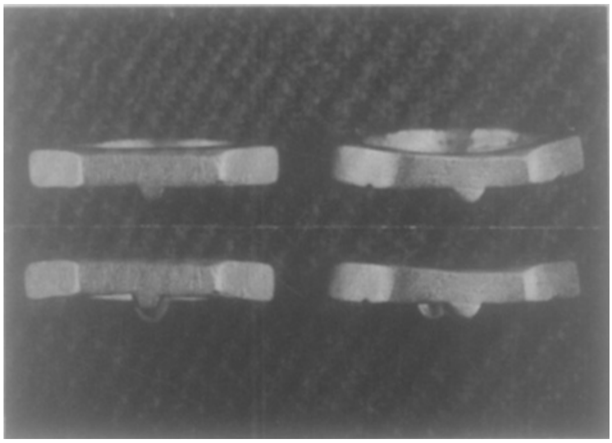


Figure 7.6 : Washer before and after testing.

With the 316 LVM stainless steel implants the washer did not undergo any deformation, as it is much thicker. This did not affect the strength of the nail-plate junction significantly. With both types of implants bending of the threads of the top bolt was furthermore observed, as well as slight bending of the entire bolt.

Table 7.2 : Bending moments about nail-plate junction in McLaughlin hip nail-plates.

Implant McLaughlin	Plate-angle	Moment arm MA_1, mm	Elongation of moment arm ΔMA_1, mm	Yield load J Newton	Bending Moment M_B Nm
Co-Cr-Mo	126°	50.7	0.07	225	11.4
	132°	49.7	0.05	230	11.4
	138°	48.4	0.88	250	12.3
	150°	45.8	1.78	280	13.3
316 LVM	126°	51.1	1.37	260	13.6
	132°	50.0	1.07	245	12.5
	138°	48.7	1.59	250	12.6
	150°	46.0	3.84	260	13.0

The bending moments applied to obtain failure at the nail-plate junction were calculated from equation (3) and (4) in Chapter 6, as listed in Table 7.2. There was no significant difference between the bending moments leading to failure of the nail-plate junction in McLaughlin implants.

As seen from Table 7.1 the varus angulations, calculated according to equation (5) in Chapter 6, for the lowest yield points were as low as 1.2° - 1.5° in Cobalt-Chromium-Molybdenum implants and 1.7° - 2.3° in 316 LVM stainless steel implants.

It has been claimed before that the nail-plate junction of the McLaughlin implants is a weak point of the construction (Foster 1958, Martz 1956, Scheuba 197o), but no explanation was given by these authors. McLaughlin & Garcia (1955) thought that unwinding of the bolt was the cause and consequently recommended a type of locking nut. The same supposition has led to the left-threaded, central bolt of the 316 LVM stainless steel implant from Zimmer-USA International. The explanation for the failure of the nail-plate junction is, however, to be found in the design. The curved extension of the plate is hemispherically shaped and equipped with serrations for rotational stability. The base of the trifin nail is plane and equipped with small netches for rotational stability. The dimensions of these 2 surface shapes involves a total area of contact, in case of perfect fitting, os less than one third of a square centimeter. Due to differences in geometry the fitting is not perfect. Consequently all forces are concentrated at very small areas leading to the described permanent deformations of the implant parts and loosening of the nail-plate junction. At the yield point the material starts undergoing deformation hardening and the area of contact is increased because of the deformation. The result of this process is a limited looseness. The nail-plate junction is becoming stronger, making further loading and thereby determination of the yield points for the nail and plate possible. A disadvantage of the deformation hardening is that the deformed areas becomes more susceptible to corrosion.

The second yield point for the Cobalt-Chromium-Molybdenum implants was encountered at loads of 59o - 64o N, as seen from Figure 7.2. The trifin nails were equipped with strain gauges measuring the surface strain 25 mm from the nail-plate junction. The load-strain diagrams in Figure 7.7 revealed the second yield point to be caused by bending of the trifin nail.

The corresponding bending moments about the strain gauge center could be calculated from equations (6) and (7) in Chapter 6, as shown in Table 7.3. The bending moments applied to cause bending of the nails increased with the nail-plate angle. The geometry of the trifin cross section is considered among the strongest avaible, however (Laing & O´Donnell 1961).

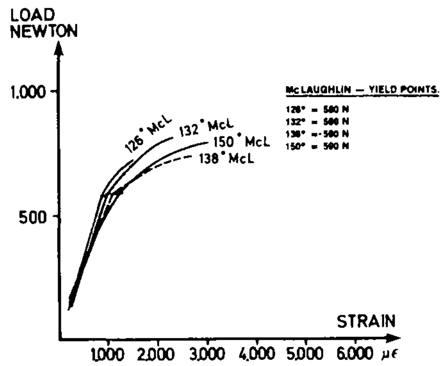


Figure 7.7 : Load-strain diagrams for McLaughlin nails (Co-Cr-Mo).

Table 7.3 : Bending moments about strain gauge center at McLaughlin trifin hip nails.

Implant McLaughlin	Plate-angle	Moment arm MA_1, mm	Elongation of moment arm ΔMA_1, mm	Yield load J Newton	Bending Moment M_B Nm
Co-Cr-Mo	126°	5o.7	5.76	59o	21.9
	132°	49.7	6.o4	63o	24.1
	138°	48.4	1o.31	59o	25.4
	15o°	45.8	8.6o	64o	28.3
316 LVM	126°	51.1	6.o9	68o	26.1
	132°	5o.o	7.16	68o	27.3
	138°	48.7	9.87	66o	28.6
	15o°	46.o	16.32	56o	28.7

The varus angulation corresponding to the second yield point for the different nail-plate angles is listed in Table 7.1 and is found to be less than 8°.

The second yield point for the implants manufactured from 316 LVM stainless steel was determined to 615 - 68o N, as shown in Figure 7.3. The load-strain diagrams in Figure 7.8 show yield loads for the trifin nails corresponding fairly well with the highest yield points. The yield loads for the plates were determined to slightly lower values. A separate yield point corresponding to bending of the plate could not be determined at the load-deflection diagrams. The second yield point is thus considered to be determined from simultaneous bending of the nail, the plate and the curved plate extension.

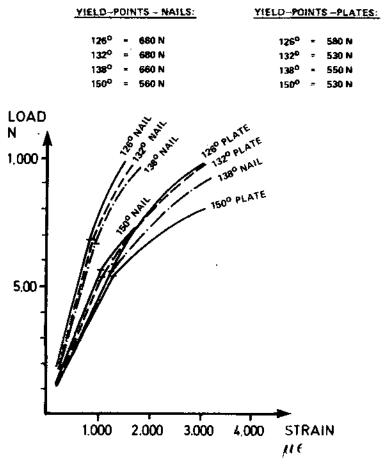


Figure 7.8 : Load-strain diagrams for McLaughlin nails and plates, manufactured from 316 LVM stainless steel.

As seen from Table 7.1 the varus angulations corresponding to the second yield point is about 6^{o}- 8^{o} in nearly all cases. This means, that a varus angulation of less than 5^{o} is caused by bending of the nail-plate junction alone. Radiological varus angulations in clinical cases of more than 6^{o}- 8^{o} even indicates bending of the nail in Cobalt-Chromium-Molybdenum implants and all 3 components of 316 LVM stainless steel implants.

The <u>highest yield points</u> in Cobalt-Chromium-Molybdenum implants were encountered at loads of 71o - 78o N, as demonstrated in Figure 7.2. These were caused by successive bending of the curved extension of the plate at the lower contact point with the nail (Figure 7.4). In $15o^{o}$ implants the highest yield point was, however, due to bending of the plate at the level between the two proximal screw holes. In the lower angled implants no bending of the plates was observed.

In conclusion, the McLaughlin implants manufactured from Cobalt-Chromium-Molybdenum alloy or 316 LVM stainless steel started to fail at loads of only about 25o N, corresponding to bending moments of about 12 - 13 Nm. This is due to an unsuitable design of the nail-plate junction with incongruent surfaces. A varus angulation of more than $1o^{o}$ definitely involves bending of the nail, the curved plate extension and even the plate in certain cases. This involves loadings of about 7oo N, corresponding to bending moments of about 28 Nm.

JEWETT NAIL-PLATES.

Loading experiments were performed with implants manufactured from Cobalt-Chromium-Molybdenum alloy. The load-deflection diagrams obtained are demonstrated in Figure 7.9.

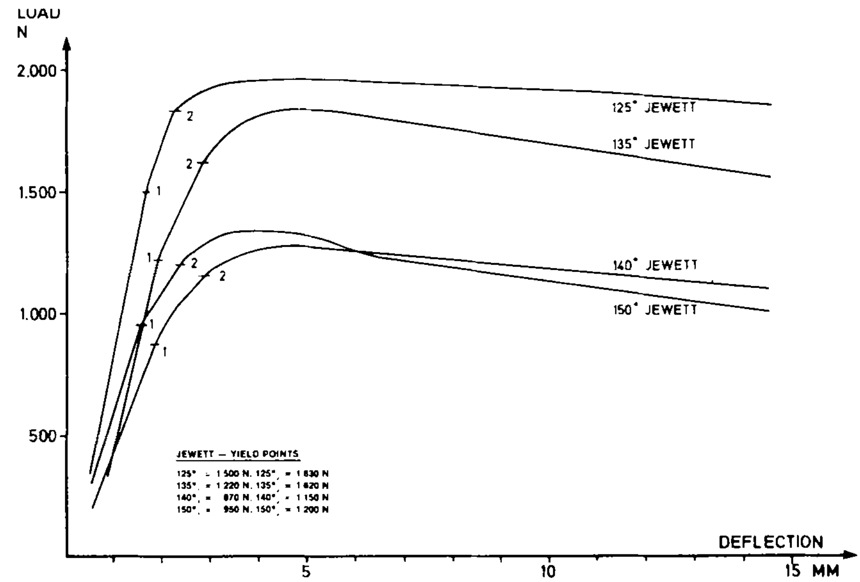


Figure 7.9 : Load-deflection diagrams for Jewett nail-plates (Co-Cr-Mo).

The <u>lowest yield points</u> were considerably lower in implants with a nail-plate angle of 14o^{O} or 15o^{O} than in cases of 135^{O} or 125^{O}.

The corresponding deflections of the implants were 1.55 - 1.9o mm and the varus angulations 2.o^{O} - 2.6^{O}, as calculated from equation (5) in Chapter 6 and shown in Table 7.4.

Table 7.4 : Deflection and varus angulation of Jewett hip nail-plates (Co-Cr-Mo) at mechanical loading.

Implant Jewett	Nail-plate angle degr.	β degr.	Nail length L_N,mm	Deflection e_1,mm	β_1 degr.	Varus angulation $\beta-\beta_1$	Deflection e_2,mm	β_2 degr.	Varus angulation $\beta-\beta_2$
Co-Cr-Mo	125°	46°	59.5	1.65	43.8°	2.2°	2.25	43.o°	3.o°
	135°	56°	74.o	1.9o	53.5°	2.6°	2.85	52.2°	3.8°
	14o°	61°	85.3	1.85	58.5°	2.5°	2.85	57.3°	3.7°
	15o°	71°	127.o	1.55	69.o°	2.o°	2.35	68.o°	3.o°

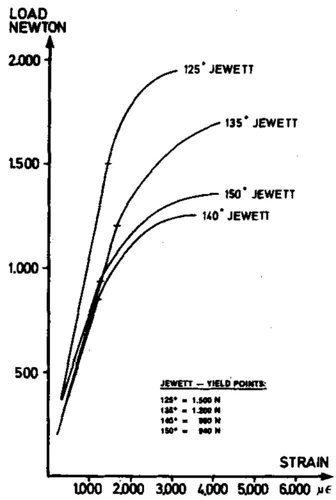


Figure 7.1o : Load-strain diagrams for Jewett nail-plates.

The load-strain diagrams in Figure 7.1o show that the lowest yield point corresponded to bending of the trifin nails. The bending moments applied are shown in Table 7.5, as calculated from equation (3) in Chapter 6. It is seen that the bending moment was about 33 Nm, except in the 14o° nail-plate angle. Theoretical calculations of the bending moments were fairly consistent with those found in the experiments.

The highest yield points of the Jewett graphs were also determined to higher values in the low angle cases, as seen from Figure 7.9.

Table 7.5 : Bending moments about strain gauge center at Jewett nails.

Implant Jewett	Plate-angle	Moment arm MA ,mm	Elongation of moment arm ΔMA , mm	Yield load J Newton	Bending Moment M_B Nm
Co-Cr-Mo	125^{o}	41.4	o.o7	1,5oo	35.o
	135^{o}	41.4	o.8o	1,22o	33.3
	14o^{o}	41.4	1.28	87o	25.7
	15o^{o}	41.4	2.4o	95o	33.o

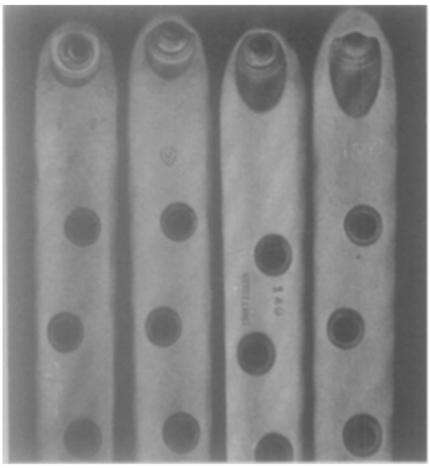


Figure 7.11 : Jewett nail-plate, posterior view.

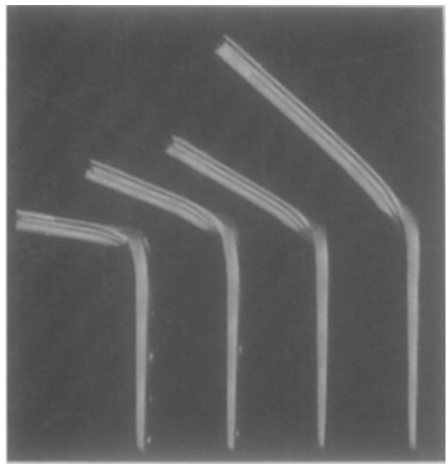


Figure 7.12 : Jewett nail-plate, side view.

The design of the implant involves a rather large counter bore in the upper part of the plate to allow space for the tools used during the operative insertion of the nail. As seen from Figure 7.11 this involves a considerable reduction of the cross section in the 14o^{o} and 15o^{o} implants. Consequently the plates were bending in the areas, where the lower edge of the nail conjoined the plate (Figure 7.12).

Table 7.6 : Bending moments about nail-plate junction of Jewett hip implants (Co-Cr-Mo).

Implant Jewett	Plate-angle	Moment arm MA ,mm	Elongation of moment arm ΔMA , mm	Yield load J Newton	Bending Moment M_B Nm
Co-Cr-Mo	125^{o}	41.4	o.56	1,83o	76.7
	135^{o}	41.4	2.16	1,62o	7o.5
	14o^{o}	41.4	3.1o	1,15o	51.1
	15o^{o}	41.4	4.6o	1,2oo	55.1

The bending moments about the nail-plate junction corresponding to the highest yield point could be calculated from equation (3) in Chapter 6, as listed in Table 7.6.

The bending moments did not differ much from the bending moments applied to the plate portion, as these points are very close to the intersection line between the back of the plate and the center line of the nail.

Recent biomechanical experiments on Jewett implants (Frankel 1963, Sonstegard et al 1974) reported failure loads consistent to this series, whereas Sunami et al (1977) stated lower values. The mode of failure for the nail-plates in the present series is in accordance with Kaufer et al (1974). Holt´s series (1963) is not comparable, as the design has been altered since. Grover (1966) already warned against holes and notches in the implants as these might lead to stress concentrations and unexpected failures at relatively small loads.

In conclusion, the strongest Jewett implants were those with nail-plate angles of 125^{o} and 135^{o}. The lowest failure loads were about 1,2oo - 1,5oo N, corresponding to bending moments of about 34 Nm. A radiological observation of 4^{o} varus angulation involves bending of the nail as well as the plate near the junction at loads of about 1,7oo N. This corresponds to bending moments of about 75 Nm. A similar observation in $14o^{o}$ or $15o^{o}$ Jewett nail-plates will be encountered after loads of about 1,2oo N, corresponding to bending moments of about 53 Nm.

SLIDING SCREW-PLATES.

Loading experiments were performed with implants manufactured from Cobalt-Chromium-Molybdenum alloy or 316 LVM stainless steel.

The load-deflection diagrams in Figure 7.13 demonstrate that 2 yield points were determined for Cobalt-Chromium-Molybdenum implants, but only one for 316 LVM stainless steel implants.

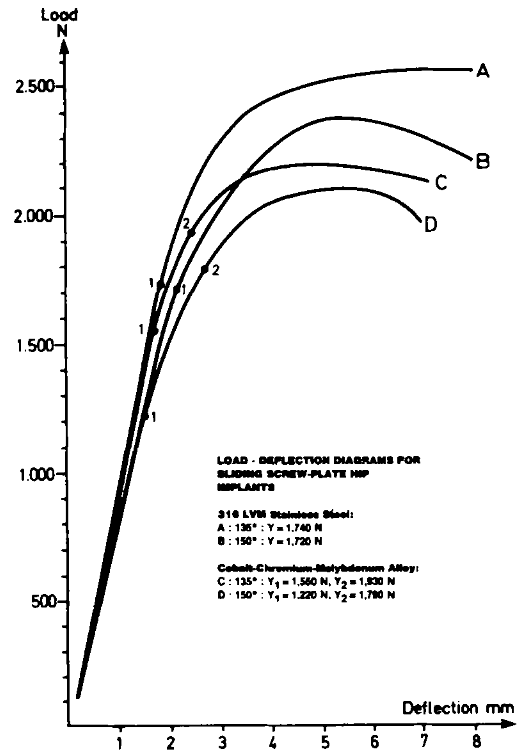


Figure 7.13 : Load-deflection diagrams for sliding screw-plates.

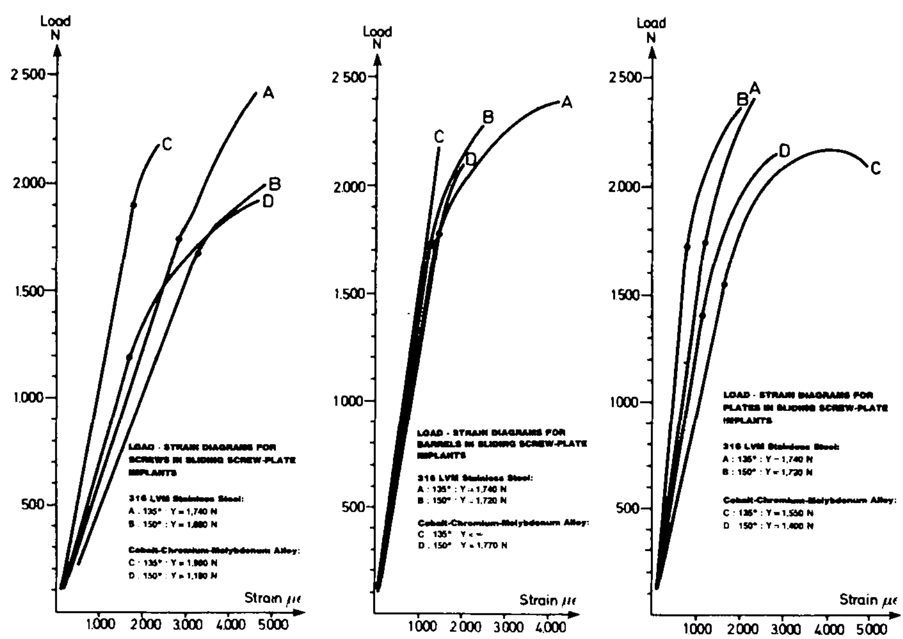


Figure 7.14 : Load-strain diagrams for the components of sliding screw-plate hip implants.

The lowest yield point in Cobalt-Chromium-Molybdenum implants corresponded to bending af the plate (Figure 7.14) in 135^{o} implants at a load of 1,55o N. For the 15o^{o} implant the screw and the plate bended simultaneously at a load of about 1,22o N. The deflection was 1.5o - 1.65 mm, corresponding to varus angulations of about 2^{o}, as listed in Table 7.7.

Table 7.7 : Deflection and varus angulation of sliding screw-plate hip implants at mechanical loading.

Implant Sliding screw-plate	Nail-plate angle degr.	β degr.	Nail length L_N,mm	Deflection e_1,mm	β_1 degr.	Varus angulation $\beta-\beta_1$	Deflection e_2,mm	β_2 degr.	Varus angulation $\beta-\beta_2$
Co-Cr-Mo	135^{o}	56^{o}	74.o	1.65	53.8^{o}	2.2^{o}	2.4o	52.8^{o}	3.2^{o}
316 LVM	135^{o}	56^{o}	74.o	1.85	53.5^{o}	2.5^{o}			
Co-Cr-Mo	15o^{o}	71^{o}	127.o	1.5o	69.o^{o}	2.o^{o}	2.75	67.5^{o}	3.5^{o}
316 LVM	15o^{o}	71^{o}	127.o	2.15	68.2^{o}	2.8^{o}			

For the 15o^{o} implant the bending moment about the strain gauge center at the screw was calculated to 4o Nm according to equations (7) and (8) in Chapter 6, as listed in Table 7.8.

Table 7.8 : Bending moments about strain gauge center at the screw of the sliding screw-plate hip implants.

Implant Sliding Screw plate	Plate-angle	Moment arm MA ,mm	Elongation of moment arm ΔMA , mm	Yield load J Newton	Bending Moment M_B Nm
Co-Cr-Mo	135^{o}	41.4	2.93	1,93o	48.7
316 LVM	135^{o}	41.4	o.39	1,74o	43.9
Co-Cr-Mo	15o^{o}	41.4	2.25	1,22o	4o.3
316 LVM	15o^{o}	41.4	o.5o	1,72o	55.4

The single yield point determined in the 316 LVM stainless steel implants corresponded to simultaneous bending of all 3 parts of the implant, as seen from Figures 7.13 and 7.14. The strength of the implants was not significantly correlated to the angle.

As seen from Table 7.8 bending of the screw corresponded to bending moments of 44 Nm for 135^{o} implants and 55 Nm for 15o^{o}. The corresponding varus angulation was about 3^{o} with deflections of 1.85 - 2.15 mm, as listed in Table 7.7.

The highest yield point of the Cobalt-Chromium-Molybdenum implants was caused by bending of the screw in the 135° implants at a load of about 1,93o N. For the 15o° implants the barrel bended at a load of about 1,79o N, as seen from Figure 7.13 and 7.14.

Bending of the screw in the 135° implants needed a bending moment of about 49 Nm, which is considerably higher than calculated for the 15o° implant (Table 7.8).

The total varus angulation involving bending of all parts of the implants for either metal was less than 4° with loads of up to 1,93o N. The corresponding bending moments about the strain gauge center at the screw were 44 - 49 Nm on average.

Bending of the plate was in all cases experienced at the level of the supporting steel bar, 25 mm distal to the intersection between the center line of the screw and the back of the plate. This bending is considered to have relevance only in an experimental situation, as this level of the plate is supported by bone in the clinical appliance of the implant.

The screws are supplied by the manufacturers in standard lengths. For testing purposes screw lengths exceeding the existing were needed for the 15o° implants, if the base of the screw were to correspond with the intersection line between the back of the plate and the center line of the screw. In order to standardize the experimental arrangement the screws were chosen of lengths ending 23 - 27 mm from the medial edge of the barrel, but this is in accordance with the operative technique applied in clinical cases (Jensen et al 1978 (X)). The results of the present series were fairly consistent with recent reports (Kaufer et al 1974, Sonstegard et al 1974).

In the present study the telescoping effect of the implant was eliminated by a glue, which did not apply any additional bending strength. In the clinical situation, telescoping of the implant is indeed encountered.

Assuming that the calculated bending moments are always corresponding to bending of the implants with an equivalent varus angulation in the different modifications, further calculations could be made on the effects of telescoping of 1o mm and 2o mm, respectively, as listed in Table 7.9.

Table 7.9 : Calculations of yield loads of screw corresponding to reduced moment arms after telescoping of implant.

Screw-plate angle	Bend.Mom. about strain gauge	Telescoping = 1o mm		Telescoping = 2o mm	
		Moment arm $(L_N-1o)\sin\alpha$	Calculated load	Moment arm $(L_N-2o)\sin\alpha$	Calculated load
135^o-Co-Cr-Mo	48.7	35.8	2,479 N	3o.2	3,464 N
135^o-316 LVM	43.9	35.8	2,235 N	3o.2	3,124 N
$15o^o$-Co-Cr-Mo	4o.3	38.1	1,354 N	34.8	1,519 N
$15o^o$-316 LVM	55.4	38.1	1,914 N	34.8	2,156 N

Load calculated from equation (7) in Chapter 6.

From the calculations it is observed that a telescoping of 1o mm improves the factual strength of the implant by about 28 % in 135^o angled cases and 11 % in $15o^o$ implants, as compared to the results obtained from the experiments. A telescoping of 2o mm improves the load bearing capacity of the 135^o implants with about 8o % and the $15o^o$ implants with 25 %.

Conclusions

Load testing of McLaughlin implants in any nail-plate angle, whether manufactured from Cobalt-Chromium-Molybdenum alloy or 316 LVM stainless steel, revealed failure loads of about 25o N, corresponding to bending moments about the nail-plate junction of 12 - 13 Nm. Due to an unsuitable geometric design the nail-plate junction becomes loose at this load. A load of about 7oo N, corresponding to a bending moment of 28 Nm results in additional failure of the nail and the curved plate extension. The resulting varus angulation is approximately $1o^o$.

In the strongest Jewett implants with nail-plate angles of 125^o and 135^o the nail started to bend at loads of 1,2oo - 1,5oo N, corresponding to bending moments about the nail of 34 Nm. A radiological appearence of 4^o varus angulation involved additional bending of the plate, very close to the nail-plate junction, at loads of about 1,7oo N, corresponding to bending moments of 75 Nm about the nail-plate junction.

The strongest sliding screw-plate implants of 135^{o} revealed the lowest yield loads to be at least 1,74o N, corresponding to bending moments of 44 - 49 Nm about the nail. A radiological appearance of 3^{o} varus angulation involved additional bending of the barrel and the plate. The loads required for this to happen was about 1,74o - 1,93o N. Telescopihg of the screw, however, improved the calculated mechanical strength of the implants considerably. The yield loads were calculated to 2,2oo - 2,5oo N and 3,1oo - 3,5oo N, respectively, for a telescoping of 1o mm or 2o mm.

The sliding screw-plate implants are thus found to be considerably stronger than the Jewett implants. The McLaughlin implants are found to be excessively weak because of an unacceptable nail-plate junction.

Chapter 8

Internal Fixation of Stable Trochanteric Fractures

Comparative studies of the internal fixation of stable trochanteric fractures have received very little interest. Anatomical reduction is achieved in most cases. Consequently the rate of secondary fracture dislocation should be low.

In comparative studies the fracture classification system according to Evans (1949) should be applied (Jensen 198o (IV)), as emphasized in Chapter 3. Stable trochanteric fractures are thus 2-fragmentary fractures with or without displacement.

The aim of the present study (Jensen et al 198o (XI)) was to compare the results of the internal fixation with the 3 most widely used implants in a large series of patients. A uniform and methodical evaluation of the roentgenograms could be applied and analysed by advanced statistical methods to disclose causal factors of failure of the internal fixation.

Patients

A follow-up of 329 patients with stable trochanteric fractures treated with either of the 3 methods was performed, as listed in Table 8.1.

The median age of the patients was 77 years (range 3o - 96) and the mean-age 75 $\pm$ 11 years. 78 % of the patients were females.

Table 8.1 : Treatment of stable fractures.

Fracture type	McLaughlin nail-plate	Jewett nail-plate	Sliding screw-plate	Total
undisplaced 2-fragmentary	78	1o9	32	219
displaced 2-fragmentary	37	55	18	11o
Total	115	164	5o	329

Methods

From the post-operative X-rays the fracture reduction was evaluated. Anatomical reduction was defined as a maximum diastasis of 4 mm over the fracture line. The positioning of the implant in relation to the bone confinements was measured.

The fractures were X-rayed regularily until fracture union. The appearance of technical failure was registrated as well as telescoping of the sliding screw-plate implant with secondary impaction. Technical failure was defined as bending, breakage or loosening of the implant and cutting or penetration of the implant tip within or through the femoral head or neck confinements.

Furthermore the rates of deep infection or osteitis, non-unions and re-operations were recorded.

Results and Discussion

Deep infection or osteitis were encountered in o.9 % (1/115) following McLaughlin, in 1.8 % (3/164) after Jewett and 2 % (1/5o) after sliding screw-plate fixation. There was no significant difference between the infection rates ($\underline{P}$ = o.9, Chi-square test).

The quality of fracture reduction is listed in Table 8.2. Anatomical reduction was obtained in 91 % (299/329) of cases with no difference between the methods. Bi-plane diastasis was encountered in less than 1 % (2/329) of cases.

Table 8.2 : Quality of reduction in stable trochanteric fractures.

Reduction	McLaughlin nail-plate	Jewett nail-plate	Sliding screw-plate	Total
anatomical in both planes	1o7 (93%)	147 (9o%)	45 (9o%)	299 (91%)
diastasis in lateral plane	6	7	3	16
diastasis in AP-plane	1	1o	1	12
diastasis in both planes	1	-	1	2

Table 8.3 : Results of treatment of stable trochanteric fractures.

Result	McLaughlin nail-plate	Jewett nail-plate	Sliding screw-plate	Total
Union in post operative position	11o (96%)	155 (95%)	45 (9o%)	31o (94 %)
Secondary displacement with union			2	2
Non-union	-	-	-	-
Technical failure	5 (4%)	9 (5%)	3 (6%)	17 (5%)
Total	115	164	5o	329

The results of treatment are listed in Table 8.3. There were no cases of non-union.

Technical failure was observed in 4 % (5/115) of McLaughlin cases, usually due to loosening of the nail-plate junction (Table 8.4). These results are slightly better than the 6 - 13 % reported previously (Foster 1958, Jensen & Michaelsen 1975, Laros & Moore 1974). Re-operation was performed in one case only, because of a 3o^{o} varus dislocation.

Jewett nail-plate fixations were followed by technical failures in 5 % (9/164), all being due to displacement of the nail tip with protrusion of the femoral head in most cases. Re-operations were performed, because of penetration, in 4 % (7/164) of cases. In previous publications the technical failure rate has been reported to 4 - 2o % (Boyd & Griffin 1949, Dimon & Hughston 1967, Jacobs et al 1976).

Technical failures after sliding screw-plate fixation of stable trochanteric fractures were observed in 6 % (3/5o) of the present cases, which is consistent with other reports (Clawson 1964, Jacobs et al 1976). Re-operation was performed in one case only due to penetration of the acetabulum.

Table 8.4 : Technical failures following internal fixation of stable trochanteric fractures.

	McLaughlin nail-plate	Jewett nail-plate	Sliding screw-plate	Total
cutting/migration <lo mm	1	2	1	4
penetration of fem.head	1	4	-	5
penetration of acetabulum	-	3	1	4
failure of nail-plate junct.	3			3
plate loose	-	-	1	1
Number of patients	5 (4%)	9 (5%)	3 (6%)	17 (5%)
Varus dislocation <lo°	3	2	1	6
Varus dislocation >2o°	1	-	-	1
Re-operations	1 (1%)	7 (4%)	1 (2%)	15 (4%)

The results obtained did not show any significant difference in the failure rates between the 3 types of hip implants (P = o.9, Chi-square test). The results are considered as fully acceptable and any of the hip implants can thus be used for the internal fixation of stable trochanteric fractures. The cause of failure was always inadequate reduction of the fracture.

Conclusions

The internal fixation of stable trochanteric fractures is neither a problem of fracture union nor a mechanical problem. Anatomical fracture reduction can be obtained in nearly all cases and the failure rates are low. Any of the hip implants included in this series can be used for the internal fixation of stable trochanteric fractures.

Chapter 9

Internal Fixation of Unstable Trochanteric Fractures

The internal fixation of unstable trochanteric fractures is primarily a mechanical problem. The instability of the fractures is due to lack of bony support over the medial aspect of the femur, as the lesser trochanter and part of the femoral arch is missing in the mechanical load transmission system. Another cause of instability is posterior detachment from the greater trochanter leading to mechanically unreliable reduction with anterior diastasis.

A classification system taking these problems into account must thus be used for comparative studies (Evans 1949, Jensen 198o (IV)). A diagram of unstable trochanteric fractures is shown in Figure 3.1.

In 1964 Clawson introduced the sliding screw-plate implant, which was meant to overcome the problems related to the reduction by allowing a secondary impaction through telescoping of the screw.

The purpose of the present study (Jensen et al 198o (XII)) was to compare the results of the internal fixation of unstable trochanteric fractures with McLaughlin or Jewett nail-plates and the sliding screw-plate in a large, thoroughly analysed series.

Patients and Methods

Unstable trochanteric fractures were treated in 948 patients with one of the 3 methods. The fractures were followed up until bony union or technical failure was encountered.

The median age of the patients undergoing follow-up examinations was 79 years (range 24 - loo) and the mean-age 76 $\pm$ 11 years. 78 % of the patients were females.

The treatment of the fractures in relation to the fracture types is shown in Table 9.1.

Table 9.1 : Treatment of unstable fractures.

Fracture type	McLaughlin nail-plate	Jewett nail-plate	Sliding screw-plate	Total
3-fragmentary % postero-lat. support	128	116	152	396
3-fragmentary % medial support	56	36	42	134
4-fragmentary	1o9	157	152	418
Total	293	3o9	346	948

The series of patients was collected consecutively during an 8-year period from 4 departments of orthopaedic surgery. The choice of fixation method was only to a very slight extent influenced by the type of fracture, as each department used a single method. The series of sliding screw-plate fixations was collected from 2 of the departments during the past 3 years. At all four departments the operations were performed by surgeons of equivalent stages of training. Accordingly the 3 methods of internal fixation are considered comparable.

The methods applied for the follow-up were identical with those described in Chapter 8. In the statistical evaluation of the results multivariate logistic analysis as well as multiple contingency table analysis with successive testing as described by Madsen (1976) were applied.

Results and Discussion

Deep infection or osteitis were encountered in 3.4 % (1o/293) following McLaughlin nail-plate fixation, in 2.3 % (7/3o9) after Jewett and 2.o % (7/346) after sliding screw-plate fixation. There was no significant difference between the methods ($\underline{P}$ = o.8, Chi-square test). No antibiotics prophylaxis was used. The total infection rate following surgery in the hip region was thus 2.5 % (24/948) on average, which is considerably lower than claimed recently (Tengve & Kjellander 1978).

Table 9.2 : Quality of reduction in unstable trochanteric fractures.

Reduction	McLaughlin nail-plate	Jewett nail-plate	Sliding screw-plate	Total
anatomical in both planes	69 (24%)	1o2 (33%)	99 (29%)	27o (29%)
diastasis in lateral plane	46 (16%)	53 (17%)	75 (22%)	174 (18%)
diastasis in AP-plane	57 (19%)	62 (2o%)	4o (11%)	159 (17%)
diastasis in both planes	121 (41%)	92 (3o%)	132 (38%)	345 (36%)

The quality of the fracture reduction is listed in Table 9.2.

A multiple contingency table analysis revealed that the quality of reduction was primarily determined by the comminution of the fracture ($\underline{P}$ < o.oooo5), but also correlated to the method of treatment ($\underline{P}$ < o.oo4). Fractures treated with McLaughlin nail-plates were reduced with diastasis more frequently than with the other methods.

Table 9.3 : Results of treatment of unstable trochanteric fractures.

Result	McLaughlin nail-plate	Jewett nail-plate	Sliding screw-plate	Total
Union in post operative position	137 (47%)	156 (5o%)	117 (34 %)	41o (43%)
Secondary displacement with union	-	-	2o8 (6o%)	2o8 (22%)
Non-union	2 (o.7%)	6 (2%)	-	8 (o.8%)
Technical failure	154 (53%)	147 (48%)	21 (6%)	322 (34%)
Total	293	3o9	346	948

The results of treatment are listed in Table 9.3.

Non-union was encountered in o.8 % (8/948) of cases, following McLaughlin or Jewett fixation. The difference between the 3 methods is significant ($\underline{P}$ < o.o25, Chi-square test).

Union in post-operative position was achieved in 47 % (137/293) of McLaughlin fixations and 5o % (156/3o9) of Jewett fixations. Following sliding screw-plate fixation 6o % (2o8/346) of the fractures impacted through telescoping of the screw. By this secondary dislocation bony contact was obtained and union could take place. This resulted in uncomplicated union in 94 % (325/346) of cases and is considered as the primary benefit of this internal fixation method. It is known, however, that the telescoping is often painful and followed by a leg shortening of 1 - 2 cm (Clawson 1964, Ecker et al 1975, Harrington ? Johnston 1973, Jensen et al 1978 (X), Laskin et al 1979).

Table 9.4 : Technical failures following internal fixation of unstable trochanteric fractures.

	McLaughlin nail-plate	Jewett nail-plate	Sliding screw-plate	Total
migration/cutting <lo mm	25	63	1	89
migration/cutting >11 mm	4	5	2	11
penetration of fem.head	9	31	2	42
penetration of acetabulum	15	33	3	51
cutting through fem.head	12	13	12	37
failure of nail-plate junct.	loo			loo
nail bend or broken	7	12	-	19
plate loose	1	2	1	4
plate bend or broken	2	2	-	4
Number of patients	154 (53%)	147 (48%)	21 (6%)	322 (34%)
Varus dislocation <lo^{o}	63	26	6	95
Varus dislocation >2o^{o}	74 (25%)	36 (12%)	13 (4%)	123 (13%)
Re-operations	5o (17%)	37 (12%)	11 (3%)	98 (lo%)

Technical failures were encountered in 53 % (154/293) of McLaughlin fixations. A total of 175 failures were observed, as listed in Table 9.4. In 3o % (88/293) of cases failure of the nail-plate junction was the only explanation and implant failures accounted for a total of 38 % (11o/293). Re-operations were performed because of implant failures in 9 % (26/293) of cases. The remaining failures were due to osteoporosis with displacement of the nail tip within or through the femoral head and neck confinements. The technical failures resulted in varus dislocation of more than 2o$^{\circ}$ in 25 % (74/293) of cases and re-operation in a total of 17 % (5o/293). The results of the present series were somewhat worse than previous reports on failure rates of 2o - 46 % following internal fixation of unstable trochanteric fractures with the McLaughlin nail-plate (Bremner & Graham 1958, Clawson 1957, Foster 1958, Friedenberg et al 1972, Jensen & Michaelsen 1975, Laros & Moore 1974, McLaughlin & Garcia 1955).

In the present series any measurable technical failure is included without regard to the clinical implication. It is obvious that displacements of the nail tip within the bone confinements as well as minor varus dislocations due to loosening of the nail-plate junction are of minor clinical relevance. For a true clarification of the quality of the internal fixation methods and the involved biomechanical problems, any change in the position of the fracture or implant must be considered, however. The high percentage of re-operations, either because of implant failure or penetration of the osteoporotic bone with subsequent varus deformity, makes the McLaughlin nail-plate an unsuitable method of internal fixation of unstable trochanteric fractures.

Concerning Jewett nail-plate fixation technical failures were encountered in 48 % (147/3o9) of cases, representing 161 failures. Implant failures were observed in 5 % (16/3o9). The majority of failures were due to osteoporosis with movement of the nail tip in relation to the bone, often protruding outside the femoral head and neck. Varus dislocation of more than 2o$^{\circ}$ was observed in 12 % (36/3o9) of cases. Re-operations were performed in 12 % (37/3o9), mostly because of acetabular protrusion. Only 2 % (7/3o9) of the re-operations were caused by implant failure.

From literature failure rates of 14 - 51 % have been reported in series of unstable fractures (Boyd & Griffin 1949, Dimon & Hughston 1967, Evans 1951, Fielding 1973, Jacobs et al 1976, Johnson et al 1968, Kyle et al 1979, Laros & Moore 1974, Morrison et al 1978, Parker 1955, Robey 1956). It has already been pointed out that the problem in unstable fractures is the inability of obtaining mechanically reliable reduction. During weight-bearing the main fragments of the fracture will seek together to create a reliable weight transmission system. In this process of secondary impaction the implant must either give way, as was the case with the McLaughlin implants, or protrude through the bone. Alterations of the operative technique by using a shorter Jewett nail might solve the problems with penetration, but would lead to a higher amount of cuttings with varus dislocation (Boyd & Griffin 1949, Evans 1951). Consequently the Jewett nail-plate implant can not be recommended for the internal fixation of unstable trochanteric fractures.

Sliding screw-plate fixation was followed by technical failure in 6 % (21/346) of cases. Implant failure was experienced in only one case with loosening of the plate. Nearly all failures were caused by the implant being stronger than the bone and thus protruding through the femoral head or neck. Varus dislocation of 2o^{o} or more was observed in 4 % (13/346). Re-operations were performed in 3 % (11/346), because of penetration or severe varus dislocation.

The failure rate of the present series is consistent with previous reports (Clawson 1964, Doherty & Lyden 1979, Ecker et al 1975, Harrington & Johnston 1973, Jacobs et al 1976, Jensen et al 1978 (X), Mulholland & Gunn 1972). Friedenberg et al (1972), however, reported a failure rate of 19 %, but with a re-operation rate identical with the present series. Jacobs et al (1976) found the sliding screw-plate fixation significantly better than the Jewett nail-plate. This was confirmed by the present study, which also showed superiority to the McLaughlin fixation method.

A multivariate logistic analysis revealed, that the fracture diastasis following the reduction was the main cause of secondary displacement or technical failure ($\underline{P}$ < o.ooo5). This means, that a mechanically reliable reduction is the primary safe-guard against technical failures. The distance from the nail tip to the bone confinements, however, should even be between 11 and 15 mm ($\underline{P}$ < o.ool).

Conclusions

In the treatment of unstable trochanteric fractures the sliding screw-plate fixation is found to be the most suitable of the 3 methods investigated in the present series. This is because, in fractures reduced with diastasis, a secondary impaction is necessary for the establishment of bony contact and consequently reliable weight transmission. In this situation, the sliding screw-plate implant is the only method to avoid technical failures of fixation, as the device is telescoping to comply with the problems.

Chapter 10
Biomechanics in Trochanteric Fractures

The primary goal of any fracture treatment is to achieve fracture union with a satisfactory functional result.

In the present chapter, biomechanical considerations will be brought into the planning of the internal fixation of trochanteric fractures, summarizing the observations made in this dissertation.

Prior to any attempts at internal fixation of fractures it is of utmost importance to realize what forces the implant has to neutralize.

Numerous investigations have been done concerning the force vectors around the hip joint. The only records on direct measurement of the hip joint force were published by Rydell (1966), who inserted a strain gauge mounted femoral head prosthesis. He found, that moving the hip joint resulted in loads of about 1.5 times the body weight, whereas normal walking on a level surface was followed by loads of 2.5 - 3.5 times the body weight on the femoral head. Mathematical calculations have stated a hip joint load of about 6 times the body weight in walking (Williams & Svensson 1968) and calculations from ground-to-foot force measurements by force plates led to values of 4 - 6 times the body weight at normal walking (Paul 1966, 1967, 1971, 1976, Poulson 1973).

Non-operative treatment of trochanteric fractures with tibial traction is known to be followed by mortality rates of about 4o % (Arlt et al 1973, Clawson 1957, Cleveland et al 1947, 1948). In an attempt to reduce lethal cases of cardio-pulmonary or thrombo-embolic complications the modern trend in the treatment of trochanteric fractures is internal fixation followed by early weight-bearing mobilization (Ainsworth 1971, Bosacco et al 1973, Jensen et al 1978 (X), Jensen & Sonne-Holm 198o, Parker & Reitmann 1976, Rennie & Mitchell 1976, Sahlstrand 1974, Sarmiento & Williams 197o). As a consequence of this the internal fixation has to resist forces of about 3 - 6 times the body weight.

It has been pointed out that anatomical fracture reduction with bony contact is mandatory for a reliable load transmission from the femoral head to the femoral shaft (Jensen et al 198o (XII), Johnston 1973, Parker 1955, Sarmiento 1957), but this reduction is difficult to achieve in unstable trochanteric fractures (Clawson 1957, Jensen 198o (IV), Jensen et al 198o (XII), Kennedy et al 1957, Kumar 1973). The reason for this is the detachment of fragments from the femoral arch or the greater trochanter of the majority of trochanteric fractures, leading to mechanically unreliable reduction (Jensen 198o (IV), Jensen et al 198o (XII)). The second corner stone in the treatment of trochanteric fractures is thus an adequate classification of the fractures prior to the internal fixation, taking into account the inborn instability of the fracture reduction (Evans 1949, Jensen 198o (IV)), which leads to high failure rates of fixation (Jensen et al 198o (XII), Jensen & Sonne-Holm 198o).

About 75 % of trochanteric fractures are encountered in females with a median age of 79 years (Jensen 198o (I), Jensen & Tøndevold 1979 (II), Jensen et al 1979 (III)). It is known that the femoral head and neck becomes osteoporotic with increasing age (Brown 1965, Farkas 1948, Harty 1957), and especially in females over the age of 5o years (Nordin et al 1966). The osteoporotic changes lead to reduced mechanical strength of the femoral head and neck (Hall 1961, Hirsch & Brodetti 1957, Freeman et al 1974, Singh et al 197o, Spears & Owen 1949, Yamado 197o). As a consequence of this failures of fracture fixation by migrating or protruding nails might be encountered in numerous cases (Jensen et al 198o (XII)), and it has thus been recommended to place the nails parallel to the trabecles of the femoral neck (Backman 1957, Frankel 196o, Harvey 1959, Scheuba 197o).

The third problem in the treatment of trochanteric fractures is thus to avoid failures of the fixation. In unstable fractures reduced with diastasis over the fracture line the implant might have to transmit the entire hip joint load of 3 - 6 times the body weight to the femoral shaft (Dimon 1973, Fielding 1973, Frankel 1963, Johnston 1973, Jensen et al 1978 (X), Jensen et al 198o (XII), Kaufer et al 1974, Sonstegard et al 1974).

Failure of fixation might be due to osteoporosis of the femoral head and neck. In Figure lo.1 a 3-fragmentary fracture with detachment from the greater trochanter is demonstrated.

Figure lo.1 : Jewett nail-plate fixation of a 3-fragmentary fracture without postero-lateral support.Reduction with diastasis medially and anteriorily.

The fracture was reduced with diastasis medially and anteriorily. The unstable reduction was followed by secondary impaction of the fracture during weight-bearing, resulting in migration of the nail (Figure lo.2) until bony contact over the fracture line was established.

Figure lo.2 : Secondary impaction with migration of the Jewett nail.

In this case the nail tip was per-operatively placed fairly distant from the femoral head confinements and the secondary impaction had no clinical implication.

Figure lo.3 : Jewett nail-plate fixation of 3-fragmentary fracture without postero-lateral support.Nail tip at cartilagenous border.

Figure lo.4 : Secondary impaction followed by penetration into the acetabulum

In another case (Figure lo.3) of unstable fracture reduction in a similar fracture the nail tip was per-operatively placed at the cartilagenous border of the femoral head. Weight-bearing was followed by penetration through the acetabular roof and a considerable varus angulation (Figure lo.4). This patient needed re-operation.

As reported in Chapter 8 failure of fixation due to osteoporosis and inadequate fracture reduction is encountered in only about 5 % of cases in stable trochanteric fractures, independent of the method of internal fixation. Any implant can thus be used for stable fractures, but a perfect reduction is the prerequisite of obtaining good results.

Concerning the unstable trochanteric fractures similar failures are experienced after McLaughlin osteosynthesis in about 2o % of cases and after Jewett nailing in more than 4o % of cases,as stated in Chapter 9. It is quite obvious, that a fixation system allowing secondary fracture impaction resulting in bony support across the fracture line must be applied. The sliding screw-plate is able to telescope during the process of impaction and immediate weight-bearing can thus be allowed. Telescoping was experienced in about 6o % of cases (Figure lo.5 and lo.6), whereas failures of fixation due to displacement of the screw were observed in only 6 % of cases (Figure lo.7). The sliding screw-plate is thus considered the optimal fixation device to prevent failures due to osteoporosis.

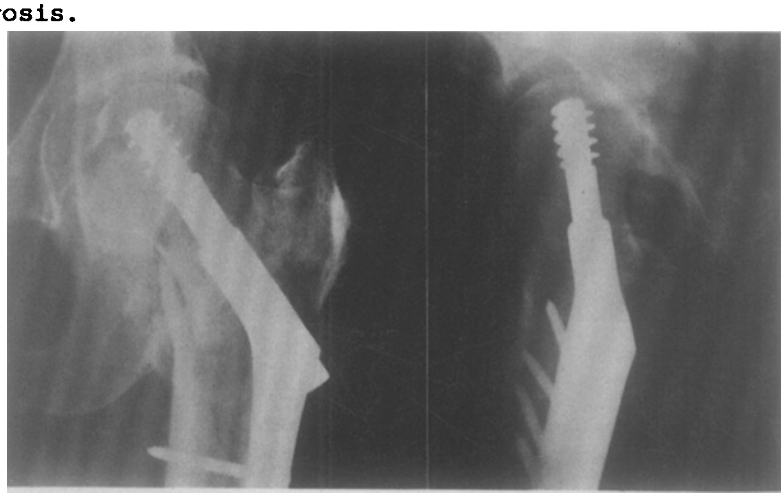


Figure lo.5 : 4-fragmentary fracture reduced with medial and anterior diastasis

Figure lo.6 : **Secondary impaction with telescoping leads to bony contact across the fracture line.**

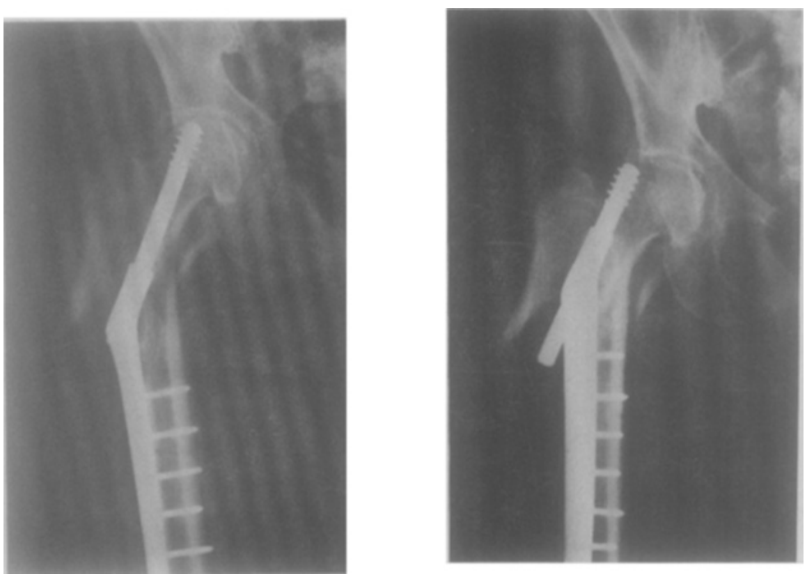


Figure lo.7 : 4-fragmentary fracture with inadequate reduction. Screw tip in upper lateral quadrant of head with weak bone, trabecular system crossed by screw. Telescoping did not prevent protrusion of the screw outside the femoral head.

Failure of fixation might also be due to failure of the implant in unstable trochanteric fractures. In such cases either the femoral head has sufficient strength to resist protrusion of the nail or the mechanical strength of the implant is lower than for the bone.

According to Chapter 9 implant failure is encountered in about one third of unstable trochanteric fractures treated with the McLaughlin nail-plate. Mechanical testing of these implants revealed a failure load of approximately 25o N for the nail-plate junction (Chapter 7), which equals about one third of the body weight of a normal person. The mechanical strength of the implant is thus considerably lower than the load applied by movement of the hip joint.

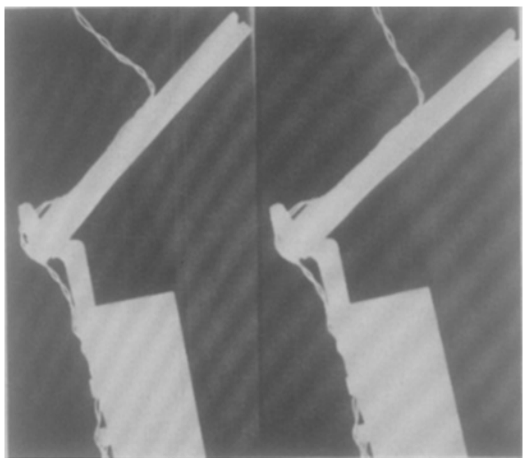


Figure lo.8 : McLaughlin nail-plate after testing, demonstrating loosening of the nail-plate junction.

In Figure lo.8 an X-ray of a 135^{O} McLaughlin implant is demonstrated after the laboratory testing, showing a varus angulation of lo^{O} due to loosening of the nail-plate junction.

From the clinical files a 3-fragmentary fracture with detachment from the greater trochanter was found, demonstrating reduction with medial diastasis (Figure lo.9). Weight-bearing was followed by a varus dislocation of about $2o^{O}$ due to failure of the nail-plate jeunction. The dislocation resulted in a reliable weight transmission system through bony contact.

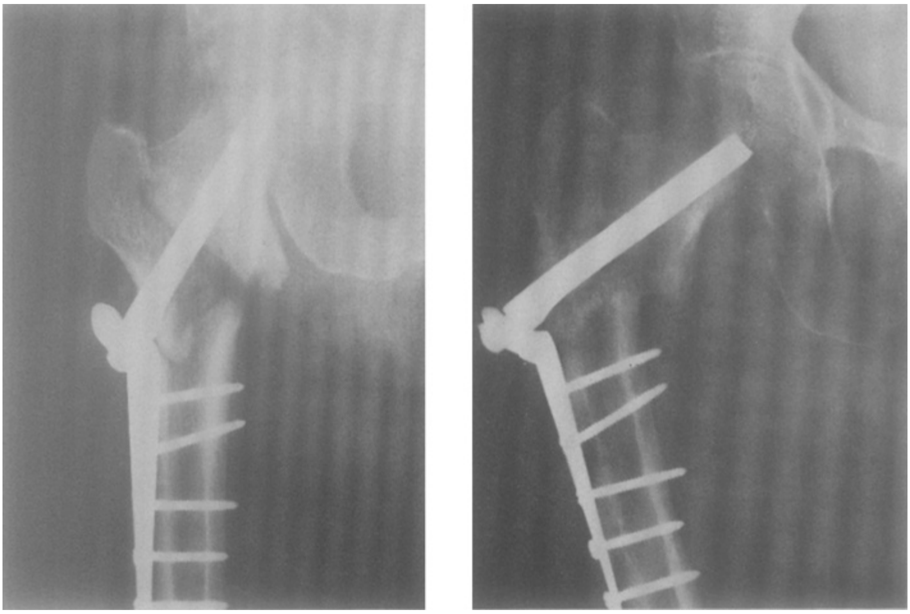


Figure lo.9 : 3-fragmentary fracture reduced with medial diastasis. Secondary impaction results in failure of nail-plate junction of the McLaughlin implant with considerable varus angulation.

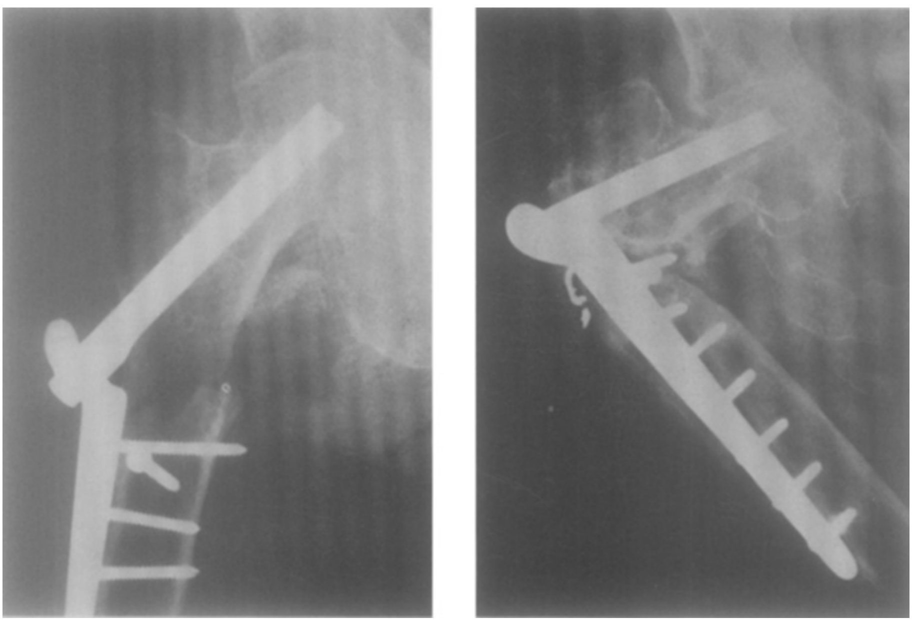


Figure lo.lo : 4-fragmentary fracture reduced with medial diastasis. Nail-plate junction of McLaughlin implant disintegrated totally with broken washer.

Another case of a 4-fragmentary fracture reduced with medial diastasis resulted in total disintegration of the McLaughlin implant with failure of the washer and extrusion of the top bolt (Figure lo.lo).

According to Chapter 7 the components of the nail-plate junction undergo deformation hardening following the initial failure. By this process the nail-plate junction is strengthened and other components of the implant might undergo failure.

In the biomechanical experiments the failure load for the nail was determined to about 6oo N, which approximately equals the body weight.

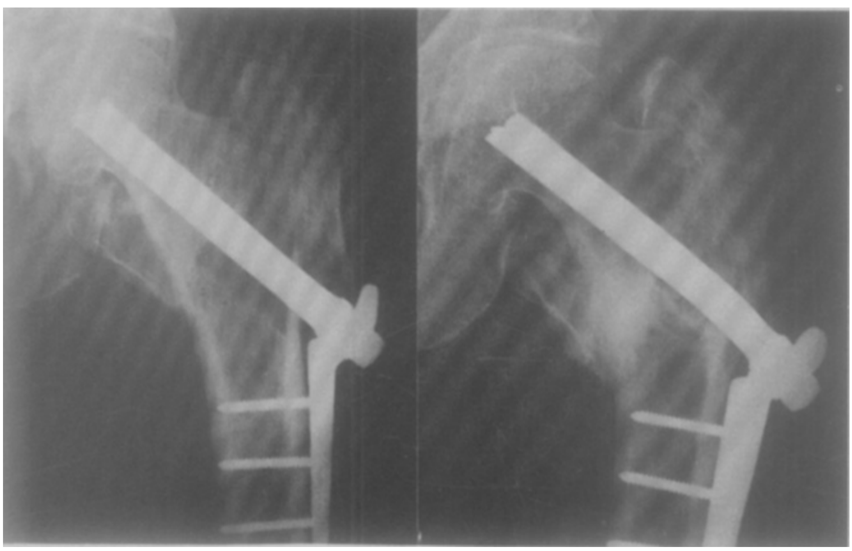


Figure lo.11 : 4-fragmentary fracture reduced with medial and anterior diastasis, resulting in bending of the nail 2.5 cm from the nail-plate junction. Minor cracks are observed superiorily at the bending area.

Failure of the nail is demonstrated in Fihure lo.11, but was in the clinical series experienced in less than 3 % of cases.

The last component to fail in the experiments was the curved plate extension at loads of about 75o N.

Figure lo.12 illustrates such a failure mode, which was encountered in less than 1 % of cases.

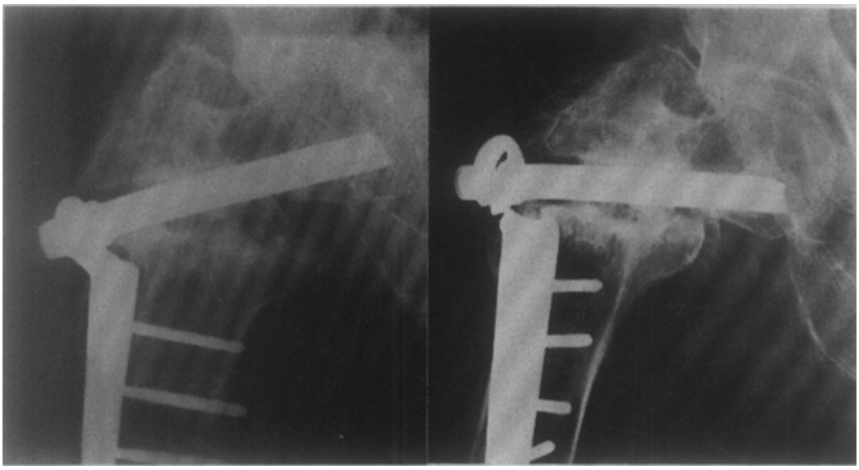


Figure lo.12 : Non-union following McLaughlin nail-plate fixation with failure of the nail-plate junction. Fatigue failure observed later of the curved plate portion at the lower contact point with the nail base.

The very low failure loads encountered at the mechanical testing of the implants thus give a sufficient explanation for the high rate of implant failures following the McLaughlin fixation of unstable trochanteric fractures. In consequence of these experiences the McLaughlin implant in the present design is considered totally unsuitable for the internal fixation of unstable trochanteric fractures.

Concerning the Jewett nail plate, implant failure was encountered in the clinical series in about 5 % of cases. The failure loads determined in the biomechanical experiments with 125^{o} and 135^{o} implants could withstand about 2 - 2.5 times the body weight, whereas bending was observed after loads of about 1.5 times the body weight in $14o^{o}$ and $15o^{o}$ angled implants. This is in accordance with the clinical observations of implant failure in 5 % of cases. Figure lo.13 demonstrates a case of inadequate reduction with medial diastasis followed by fracture of the nail. As mentioned, the Jewett nail-plate fixation, however, in a high percentage of cases leads to failure of the osteoporotic bone.

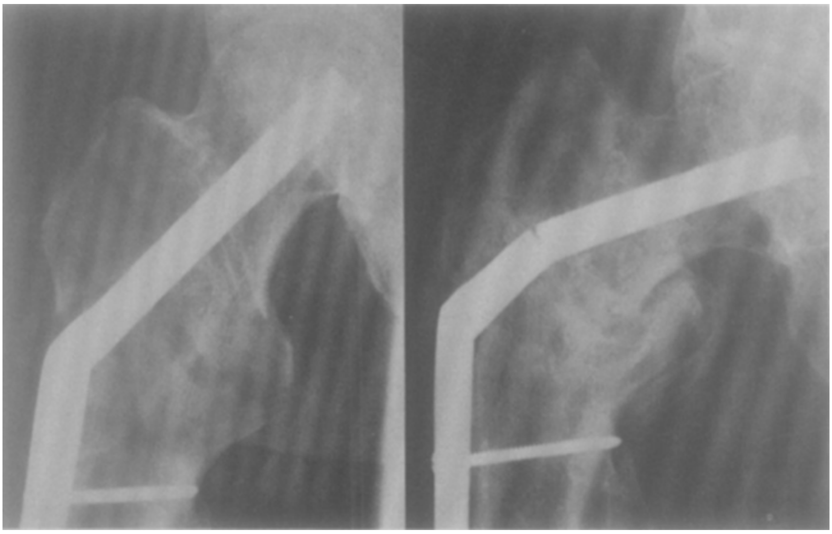


Figure lo.13 : Jewett nail-plate fixation with medial fracture diastasis, resulting in breakage of the nail about 3 cm from the junction.

The sliding screw-plate implant did not reveal any implant failures in the clinical series. This is in accordance with the biomechanical experiments, revealing failure loads of about 2.5 - 3 times the body weight in implants with locking of the telescoping facility. Mathematical calculations showed improvement of the implant strength by at least 3o % following telescoping. In combination with the clinical observations the sliding screw-plate implant is thus found to be the preferred implant for the internal fixation of unstable trochanteric fractures.

Concerning the mechanism of failure in the clinical service of implants it has been pointed out that fatigue is more liable to cause implant failure than sudden overloading of the device (Bechtol & Murphy 1952, Gallinaro et al 1977). Even in the attempted stable fixation of the fractures micro-movements will take place across the fracture line (Jergesen 1964) due to repeated loading and unloading during walking or movement of the hip. This leads to stress concentrations in areas, where the geometry of the implant is altered and especially in areas with edges or notches (Bechtol & Murphy 1952, Pugh 1976). Fatigue failure will thus be the result of cyclic loading with loads less than the yield loads determined.

In the McLaughlin implants the most susceptible area of stress concentration is the nail-plate connection (Grover 1966), where the geometry of the components does not fit together. Ghista & Elongovan (1977) stated that the nail-plate implants marketed were sufficient enough for the internal fixation of trochanteric fractures, but in their calculations only 2-fragmentary, stable fractures were considered. The results of our observations clinically as well as biomechanically prove the McLaughlin implants and high angled Jewett nail-plates to be insufficient for the internal fixation of unstable trochanteric fractures.

Alterations of the design with additional thickened flanges or a smoother nail-plate junction of Jewett nails as well as a re-design of the McLaughlin nail base and curved plate extension with extended area of contact and perfectly fitting shapes are not likely to solve the problems. The mechanical strength of the implants would naturally be improved by such alterations, but in the clinical service of the implants an increased number of nail protrusions with subsequent re-operations could be expected, as the strength of the implants would exceed the strength of the osteoporotic bone. The inability of achieving mechanically reliable reduction of the predominant unstable trochanteric fractures implies that secondary impaction of the fractures must be allowed. This is indeed the case with the sliding screw-plate implants. The disadvantage of these implants are, however, the difficulties of insertion because of a fixed nail-plate angle. Consequently there might be a future demand for a free angled device. This could be achieved by re-designing the nail-plate junction of the McLaughlin implant to fulfill the mechanical specifications given from the hip joint loads and exchanging the trifin nail with an ordinary sliding nail. The one-piece, fixed angle Jewett nail-plate implant has hardly any future in the internal fixation of unstable trochanteric fractures.

Chapter 11
Statistical Methods

The aim of this chapter is to give a short survey of the statistical methods applied in the investigations of hip fractures.

The chapter is written by Svend Kreiner-Møller (cand. stat.) from the Department for Data Processing, Herlev Hospital, Denmark.

Two specific problems will be described, namely the analysis of survival data and the analysis of multiple contingency tables.

In both cases only standard statistical methods were applied, as described comprehensively in the mathematical statistical literature. The following notes therefore give only a brief presentation of the practical appliance of the statistical methods.

THE ANALYSIS OF SURVIVAL DATA

The methods used are discussed in several papers, the most pertinent being Kaplan & Meier (1958), Gehan (1965) and Cox (1972). A short description of the methods was given by Kjøller et al (1978).

The problem concerning the analysis of survival data is in most cases rather simple. It is a question of the lapse of time from some kind of event (e.g. birth or occurrence of a specified disease) to death, and how the survival time varies from one sub-population to another. In other words, it is a question of estimating and comparing the distribution of several continous variables.

The standard models and methods for such kinds of problems should be applicable also in connection with the analysis of survival data.

Special methods have been developed, however, because the observations of survival times will usually be incomplete. For some individuals the date of death, and thus the survival time, will be known. For other individuals it will be known that they are alive at a given date. Consequently only a shorter range of their survival time is known.

In such cases the standard estimates and the standard statistical tests are not directly applicable. In several cases it is possible, however, to generalize these methods to estimates and tests also in case of incomplete survival times.

Kaplan & Meier (1958) described the possibilities of calculating simple estimates of the cumulative distribution function through a primary estimation of conditional probabilities. Gehan (1965) described how the traditional Wilcoxon test could be generalized for the comparison of two distributions containing incomplete observations.

In both cases the test-statistics are estimates of the probability that an observation from one of the samples is greater than an observation from the other sample. Both the methods of calculating the test-statistics and the distribution under the zero-hypothesis of equal distributions will have to be modified to compensate for the incomplete observations.

Cox (1972) suggested a regression-model where the logarithm of the hazard is assumed to be a linear function of one or more explanatory variables, but without any assumption regarding the shape of the underlying distribution. This model may be analysed by standard likelihood methods with or without incomplete observations.

In the present series the method described by Gehan (1965) was applied.

THE ANALYSIS OF MULTIPLE CONTINGENCY TABLES

The principal reference for the methods used in connection with the analysis of multiple contingency tables was published by Bishop et al (1975). A short review of these methods was given by Madsen (1976), who also discussed the strategy used in stepwise testing procedures.

Andersen (1977) introduced a special case of the general log-linear model, which was described in detail by Bishop et al (1975). This model, the multiplicative Poisson model with unequal cell rates, was used in the analysis of the number of hip fractures per year.

The multidimensional contingency tables are obtained by classifying a group of patients according to specific criteria, which are sub-divided into categories. Each patient is thus characterized by a multidimensional vector. Each cell of the table contains patients defined by one category from each criteria.

The statistical model used to describe the variation in the contingency table depends on the sampling plan. The following 3 plans are those most commonly encountered. The technical and mathematical aspects of the statistical analysis are the same in all 3 cases, but the interpretation of the parameters and the results of the analysis differs from sampling plan to sampling plan. The following 3 sampling situations are considered :

A) Independent Poisson Sampling.

With no restrictions on the total sample size, the number of observations in each cell may be described by an independent Poisson distribution.

B) Simple Multinomial Sampling.

Only the sample size is fixed. The distribution of the total number of observations follows an independent multinomial distribution with different probabilities. The sum of all the probabilities adds to 1.

C) Product Multinomial Sampling.

A sub-set consisting of a selected number of the original criteria used in the table is considered. From the multidimensional contingency table the distribution of the patients according to the selected number of criteria is calculated, leading to new marginal contingency tables. If not only the number of patients, but also the marginal multidimensional table, determined by the selected number of criteria, is fixed, a case of product multinomial sampling is encountered. This situation occurs either as a result of a specified sampling plan OR because it is relevant to analyse the conditional distribution according to the remaining criteria, when the distribution according to the selected criteria is given. In either case several conditioned multidimensional distributions must be considered.

In all 3 sampling situations the series of patients are primarily distributed into the cells of the multiple contingency tables. The model may further be completely specified by the expected number of patients in the different cells.

For simplification of the further statistical analysis several models have been suggested, based on different parametrizations of the expected values.

The so-called log-linear model has been the most commonly applied and also formed the basis of the present analysis.

The model is constructed of 4 sets of parameters :

1) level parameters, which may be interpreted as characterizations of the expected number of patients, not considering the observed distributions.
2) parameters with main effects, which are correctives adjusted for uneven distribution of the patients.
3) parameters indicating first order interactions, which are correctives originated from the immediate interactions between pairs of criteria.
4) parameters indicating higher order interactions, which are correctives adjusting for complex multiple related criteria.

In an investigation, where the primary aim of the statistical analysis is to determine the possible correlation between different variables, so-called hierarchical models are fully applicable. With the log-linear model the above mentioned parameters of higher order can thus be excluded, if the influence of a lower order parameter or a level parameter is insignificant.

The statistical analysis used in the present series consisted of several stepwise tests of hypothesis relating the observed number of patients in the cells to the expected number. By the hypothesis testing one or more level parameters is specified to disappear.

The results of the analysis were validated by several stepwise procedures, which all led to identical results.

The analysis consisted of 2 main steps.

In the first step of the analysis the interactions of a given order, beginning with the highest order of interactions, was eliminated. The result of the tests was, that all interactions higher than the first order interaction could be regarded as non-existent.

The second main step, also consisting of smaller steps, determined whether any of the first order interactions could be eliminated. This part of the analysis may proceed by either forward selection, where parameters are added to the model specifying no first order interaction, or by backwards selection, where parameters are eliminated from the model containing all the possible first order interactions.

In both main steps of the analysis the tests were performed as standard likelihood tests.

In addition a minimum discriminate information analysis (Kullback 1959) was carried out. In this analysis the observed contingency tables were compared to the table, which minimizes the discrimination information statistics.

An analysis based on the logistic-linear, rather than the log-linear, model was performed to validate the results of the analysis, when possible. The difference between these 2 models is, that the log-linear model analyzes the logarithms of the frequencies of the distribution, whereas the logistic-linear model analyzes the logarithms of the odds of the frequencies.

<u>The multiplicative Poisson model with unequal cell rates.</u>

This so-called non-hierarchical log-linear model was used for the analysis of hip fractures per year.

In this model the parameters of certain order are not disappearing although the related parameters of lower order are equal to zero. It is also assumed that higher order parameters are known a-priori.

This situation occurs in the following way :

The number of individuals is known exactly and distributed according to 2 criteria in a contingency table. The probability of an event, which may occur for each of the individuals, depends on these 2 criteria. The expected number of events in each cell of the table is thus equivalent to the combined probability multiplied by the number of individuals.

The number of events in each cell will be distributed approximately by a Poisson distribution, when the combined probability is sufficiently small and the number of individuals sufficiently large. It is furthermore assumed that the effects of the 2 criteria on the probability may be generally separated into other factors describing the effects of the 2 different criteria.

This model is a log-linear model of quite similar type as those descussed previously, but the model is non-hierarchical.

A test of the hypothesis that one or both of the criteria has no effect on the probabilities is a test of whether all the logarithmic factors disappear with the logarithms of a fixed number of patients, in which the logarithm should not be equal to zero, even if any of the above mentioned hypothesis should be accepted.

It should be mentioned that the problem might be re-formulated by defining the occurrence or non-occurrence of the event as a third criteria. The following analysis of the 3-dimensional contingency table containing the distribution of all individuals (and not just events) according to all 3 criteria would be equivalent to the analysis in the hierarchical table. The sampling situation would be changed from Poisson sampling to product multinomial sampling and the models changed from non-hierarchical to hierarchical models.

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