Healing of plated femoral osteotomies in dogs

A mechanical study using a new test method

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We investigated changes in whole bone flexural rigidity during healing of plated osteotomized beagle femora. Using a recently developed mechanical method, healing femora and their intact contralateral controls were tested in non-destructive bending in 24 planes at 15 degree angular increments. The elliptical distributions of flexural rigidity were used to define 4 parameters which describe the mechanical status of a healing bone relative to its control. Plates of 3 different rigidities were used in 21 beagles; 6 for 2 months and 15 for 6 months. 2 healing efficiency parameters, describing bone rigidity, indicated that plated femora may never reach the rigidity of their controls. One of the parameters, describing bone asymmetry, showed that changes in bone asymmetry occurred early in the healing process. Results at 6 months showed no differences in rigidity and asymmetry of bones plated with the different plates. This is attributed to antagonistic effects of axial and flexural rigidities of the plates on bone healing. Our results indicate that the method may be useful for bone healing research.

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Undesirable consequences are associated with the use of rigid compression plates. External callus formation is suppressed, limiting the healing to direct growth of the haversian system across the fracture gap—primary healing. Another consequence is the development of osteopenia underneath the plate, probably caused by stress shielding of the underlying bone (Akeson et al. 1976, Woo et al. 1976, Slätis et al. 1980, Terjesen and Benum 1983, Uhthoff and Finnegan 1983) and/or interference with blood circulation in the bone under the plate (Luehti 1980). Less rigid fixation, which allows limited interfragmentary motion, results in callus formation and more rapid healing (Goodship and Kenwright 1985). As the maintenance of bone mass and structure depends on the loading of the bone, a less rigid plate reduces stress shielding and the resulting osteopenia. Reduced contact between plate and bone may cause less interference with blood circulation and reduced local porosis (Perren et al. 1988).

These ideas are explored in this work by using a novel mechanical test method—the Polar Flexural Rigidity Profile (PFRP) method (Foux et al. 1990). The method produces an assessment of the mechanical status of a healing bone defined by 4 quantitative Healing Efficiency Parameters (HEP). The PFRP method is used to investigate healing of osteotomized canine femora fixed with plates of 3 different rigidities for 2 time periods. HEP are evaluated and the effects of time and of plate type on these parameters are studied. The main purpose of this work was to evaluate the PFRP test method and, to a lesser extent, the 3 plate types used for this study.

Materials and methods

Experimental procedure

Experiments were conducted on 21 young mature female beagles with closed epiphyses and under 2 years of age. The dogs underwent a unilateral femoral osteotomy and plating on alternate sides. The surgical procedure was performed under general anesthesia. A lateral incision was made and the femur was approached between the vastus lateralis and the biceps. At this site (anterior lateral aspect) the femor is quite straight and the plate was not bent to conform to the shape of the bone.

3 types of 6-hole metal plates were used, all having the same length (72 mm) and hole-spacing. Plate materials, geometric and elastic properties of the plates, and the properties of the plates relative to those of a typical beagle femur are listed in Table 1. Two of the plate types—railed titanium (R-TA) and railed

Table 1. Properties of plates

Plate	Material	E (GN/m^2)	A (mm^2)	I (mm^4)	AE (MN)	EI ($N\,m^2$)	AE′	EI′	EI/AE (mm^2)
1/3 TUB	Stainless Steel (316 LVM)	210	13.7	11.7	2.88	2.46	4.88	0.54	0.85
R-TA	Titanium Alloy (Ti-6Al-4V)	110	34.6	50.0	3.81	5.50	6.46	1.20	1.44
R-SS	Stainless Steel (316 LVM)	210	34.6	50.0	7.27	10.50	12.32	2.28	1.44
Typical Beagle femur		10	58.9	460	0.59	4.60	–	–	–

E Modulus of elasticity
A Cross-sectional area
I Moment of inertia
AE Axial rigidity
EI Flexural rigidity
AE′ Relative axial rigidity $= (AE)_{Plate} / (AE)_{Femur}$
EI′ Relative flexural rigidity $= (EI)_{Plate} / (EI)_{Femur}$

stainless steel (R-SS)—were compression plates, identical in design but made of different materials. These plates were railed on their underside to reduce the contact area with the bone. The third plate type—1/3 tubular stainless steel (1/3 TUB)—had circular screw holes and during fixation the bone fragments were brought into contact without compression. The undersurface of a plate of this type was contoured with a curvature similar to that of the bone, to increase the area of contact with the bone.

Femora of 6 dogs were plated for 8 weeks, 2 with each of the 3 plate types. The femora of the remaining 15 dogs were plated for 24 weeks, 5 with each of the plate types. The 8-week and 24-week periods were chosen because they correspond to the end of the healing and the end of the external remodeling stages, respectively. The dogs were euthanized, their femora dissected and the plates removed. The bones were preserved in a 10% formalin solution until mechanical testing was performed (within 12 weeks).

Mechanical testing

The osteotomized bones and their intact contralateral controls were tested in 3-point-bending, following the Polar Flexural Rigidity Profile (PFRP) method described in detail by Foux et al. (1990). For clarity of presentation the method is described here in brief.

The femur ends, stripped of soft tissues, are potted with low melting point bismuth alloy in 2 coaxial cups placing the osteotomy at the center. These cups are integral parts of a 3-point-bending device mounted on an Instron testing machine. The cups with the potted bone can be rotated around their common axis and locked at angular increments of 15 degrees. At each angular position, a low moment bending test (1.0 Nm at the center) is conducted on the bone at a fixed rate of center deflection (0.5 mm/min) measured with a linear-variable-differential transformer (LVDT). 25 consecutive bending tests are thus conducted on each bone to complete a full revolution, with the last test repeating the first. Load and center deflection are recorded in each test and a load vs deflection curve is plotted. The lower section of this curve, 5–10 percent, has an increasing slope. Thereafter the curve becomes linear and the slope of this linear section is determined by regression.

The flexural rigidity (EI) is the product of the modulus of elasticity and the moment of inertia at any cross-section of the bone. As these properties are not uniform along the bone length, the diaphyseal shaft is considered as a uniform beam which has the same load deflection characteristics as the whole bone. This concept of mechanical functional equivalence is utilized to calculate a representative EI, using the slope of the load deflection curve and the test specimen length dimensions, by using beam theory.

25 radial values of EI are thus obtained for each bone, starting with the anterior direction, encircling its perimeter and ending again at the anterior direction. This is used as a precaution for test repeatability. The mean value of the first and the twenty-fifth is taken as the EI value in the anterior direction. The 24 EI values are plotted in polar coordinates to form an ellipse, which is referred to as the PFRP. This ellipse is curve fitted by regression analysis and is defined by 3 parameters: major semiaxis (a), minor semiaxis (b), and angle of inclination (α). The flexural rigidity characteristics of each bone are thus defined by these 3 parameters.

The PFRPs of both the healing bone and its contralateral control are shown on the same set of polar coordinates for comparison. As this pair of bones consists of right and left bones, the PFRP of the right bone is shown in its coordinate system and that of the left bone is presented by a mirror image on the same coordinate system. Thus, if both bones are identical, their PFRPs coincide; if not, the differences are emphasized. A typical example is given in Figure 1. The data points and the fitted PFRPs are shown, as well as the definitions of the plate angle θ_p and the PFRP inclination angles: α_{os} for the osteotomized bone and α_c for

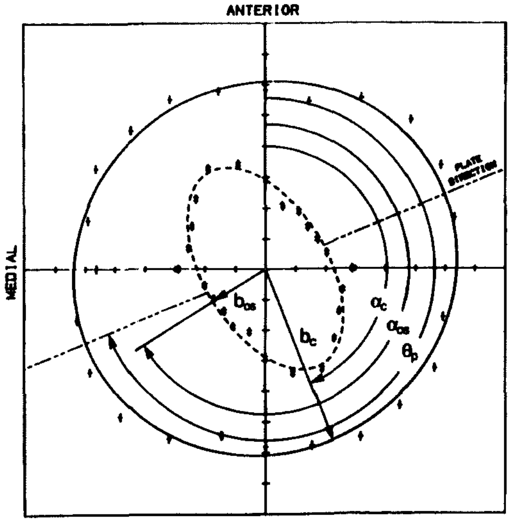


Figure 1. Polar flexural rigidity profiles of an osteotomized bone and its contralateral control. The angles α_c to the minor axis of the control bone, α_{os} to the minor axis of the osteotomized bone and θ_p to the direction where the plate was mounted are defined with respect to the anterior direction. All angles were increased by 180 degrees to simplify calculations of the parameter RI.

its control. These angles are measured in the clockwise direction from the anterior axis. In most cases the angles θ_p and α_{os} fall in the first quadrant (anterior-lateral aspect) while in many cases α_c is in the fourth quadrant (anterior-medial aspect). It was decided to add 180 degrees to all angles and to define them in the second and third quadrants, in order to simplify mathematical operations.

Healing efficiency parameters (HEP)

The parameters of the 2 PFRPs and the plate angle on the osteotomized bone are used to define 4 new parameters. These parameters are sensitive to changes in the mechanical status of the healing bone and thus may serve as measures for healing efficiency of the osteotomized bone. Such parameters are referred to as the HEP and are defined as follows:

$$SI = [(EI)_{os} / (EI)_c]_{min} \quad (1)$$

Stiffness-Index (SI)—a ratio of EI of osteotomized to control bones, both in the same direction that yields the minimum value of this ratio;

$$AR = (ab)_{os} / (ab)_c \quad (2)$$

Area-Ratio (AR)—the relative area of the EI ellipses, equals the square of the ratio of the mean EIs;

$$FR = (b/a)_{os} / (b/a)_c \quad (3)$$

Flatness-Ratio (FR)—a relative measure of flatness of the PFRPs, when FR < 1 the PFRP of the osteotomized bone is flatter than that of the control bone and when FR > 1 the PFRP of the control bone is flatter than that of the osteotomized bone;

$$RI = (\alpha_{os}-\alpha_c) / (\theta_p-\alpha_c) \quad (4)$$

Rotation-Index (RI)—a measure of the rotation of the PFRP of the osteotomized bone, expressed as the ratio of the angle of rotation to the angle between the minor axis of the control ellipse and the plate direction (θ_p) (Figure 1).

The numerical values of the HEP represent the status of the osteotomized bones in relation to their controls. For the first 3 HEP a value of 1 indicates no change. For the rotation-index, RI = O indicates no rotation; a positive value indicates that the PFRP of the osteotomized bone is rotated in a direction such that its minor axis approaches the direction of the plate, with coincidence at RI = 1.

Statistics

Parametric statistical methods were used to analyze the experimental data. One-way analysis of variance (ANOVA) was used to test for inconsistency of the null hypothesis when more than 2 experimental groups were at hand. As this test does not provide information about which sample (or samples) differed from the others, multiple comparison was carried out by the Student-Newman-Keuls (SNK) test to test for differences between any 2 groups. The *t*-test was used for comparison of only 2 experimental groups. At least 5 separate results were used for each experimental group tested. A *P*-value of 0.05 was considered significant.

Results

A data sheet was prepared for each dog containing a graphic presentation of the results (Figure 2). Time-effects on healing have been evaluated by studying the HEP of all bones plated for 8 weeks (n 6) and of all bones plated for 24 weeks (n 15) (Table 2). Added to these experimental results are the values of the HEP defining the state of the bones at the onset of the healing process. It is obvious that at the time of fixation, t = 0, the flexural rigidity, EI, of a non-plated osteotomized bone must be equal to zero and its PFRP is degenerated to a point. Therefore, the values of the 2 HEP representing bone rigidity, SI and AR, are

Table 2. Effect of time on healing, mean *SEM*

Group	Time	n	Stiffness index	Area ratio	Flatness ratio	Rotation index
1	t = 0	15 [a]	0.000 *0.000*	0.000 *0.000*	– –	– –
2	8 weeks	6	0.369 *0.066*	0.218 *0.059*	0.845 *0.100*	0.547 *0.109*
3	24 weeks	15	0.548 *0.030*	0.437 *0.053*	0.918 *0.043*	0.513 *0.182*
4 Intact bones	t < 0	10	0.967 *0.016*	1.018 *0.037*	1.007 *0.012*	–0.024 *0.013*
Statistics, test groups and P-values						
ANOVA	1–4[b]; 2–4[c]		0.000	0.000	0.143	0.033
SNK-test	1 vs. 2		< 0.01	< 0.01	–	–
	1 vs. 3		< 0.01	< 0.01	–	–
	1 vs. 4		< 0.01	< 0.01	–	–
	2 vs. 3		< 0.01	< 0.01	ns	ns
	2 vs. 4		< 0.01	< 0.01	ns	ns
	3 vs. 4		< 0.01	< 0.01	ns	ns
t-test	2 vs. 3		–	–	–	ns
	2 vs. 4		–	–	–	0.000
	3 vs. 4		–	–	–	0.025

[a] Zero Mean is exact for any n. 15 was chosen to match Group 3.
[b] For SI and AR
[c] For FR and RI

identical with zero. These values are also listed in Table 2. The values of the other 2 HEP representing bone asymmetry, FR and RI, are indeterminate at t = 0.

For evaluating time-effects on healing it is important to know the values of the HEP of intact bones. From the definition of HEP, these values are 1.0 or 0.0, depending on the parameter, but due to left–right variability of the bones these values may be different. Experimental values of the HEP of intact bones (Foux et al. 1990, Table 3) are also listed in Table 2, as well as statistical analyses of the results. In this work the bones were not plated and no record of RI was given. The rotation index is simulated by RI = $(\alpha_R - \alpha_L)/\alpha_L$ which gives a value close to zero.

During the first 8 weeks of healing, the mean values of SI and AR have risen from zero ($P < 0.01$) and further increased during the following 16 weeks ($P < 0.01$). These changes indicate the rate of stiffening of the healing bones. It is clear that the values of these parameters at 24 weeks are still well below those of the intact bones ($P < 0.01$).

Results for the FR parameter have shown that there are no changes between the 3 groups (*P* 0.14 for the ANOVA). Those of the RI are significant (*P* 0.03 for the ANOVA), but the SNK-tests have shown no differences between any 2 groups. Further testing, using the *t*-test, has shown no significant difference between the 8- and 24-week groups but differences between the 8-week and the intact-bone groups (*P* 0.000) and between the 24-week and the intact-bone groups (*P* 0.025). As both the ANOVA and the *t*-test have shown changes, the results of the SNK-tests were assumed to be overly conservative and the differences

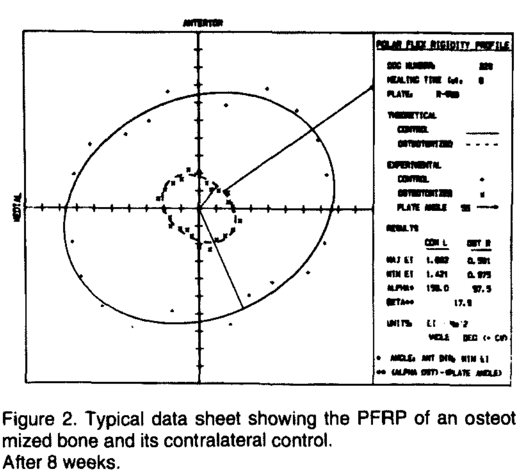
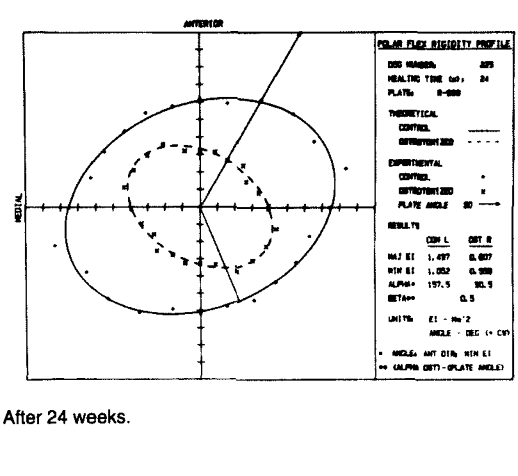


Figure 2. Typical data sheet showing the PFRP of an osteotomized bone and its contralateral control.
After 8 weeks.



After 24 weeks.

Table 3. Effect of plate type on healing at 24 weeks, mean SEM

Group	Plate	n	Stiffness index	Area ratio	Flatness ratio	Rotation index
1	Unplated intact bones	10	0.967 *0.016*	1.018 *0.037*	1.007 *0.012*	−0.024 *0.013*
2	1/3 TUB	5	0.566 *0.052*	0.412 *0.067*	1.025 *0.046*	0.174 *0.459*
3	R-TA	5	0.583 *0.062*	0.537 *0.137*	0.900 *0.096*	0.441 *0.167*
4	R-SS	5	0.496 *0.040*	0.361 *0.042*	0.828 *0.054*	0.923 *0.191*
Statistics, test groups and P-values						
ANOVA	1–4		0.000	0.000	0.04	0.02
SNK-test	1 vs. 2		< 0.01	< 0.01	ns	ns
	1 vs. 3		< 0.01	< 0.01	ns	ns
	1 vs. 4		< 0.01	< 0.01	ns	< 0.05
	2 vs. 3		ns	ns	ns	ns
	2 vs. 4		ns	ns	ns	ns
	3 vs. 4		ns	ns	ns	ns
t-test	1 vs. 2		–	–	ns	ns
	1 vs. 3		–	–	ns	0.001
	1 vs. 4		–	–	0.000	0.000
	2 vs. 3		ns	ns	ns	ns
	2 vs. 4		ns	ns	0.02	ns
	3 vs. 4		ns	ns	ns	ns

in the RI of the 8-week vs intact-bone groups and the 24-week vs intact-bone groups were considered significant.

Effects of plate rigidity on healing have been studied on the bones plated for 24 weeks. Only 6 femora have been plated for 8 weeks, 2 with each of the 3 plate types. This sample size is not sufficient to substantiate, with statistical significance, the effects of plate rigidity on healing at this period. Results of groups of 5 femora plated with each of the 3 plate types are presented (Table 3). The table also contains the values of the HEP of unplated intact bones (Foux et al. 1990), for comparison, as well as the statistical analyses of the results.

No differences have been observed between the mean values of SI and AR of the bones plated with the 3 plate types, either by the SNK-test or by the *t*-test. The SI and AR of all the groups plated with any of the 3 plate types were lower than those of the unplated intact bones ($P < 0.01$). The ANOVA of the FR parameter has shown that the 4 tested groups are not of the same population (*P* 0.035), but the SNK-test failed to indicate any differences between any 2 groups. Here again, a *t*-test was used to yield a difference between the R-SS group and the unplated group (*P* 0.000) and between the bones plated with the 1/3 TUB plate and those plated with the R-SS plate (*P* 0.02). The ANOVA of the results of the RI indicated that the 4 groups are different (*P* 0.02). The SNK-test revealed a difference only between the R-SS group and the unplated group ($P < 0.05$), further testing with the *t*-test showed a difference between the bones plated with the R-TA plates and the unplated bones ($P = 0.001$). As the confidence level of the *t*-tests was in all cases high ($P < 0.025$), the differences detected by this test were considered significant.

It must be noted that the scatter in the rotation-index is quite high (Tables 2 and 3). This is due to the fact that this parameter is inherently inaccurate (Foux et al. 1990). Despite this inaccuracy it was decided to use this parameter for its descriptive value.

Discussion

Effects of preserving the bones in formalin solution

During interim periods the bones must be preserved so that there are least possible effects on their mechanical properties and on their histologic structure. The most common preservation methods are freezing or submersion in formalin solution. Repeated freezing and thawing of a whole bone may cause cell disruption which affects histologic findings. On the other hand, immersion in formalin solution increases the cross-linking of the collagen phase of the bone. This may not be meaningful for the elastic properties of a mature compact bone, but it significantly increases the elastic properties of the partly calcified collagen structure in the callus and the interface between the fragments of the healing bones after osteotomy. The relation between increased cross-linking and the elastic properties of collagen in tension is well known, but nothing is known, to the best of our knowledge, about the effect of cross-linking on compression properties. The complex spatial structure of the collagen matrix, suggests that an increased cross-linking may affect its compression elastic properties to a much lesser extent. This conjecture, if true, may imply that the formalin solution effect on the results of the bending tests used in the PFRP method is not so erroneous, since part of the bone cross-section is subjected to compression when the bone is tested in bending. In any case, our findings are on the conservative side since the actual differences between the experimental groups may be even bigger than the reported findings.

Effects of plating time on healing

At the end of the healing period, 8 weeks after osteotomy and plating in beagles, the osteotomized bones are not really healed. This point in time signifies a change in the bone-repair-mode. Up to this time the bones grow a callus around the fracture site, if it is not suppressed by rigid compression plates. From this time on, the callus begins to diminish until the end of the external remodeling period, reached after 24 weeks, when the external shape of the bone returns to normal. For this reason a comprehensive study of the effect of plate rigidity on the healing status at the end of 8 weeks is left for future studies.

As can be seen from the results (Table 2), in the early stages of healing the rate of change of the processes involved is high. It is obvious that this rate of change diminishes with time and the mechanical status of the healing bone eventually reaches a new steady state. The PFRP of the healing bone changes during this time from a point to its final shape and the values of the 2 parameters SI and AR, which have a zero value at t = 0, increase with time at a diminishing rate and approach asymptotically their final values. The simplest mathematical expression to describe such changes with time is the following exponential equation:

$$P_i = P_{io} [1 - e^{-(t/\tau i)}] \qquad (5)$$

P_{io} are the asymptotic values of parameters P_i at $t >> \tau i$, where τi are the time constants of the changes. Index i refers to SI or AR such that P_i, P_{io}, τi are either SI, SI_o, τ_{SI} or AR, AR_o, τ_{AR}. The time constant means that at $t = \tau i$; $Pi = 0.632\ P_{io}$ and at $t = 3\ \tau i$; $Pi = 0\ 950\ P_{io}$.

Equation (5), which is equal to zero when t = 0, has been curve-fitted to the mean values of SI and AR of all bones plated for 8 weeks and for 24 weeks (Figure 3). The constants thus obtained are: $SI_o = 0.575$, $\tau_{SI} = 7.784$, $AR_o = 0.573$ and $\tau_{AR} = 16.725$. These values are based on a curve-fit of an equation having 2 constants to 2 data points only, which forces the curve through the points and ignores experimental scatter in the results. Moreover, these 2 experimental points are

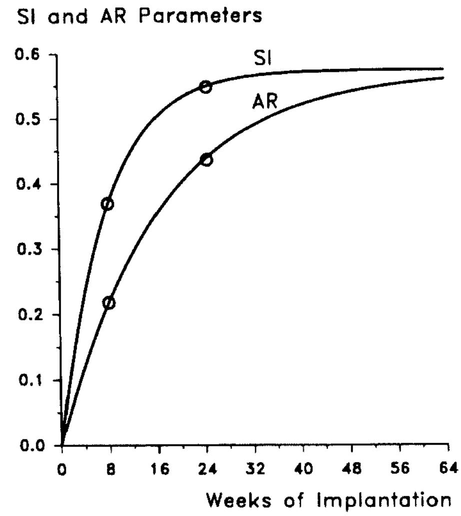


Figure 3. Effect of time on the SI and AR parameters. Data points (o) are based on means of results of all bones plated with the three plate types for the same time period .

the means of results obtained from bones plated with different plates. Therefore, the above values of the calculated constants are within a certain range of error. Nevertheless, these values signify the trend of the healing process with time.

Based on this analysis, SI and AR approach an asymptotic value which seems to be the same for both parameters (≈ 0.57). It is also seen that changes in SI occur faster than those in AR. The time at which SI reaches 95 percent of its asymptotic value is about 23 weeks and the time required for AR to reach the same value is about 50 weeks.

Values of FR at 8 and 24 weeks and that of the intact bone are not different from each other which indicates that, with these plates, no changes in the flatness of the PFRP have been observed. The RI values at 8 and 24 weeks are the same, but both are different from that of the intact bone. This suggests that asymmetry changes in the healing bone, represented by the PFRP rotation, occur rather early in the healing process and remain unchanged with time.

These findings throw some light on the effect of time on the healing process of an osteotomized bone plated with a rigid plate. It is apparent that the bone senses the plate reinforcement and its direction from the onset of healing. As a result, the healing is more intense in the direction which is perpendicular to the plate direction. This is manifested by the rotation of the PFRP such that the direction of its minor axis approaches the plate direction (RI ≈ 0.53 > 0). The slow rise of the area ratio emphasizes the fact that the remodeling process is far from being complete at 24 weeks. The asymptotic values of both the stiffness index and the area ratio (≈ 0.57) indicate that an osteotomized bone plated with a rigid plate may attain only a fraction of the rigidity of the control bone as long as the plate is in situ.

Effects of plate rigidity on healing

Healing efficiency parameters of the femora plated for 24 weeks, with each of the 3 plate types, were used to evaluate the effects of plate rigidity on healing. To our surprise, the results have shown that the rigidity of the 3 plate types, used in this study, had very little effect on the healing of the osteotomized bones at 24 weeks. Our findings may be ascribed to the antagonistic effects of the axial and flexural rigidities on the healing bone. A low axial rigidity is said to improve the healing process (Woo et al. 1983, 1984), whereas low flexural rigidity which causes inadequate fracture stability may in turn inhibit fracture healing. This implies that the healing efficiency is proportional to the flexural rigidity, EI, and inversely proportional to the axial rigidity, AE. The value of EI/AE for each of the plates is listed in Table 1. Indeed, this ratio is the same for the R-TA and R-SS plates and that of the 1/3 TUB plate is not much different. Such an hypothesis must be substantiated experimentally and we intend to do so. In order to separate the variables, special plates of various axial rigidities but with identical flexural rigidities were designed and experiments are under way.

As stated in the previous section, the remodeling process is not over after 24 weeks of plating and these intermediate results may not represent the effect of plate rigidity on the final status of the healing bones after a longer time period.

Another point of interest is the similarity of the results of the 1/3 TUB plate, with the larger area of contact between plate and bone, to those of the railed plates, with a much smaller area of contact. This rules out the hypothesis that interference with blood circulation may be the cause of osteopenia in the bone under the plates.

The PFRP method

The shortcomings of existing plates for internal fixation of fractures led many clinicians to the conclusion that an improved plating system may result in a more efficient healing process. Indeed experimental plates with various rigidities and geometries were tested on experimental animals (Woo et al. 1977, Moyen et al. 1978, Akeson et al. 1980, Brown et al. 1980, Claes et al. 1980, Comtet et al. 1980, McKibbin 1980, Moyen et al. 1980, Nunamaker and Perren 1980, Tayton et al. 1982, Yoshida 1982, Anderson 1985). In most of these studies histologic and morphometric analysis of selected sections were the main methods used to evaluate the healing of plated bones. The information produced by these methods, in addition to cell and tissue types, is on the degree of bone loss which is sometimes believed to be associated with the load carrying capacity of the healing bone. Based on theories from the field of mechanics, only the axial load is related directly to bone loss while load carrying capacities in bending and in torsion are related to the respective rigidities (Jurist and Foltz 1977). The flexural rigidity (and thus torsional rigidity) is associated with the distribution of bone mass. As such, there may be cases in which reduction of cross-sectional area (bone loss) results in an increase of flexural rigidity and vice versa. For this reason, there is no direct relation between bone loss and bone flexural or torsional rigidities.

In some other studies, mechanical tests were employed for the evaluation of effects of plate rigidity and shape on bone healing (Ekeland et al. 1981, Carter et al. 1984, Terjesen and Svenningsen 1988, Claes 1989). Since Uhthoff and Dubuc (1971) have shown, from histologic studies, that asymmetrical changes may be introduced in the bone structure during the healing process, one would expect that the mechanical test methods used for healing evaluation should have been sensitive to bone asymmetry. However, many researchers used test methods which are insensitive to the asymmetric properties of the whole bone. Among such tests are the torsion tests, whole bone compression tests and compression or bending tests on specimens cut out of the bone cortex. Some other researchers used the whole bone bending test to failure. In these tests the plane of loading of the test bone and of its contralateral control was chosen empirically. Results of such tests showed the relative rigidity, or strength, of the test bone to its control in the test direction only, and significant changes that may have occurred in other directions were totally missed.

The new PFRP test method and analysis, for the mechanical study of healing fractures of long bones in experimental animals, produce quantitative measures to define the mechanical status of the healing bones at the end of the plating period. These parameters are sensitive to rigidity and asymmetry changes in the healing bones. The graphic presentation of the results, the 2 PFRPs superimposed one on the other, provides an easy-to-understand means for immediate comparison of the mechanical status of the healing bones (Figure 2).

The quantitative healing efficiency parameters determined by the use of this method may be utilized, in conjunction with equation 5, to predict the final status of healing bones which may occur at times well beyond reasonable test periods in an experimental study. To substantiate this hypothesis, a further study with a better statistical base for the analysis is required. More plating periods are needed, for instance, 8, 16, 24 and 32 weeks, and at each such period no less than 5 bones should be tested with each of the plate types.

The method, although used on plated osteotomized bones, may be used to evaluate healing of long bones of experimental animals fixed by any fixation method. In addition, the bones tested by this non-destructive test method remain intact and may be used for histologic and morphometric studies to determine their biological status.

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