DISCUSSION
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With the increasing frequency, in the incidence of long bone fractures, especially that of the leg, interest of orthopaedic surgeons has once again been revived for the use of external fixation in the treatment of these difficult fractures. External fixation by incorporating the transfixed Steinmann's pins into a plaster cast or by attaching them to a metallic external fixator device, has been particularly useful in cases of compound fractures. However experimental trials to evaluate the extent of efficacy of these two methods of external fixation in the treatment of fracture leg and its effect on the rate and quality of fracture healing are rather lacking. Hence, it was endeavoured to take up the present study.

Rabbits were chosen as experimental animals because of their benign nature, easy availability and adequate size to allow application of external fixation.

Every attempt was made to eliminate any factor which was not common in both the groups and could affect either the healing process or any other observations. Hence all the animals chosen were of same genus, all
were male and belonged to a weight group ranging between 1.1 to 1.3 kg. All of them were fed on a standard diet throughout the study.

External fixator used was specially fabricated to suit the small size of the experimental animal. The external fixator used in the study was the one fabricated by Sharma and Sahu 1984. It consisted of two side bars, instead of one, because by bio-mechanical studies, the stability of fixation by mounting with one tie bar has been found to be approximately 1/3rd of that having mounting with two bars (Alto 1980).

The biomechanical studies have also revealed the connecting joints between the bars and transfixing pins to be the weakest point of an external fixator (Alto 1980). Hence these joints have been eliminated from this external fixator and the transfixing bars have been directly fixed with the help of grub screws of the sleeve of the side bar (Sharma and Sahu 1984).

Fracturing the bone manually produced 73 (81.1%) transverse fractures and 17 (18.9%) short oblique fractures. These long oblique or comminuted fractures were produced which were discarded from the study. Though some workers (Pikarski 1969, Ellsasser et al 1975) have preferred to osteotomise the diaphysis to
produce a transverse fracture, we followed the method of Varma and Kumar (1973) to produce a closed fracture in the shaft of tibia manually and found it completely satisfactory and less traumatizing to the soft tissues. It also simulates to the usual mechanism of injury of fracture leg in clinical practice and transverse and short oblique fractures produced are also of a common type met in the clinical practice.

Clinically the animals showed a better tolerance to the external fixator as compared to pins and plaster. They started using the fractured limb on the first postoperative day in both the groups. Stader (1942) also noted a better tolerance and free movements in experimental animals treated by external fixator.

Sharma and Sahu (1984) in their experimental study comparing the results in experimental external fixator groups and conventional above knee plaster group observed similar behaviour in external fixator group while in plaster group none of the animals started using the fractured limb within the first postoperative week. Perhaps because the transfixing pins in our pin and plaster group provide a better fixation and less movements at the fracture site causing less pain while using the limb. Varma and Kumar (1973) also observed the same problem with the experimental animals treated with plaster.
In clinical studies also the external fixator is reported to have yielded almost similar results regarding the weight bearing on the injured limb and return to the profession. Mazet (1941) allowed his patients ambulation with the help of crutches the day after application of external fixation. Most of the workers have observed that partial weight bearing can be started within the first week of application of external fixator (Vincent et al 1969), leading to an early return to profession by the patient. Similarly in the pins and plaster method of treatment partial weight bearing can usually be started on the second postoperative day (Anderson 1934).

**Quality of reduction achieved**

In our study 31.1% cases could be reduced anatomically or near anatomically with the help of external fixator while only 6.6% cases in the group A could be reduced near anatomically. Provision for distraction, compression and side to side displacement helped to bring about an accurate reduction in the external fixator group.

Various workers have achieved anatomical reduction in most of the cases both experimentally

In our study the average displacement remaining after reduction in A.P. view in group A was 2.13 mm (42% of cortex) while in group B it was 1.86 mm. In oblique view the displacements remaining were 2.6 mm and 1.2 mm in groups A and B respectively (Tables No. 5 and 6).

Angular deformities remaining in both the groups after reduction were - Group A, in A.P. view 11.71°, in oblique view 15.8°. Group B - in A.P. view 3.06° and in oblique view 1.92° (Tables No. 9 and 10).

Mean overriding observed in group A after reduction was 0.17 cm while in group B it was 0.06 cm (Sharma and Sahu 1984 in their study observed almost similar results in their external fixator group).

**Stability of fixation and maintenance of reduction**

It was generally observed in our study that external fixator provided a very stable fixation of fracture fragments and in maintenance of reduction throughout the period of immobilization, while pins and plaster was not able to hold the fracture fragments so efficiently.
While in the pins and plaster group 25 (55.5%) cases showed a loss of reduction or a deviation from the initial position (to assess the rigidity of fixation at the fracture site, both the increase and decrease in the initial displacement or angulation were taken to indicate a loose fixation), in group B, the fragments were maintained firmly and practically no deviation from the initial position was recorded. Only 12 cases showed a minimal change in position. Apart from the redisplacement within the plaster another common problem encountered is the overriding of fragments within the plaster. This tendency was prevented in both the groups due to transfixing K-wires. In the study of Sharma and Sahni overriding was the main problem in the plaster group where all the animals (100%) showed an increase in overriding of some degree or the other. In our study the external fixator did not allow any overriding inspite of a full weight bearing on the limb, except a minimal increase in 5 cases, which might have been produced while tightening the screws during check-ups. A slightly increased rate of change in overriding in pins and plaster group indicates that plaster does not hold the transfixing K-wires as firmly as an external fixator can.
The clinical studies conducted on external fixator have shown the rigidity of fixation achieved after application of external fixator in accordance to our study (Hasek 1942, Clancy 1979, Vidal 1979, Lawyer 1980). Biomechanical studies also confirm our observations (Burney 1979, Chao 1971, Vidal 1979).

In the series of Lawyer in 1980 primary healing occurred with external fixator, when the fracture was anatomically reduced and fracture site had minimal movements, as shown by clinical stability, in 2 to 3 months, without evidence of visible callus on roentgenograms. Studies have shown that primary bone healing resulted after anatomical reduction and rigid immobilization which did not permit more than 5 to 10 microns of fracture site.

**Time of Healing**

Healing of fractures treated by pins and plaster occurred in four weeks time in 83% of cases in our study. In most of the cases abnormal movements at the fracture site were absent clinically and well consolidated peripheral callus was present radiologically. While in group B most of the cases (78%) lost the mobility at the fracture site at the end of three weeks,
radiological union was also present in majority of cases at this time.

Varma and Kumar (1973) studying the fracture healing in rabbit tibia also found the clinical and radiological union time to be 4 weeks in the plaster treated group which was equal to the time taken for union by the tibias treated by stable internal fixation in their study. Comparing these studies, it can be concluded that with application of external fixator union can be achieved much earlier as compared to those cases, where either plaster cast, internal fixation or pins and plaster method has been used as a method of treatment. The reasons can be many. As outlined by Naeot in 1943 the following advantages of external fixator are also reported to have a favourable effect on fracture healing leading to an early and stronger union.

1. Perfect and accurate reduction.
2. Firm fixation and maintenance of reduction.
4. Avoidance of distraction.
5. Early mobilization and weight bearing.

Mainlander in 1963, while studying the healing by microangiography in dogs, observed that, in cases of
stable reduction of fragments the medullary circulation crossed the fracture gap within at least 3 weeks, but when the reduction was unstable the chief medullary arteries remained blocked at fracture fibrocartilage for a longer period. He also reported that when the fracture fragments were stable, osseous callus at 3 weeks had united in the portion of living cortex across the fracture line. According to Varma and Mehta (1967), perhaps continued mobility following loose fixation, is responsible for prolonged relative or complete avascularity at the fracture site, by hampering with the ingrowth of capillaries which does not take place till the morbidity is reduced by formation of primary fibrocartilaginous callus, favoured due to low oxygen caused by relative ischaemia. When the fracture is frigidly immobilized the ingrowth of capillaries can take place more rapidly, hence, there is direct bone formation. Compression over the fracture site also helps in promoting bone union (Basset, 1962, Anderson, 1965, Simmons, 1980), which can be effectively provided by the external fixator.

Basset 1962, who worked on tissue cultures, has shown that primitive mesenchymal cells exposed to high oxygen concentration and tension develop into osteoblasts. Low oxygen tension or distraction produced osteoclasts.
Anderson 1965, holds that compression appears to be beneficial in cortical bone healing, because it increases the rigidity of fixation by impacting the bone ends, and the space between the bone ends, which must be bridged by the callus, is narrowed. He achieved 100% union of osteotomies in experimental animals, sacrificed 6 weeks after the operation, with direct cortical healing of osteotomies by treating with rigid fixation by compression plating.

External fixation also seems to accelerate the bone healing by not draining the fracture haematoma and not disturbing the formation of either the endosteal or peripheral callus. While the contrary is true for internal fixation which not only drains the fracture haematoma but also hampers with the formation of either endosteal or periosteal callus.

Quantity of callus - In our study, healing occurred mainly by peripheral callus in group A. (pins and plaster). In most of the cases union occurred either by a moderate amount of callus 44%, or abundant callus 27%. On the other hand, in group B most of the animals had a healing, either with a little amount of callus (33%) or very little amount of callus (31%). Similar observations were made by Schenk and Willenegger 1964, Anderson 1965, Lettin 1966.
Lane 1979, Li 1969, Sharma and Sahu, 1984, while studying fracture healing in experimental animals under different types of fixations. According to Anderson 1963, there are three areas of osteogenic potential in healing of any diaphyseal fracture:

1. Periosteal reaction
2. Endosteal or medullary callus
3. Fracture haematoma

The cortical fracture ends are fourth possible area of osteogenic potential.

In the fractures, treated with over riding of fragments, union is almost entirely by massive formation of cartilage within organising fracture haematoma and gradual conversion of this cartilage to bone by enchondral ossification. This was the case with the animals in group A treated by plaster cast. Vazra and Kumar (1973) also found an abundant peripheral callus, in the healing fractured tibias, of rabbits treated by plaster cast.

Fracture treated by medullary nails, must unite by peripheral callus because, nail blocks endosteal callus and on the other hand, the plate and screw fixation also produce some damage to the medullary and cortical blood supply, by periosteal stripping. The peripheral bone formation from periosteum and bone formation in
fracture hematoma, most of which is drained out are not prominent. External fixator, on the contrary, does not hamper with either medullary vascular system or the normal effective blood flow of the cortex and thus allows the most desirable normal physiological bone healing to take place. Still, in our study very little callus was demonstrable in most of the cases treated by external fixation, while a sound union had been achieved. This can be explained by the accurate reduction achieved and rigid fixation permitting no movements at fracture site (Hicks, 1959, & Hutschenreuter, 1969).

Our observations are in conformity with those of Lawyer and Lubber (1980), who clinically achieved a primary bone healing in fractured tibias, treated by external fixator, in most of the cases. Clinical stability was achieved, without evidences of visible callus on roentgenograms.

Hicks (1959), pointed out that, the amount of callus varies with the degree of rigidity involved. Similar were the observations of Hutschenreuter (1969).

Luna (1979), and Li (1979), studying the effect of immobilization, on the healing fractured tibias of rats, observed maximum callus size in mobilised tibias at fourth week. In their model, the firmly fixed and immobilised
limbs developed a very sparse external callus, with negligible amount of cartilage demonstrable histologically. Moreover, the bone healed by direct membranous bone formation.

**Mechanical strength of callus** - Whatever may be the mode of treatment of fractures, the ultimate aim is to achieve a sound union. Thus the mechanical strength of the callus, obtained with a particular method, is of paramount importance to establish its supremacy over the other existing methods of treatment.

Since the variety of possible mechanical tests, to which a healing bone can be subjected, are virtually infinite it has been difficult, if not impossible, to compare data on the strength of callus obtained by many of the previously used techniques.

In addition to variations in test configurations, variations of test duration lead to significant changes in observed results (Burstein, 1971). For example, human tibia can absorb 45 percent more energy when broken at strain rates equivalent to trauma than when the bones were broken over a period of several minutes (Frankel and Burstein, 1965).
However, using a standard mechanical test with identical methodology, results can be compared between different groups in a single study.

In our study mechanical strength of callus was noted in both the groups using same methodology. As it was not possible to carry out the tests at a particular point of time, all the tests were performed within two hours of dissecting out the bones, thus affecting the results. Three types of loading configurations were used:

1. Axial compression
2. Axial tension
3. Bending loading configuration using one support and a single loading point.

1. **Tensile Strength**

In group A tensile strength noted was at its maximum (10.06 Kg) at 5 weeks, while the same in group B was 12.30 Kg. The difference being statistically highly significant (p \( \leq 0.001 \)). In both the groups, tensile strength showed a rapid increase after 4th week. The tensile strength of callus in group B at 5 weeks was almost equal to that in group A at 6 weeks. (Table No.14).

By applying axial tensile stress, the strength was clearly much more in the bones treated by external fixator in all the specimens.
Although Verma and Kumar (1973), did their study with conventional plaster cast instead of pins and plaster, they also observed that the strength of the callus treated by conventional plaster cast on the fractured rabbit tibias was much less than in those treated with other forms of treatment.

PiekarSKI et al (1969), also observed that tensile strength achieved in fractures of rabbit radii, treated without any internal fixation, showed a rising trend up to the end of study i.e. 6th week.

Sharma and Sahu (1984), compared the tensile strength of callus of those fractured rabbit tibias, which were treated with external fixator, with that of those treated with conventional plaster cast method. They also noted that the strength was much more in the bones treated by external fixator in all their specimens.

The values of tensile strength, in the external fixator group, in our study, was much less than those found in the study of Sharma and Sahu (1984) in all the specimens. This may be because of the different methodology adopted in our study for determining the mechanical strength (They did not use the lever system as that used in our study).
(2) **Compression Strength**

Compression strength showed a similar trend as that of the tensile strength in both the groups. However, the values of compression strength were a little higher than those of tensile strength at corresponding weeks in both the groups. Mean compression strength at 5 weeks in group B was almost equal to that in group A at 6 weeks. The difference in compression strengths in both the groups were statistically highly significant at every week. (Table No.15).

Again the values of compression strength noted in our group were less than those obtained by Sharma and Saha (1984) which could again be explained on the basis of different methodology adopted (They did not use the lever system as that used in our study). In their study also they concluded that the compression strength of bones treated with external fixator were much more than those treated with conventional plaster cast, although the difference in compression strength between both the groups in their study was much more than that obtained in our study.

3. **Ambulatory Strength**

Although the ambulatory strength also maintained more or less the same pattern yet their values were higher
in both the groups as compared with their values obtained in tensile and compression strength. This can be safely explained on the basis, that the leverage acting over the fracture site during the testing of tensile and compression strengths were much higher than that acting on the fracture site during the testing of angulatory strength. Angulatory strength in group A (pins and plaster) was 3.9 kgs at 2 weeks and reached to a maximum of 12.1 kgs at 6 weeks. Corresponding values in group B were 5.4 kgs and 15.2 kgs respectively. Both the groups showed a rigid increase of angulatory strength after 4 weeks. The difference in angulatory strength in both the groups at different weeks were statistically significant (Table No.16).

While comparing the results of our study with that done by Sharma and Sehn (1984), it was at once clear, that the values of angulatory strength in external fixator groups in both the studies were almost similar. This could be because of the similar methodology adopted in both the studies for determining the angulatory strength of callus.

Our results of mechanical strength of callus are also in conformity with those of Pickarski (1969), who explained the low strength of callus, having a large cross section, by the greater porosity of such a callus.
These mechanical tests clearly indicate that mechanically the callus obtained in group B (External fixator group), was much stronger in every parameter (compression, tension and angulation) at any period of healing, as compared to that in group A (pins and plaster group). It was also very much obvious that the callus observed in group B, though much less in volume, was well consolidated and much stronger than the callus observed in group A.

The values of angulatory strengths of the bones treated by pins and plaster, in our study, can be compared with that of the bones treated with conventional plaster cast in the study conducted by Sharma and Sahu (1984), simply because the methodology adopted to test angulatory strengths in both the studies are similar. On comparing, it was found that the angulatory strength of the bones treated with pins and plaster was 3.9 kgs at 2 weeks and reached a maximum of 12.1 kgs in 6 weeks. Corresponding values in the conventional plaster treated group were 3.1 kgs at 2 weeks and 10.53 kgs at 6 weeks, which clearly shows that the angulatory strength of the bones treated by pins and plaster method was higher than those treated by conventional plaster cast method in all the specimens.
Complications:

In our study, complications observed were minimal in both the groups. However, pins and plaster group showed an increased incidence of complications as compared to internal fixator group.

None of the animals in either group developed a problem of joint stiffness either at knee or ankle which has been a common problem with conventional plaster treatment. Almost every worker has reported significant incidence of joint stiffness after plaster immobilization (Solheim 1960, Nicoll 1964), while after application of external fixator or the pins and plaster the incidence of joint stiffness is almost nil (Vincent et al 1966, Edge and Denham 1981, Lawyer and Lubber 1980). The patient can move their joints through their full range and physiotherapy to preserve the muscle power and to avoid the wasting, can be initiated from the very beginning.

In clinical studies also the observations of other workers are consistent to our findings (Shear and Kreuz 1944, Solheim 1960, Vincent et al 1966, Lawyer and Lubber 1980, Aho et al 1988, Edge and Denham 1981).
Shortening observed in our study was 0.41 cm in group A animals. Average shortening exhibited by group B animals was 0.11 cm only. The difference was statistically significant. This insignificant amount of shortening, especially in group B can be explained by a better reduction achieved and the maintenance of limb length in external fixation, while incorporating the pins in plaster allows some amount of overriding or angulation as the plaster does not hold the transfixing pins as well as the fixator. Moreover the compression applied at the fracture site, in external fixator group, helped to increase the fixation of fracture fragments, while this compression component was lacking in pins and plaster group. However this problem of shortening is much less in the pins and plaster group when compared with that, after the conventional plaster treatment. Sharma and Sah 1984, observed on average shortening of 1.0 cm in conventional plaster treated rabbit tibias.

In clinical studies also, with the use of external fixator, shortening has not been reported to be a significant problem except in cases having bone loss (Naden 1949).
Similarly, shortening has not been significant in clinical cases treated with pins and plaster (Vincent et al. 1966, Anderson 1974). After application of plaster oedema was observed in some animals which readily subsided after slitting the plaster throughout its whole length.

Some of the complications reported to occur rarely with the use of external fixator like bending of pins (Edge and Denham 1981), and breaking of pins (Maden 1949 and Burney 1979), did not occur in our study. Bending or breaking of the transfixed K wires did not occur probably because of them being elastic enough to bear the stress and strain of the fracture site of the fracture in the rabbit tibiae. However, pin tract infection did occur in 3 cases in group A and two cases in group B. All of them responded to antibiotics.

Incidence of pin tract infection has been encountered variably by various workers. In cases of external fixator, while some of the workers observed this complication to occur, with an incidence ranging from 2-40% (Maden 1949, Burke 1977, Abe 1980, Lawyer and Lubber 1980, Edge and Denham 1981), others have found no incidence of pin tract infection (Sheer and Kreuz 1944, Cotton 1979). Shama and Sehu 1984, found an incidence of 6.6% of pin tract infection in their
experimental animals. In clinical studies of pins and plaster, Vincent et al 1965, reported an incidence of 5% of pin tract infection while Anderson 1974, reported an incidence of 2.5% of this complication.

A somewhat high incidence of pin tract infection in our study, could be because, we did not use any antibiotic pre or postoperatively. However pin tract infection was not much of a problem in our series as most of the infections subsided after antibiotic administration.

Infection occurring after internal fixation, not only involves the fracture site only, but may spread to the whole diaphysis and to eradicate it, may be a difficult, and at times, a virtually impossible task, while with external fixator or pins and plaster the pin tract infection is usually localized and at a distance from fracture site.

It would be not out of place to compare the result of our study with that of Sharma and Sahni 1984, which was a comparative study on the same genus of experimental animals between, external fixator treated group and conventional plaster group. Basic methodology and material of study being common, the two studies are very much comparable and hence inferences can be drawn regarding the role of external fixator, pins and plaster and conventional plaster methods for treatment of fracture legs.
The combined evaluation of both the studies reveals that external fixator provides a better reduction, very rigid fixation, better and early fracture healing, permits early ambulation and is relatively free of complications of these three methods of treatment.

Pins and plaster seems to occupy a position between the other two methods of treatments. It provides a better fixation of fracture fragments, a mechanically stronger callus, an early healing, permits early ambulation and gives rise to lesser complications such as joint stiffness and shortening as compared to conventional method of plaster immobilization, but of course, remains much behind the external fixator method of treatment, which in short seems to be the most versatile of all. External fixator also seems to be indispensable for treating the compound fractures of leg for which neither the conventional plaster treatment nor the internal fixation is a suitable method.

It is valuable in cases of compound fractures where dressing, skin grafting and procedures like muscle mobilization and bone grafting can be carried out without disturbing the fragments (Nezet Robert, 1943). Similar observations were made by Shaar and Kness (1942), Edwards Charles (1975), Burke et al (1977) and Lawyer and Lubber (1980).