DISCUSSION
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Immobilization of fracture fragments by the insertion of pins connected externally by plaster, metal devices or other appliances is not a new concept. In the past two centuries external fixation has enjoyed long periods of enthusiastic use alternating with interval of total disrepute.

Immobilization of compound and complicated cases in a plaster cast does not provide adequate rigid fixation and proper care of the wound.

The method of immobilization of fractures with percutaneous tranfixing pins-known as osteotaxis- attached to a rigid exoskeleton has been employed since the 1900's.

The external fixation of a fracture has the following advantages:

1. It does not destroy the medullary circulation.
2. It does not damage the endosteal elements.
3. It allows early function of the limb.
4. It allows easy surveillance of the wound.
5. It is simple, easy to use and has wide applications.

External Fixator is a well-known method of treatment and was advocated by Charnley in 1944 for compression arthrodesis of the knee. AO has developed a simple device to obtained rigid fixation (Muller et al, 1970) which can be used for arthrodesis and treatment for fractures as well as for the complications of fractures such as infection (Burri, 1975) and psuedarthrosis (Weber and Cech, 1973).

One of the most difficult problems in traumatology is an open fracture of the limb with additional severe soft tissue damage. The vast majority of authors strongly object to the use of internal fixation for stabilization of such fractures (Burri and Clases, 1981; Claude et al at 1976; Edge and Denham, 1979; Hierholzer et al 1978).

Currently, the treatment of choice in open fractures of long bone is external fixation (Cannon et al, 1985; Karstrom and olerud, 1974; Hoffmann 1938).

External fixation of fractures of long bone is a suitable method of treatment in all the age groups. In our series, the average age was 33.69 years (range 20 to 63) maximum No. of cases i.e. 50 percent were in the age group 21 to 30 years which is a most energetic and adventurous period of life (Table No 1). Shlom Porat et al (1986) applied external fixator in youngest patient of four years and the oldest 10 in their series; Kotwal et al (1990) in average age 36.8 years (range 5 to 60), Chan et al (1984) in average (36 years range 7 to 79), A J Thakur and J. Patankar (1991) in average age 38 years (range 7 to 71); Gershuni et al (1983) in average age 32 years (range 14 to 65).

In our series 87.5 percent were male and 12.5 percent were females (ratio 7.1) showing again the great vulnerability of male to fractures as they have more outdoor activities and have got more dynamic life than females (Table No. 2).

Thakur and Patankar (1991) observed in their study ratio of male to female 5:08:1 (66 males and 13 female); Behrens and Searls (1986) observed 60 males and 13 females (ratio 461.1), Chan

Out of total sixteen cases 62.5 percent belonged to urban area and 37.5 percent were resident of rural area and 93.75 percent cases of injuries were as a result of Road-Traffic accidents. Needless to mention and as the figures speak for themselves due to excess number of motor vehicles and increased traffic in the urban areas as compared to rural areas the incidence of injuries in much greater in urban population (Table -3) The incidence of 'Road traffic accidents' in this series were 93.75 percent (Table-4) Etter et al (1983) coded incidence of road traffic accidents 85.5 percent, Goldstrom et al (1984) 58.97 percent, Cannon et al (1985) 93.33 percent Thakur and Patankar (1991) 87.34 percent; Gershuni et al (1983) traffic accidents - 86.2 percent.

The incidence of bone involved in our study was tibia (75%) and femur (25%) Amongst the 12 tibial fracture, all the cases were primarily associated with fracture of tibia and fibula both. No other long bone of the body like humerus, radius and ulna were included in this series (Table-5) Cannon et al (1985) used the simple means of external fixation on 30 fractures of long bones, Tibia and Fibula (63.33%), Femur (10%), Humerus (23.33%) and Radius and ulna (3.33%) Kotwal et al (1990) treated fractures of long bone with external fixator, leg bones (59.85%); femoral shaft (13.14%), humerus (8.75%) and radius (6.6%). Chhabda et al 1990 showed tibial fractures (90.5%) and femoral fractures (9.5%).

By its very location the tibia is exposed to frequent injuries Because one third of its surface is subcutaneous throughout most of its length Open fracture are common in the tibia than any other major long bone. Fracture of the shaft of the femur are also common in orthopaedic practice since the femur is the largest and principal load-bearing bone in the lower extremity

Etter et al (1983), noted during their clinical study that left leg was involved more often than the right (Left 34, right 22) Gershuni et al (1983) right side 15 and left 14 In our series left limb was also more affected than the right limb (left 9, right 7) (Table -6)

During this study, the nature of fracture was varied, closed fractures (12.50%), open fracture (56.25%) and non-union (31.25%) Of these 77.78 percent of open fractures belonged to type III according to Muller's classification which is explained by higher incidence of road traffic accident, mode of injury (93.75%) in this study Behrens and searls (1986) observed 20% closed fractures 72% open fractures and 8% non-union in their series Lawyer and Lubber (1980) used Hoffmann apparatus in eight closed and 26 open tibial fractures.

During the work, we observed 50 percent of fractures showing level of fracture as middle third in tibia as well as femur. Out of 12 tibial fractures, Seven (58.33%) fractures were middle third, three fractures (25%) upper third and two fractures (16.67%) lower third Similarly in four femoral fractures, three fractures 75% were lower third and one fracture (25%) middle third (Table No 8) Chhabda et al (1990) showed in their series on Indigenous External Fixator for Fixation of Long Bones that out of 21 fractures of Tibia as well as femur, sixteen fractures (76.19%) were middle third In 19 tibial
fractures, 14 fractures (66.67%) was middle third, three lower third fractures (14.29) and two upper third (9.52%). There was only two femoral fractures (9.52%) of middle third level. Chan et al. (1984) reviewed 17 type III open tibial fractures retrospectively. The majority of the fractures due to traffic accidents had occurred in middle third (41.17%). Rommens et al. (1987) showed in their series of 293 fresh tibial shaft fractures which were treated in a 10 year period. More than 40 percent of the fractures were situated in the middle third of the tibia. Gershuni et al. (1983) showed more than 51 percent fractures of tibia in middle third.

Our series of sixteen fractures contained 12 cases (75%) with comminuted fractures, one transverse (6.25%) and three cases of bone loss (18.75%). According to radiological finding most of the fractures were comminuted which explained themselves by greater frequencies of high energy trauma. Table - 9. Chhabda et al. (1990) observed sixteen fractures (76.19%) were comminuted in their study and Chan et al. (1984), showed more than 47% of treated fractures to be comminuted, 35.25% with bone loss and 11.76% with transverse fractures of tibia while road traffic incidence was 70.58 percent. Behrens and Searls (1986) reported that more than 57% fractures were comminuted. Gershuni et al. (1983) reported more than 89% comminuted type of fractures. Burny (1974) reviewed 1421 cases in which external fixation was done in closed, open, transverse, comminuted as well as non-union of fractures, 70% of which were contaminated.

Gershuni et al. (1983) in their series involved 29 tibial fractures 27 of these associated with fibula fractures in our series 12 tibia fractures, ten fractures had ununited fractured fibula and two united fibula fractures.

In this series of sixteen patients, good radiological union was present in eleven fractures and only one case showed non-union later on and four case were unassessable because of insufficient time for assessment of union till completion of study.

The time interval during which the frame was held in place varied from within 24 hours to 300 days (mean 67.5 days). The cause of delay in most of the cases was trial with conservative treatment first, or the patient reported to us late (Table No. -11).

Of these eleven fractures of good radiological union five fractures (45.45%) were fixed within two weeks of injury united in average 26 weeks from fixation while rest six cases (54.56%) which were fixed after two weeks took to unite an average 31.67 weeks. We found that in 7 patients where interval between injury and fixation was less the bones took lesser time to unite. Average time for good radiological union in these fractures was 29.09 weeks (range 12-48) (Table No. 29). According to Chan et al. (1984), 17 type III open fractures were reviewed retrospectively and immediate external fixation was used following wound toilet by AO external fixator. The external fixator was usually maintained until there was evidence of early bone healing both clinical as well as radiological. The radiological union took average Seven months (range 3 to > 12).
Absolute rigid fixation is not necessary for bone healing (Aalto and Karaharju, 1981) They also pointed out that external fixation devices in general can not be considered to be rigid and found that the different devices showed variable elasticity under stress. A larger number of fixation devices have been reported in literature like Malgaigne 1840, Malgaine's "Point" and 1843 Malgaine's "claw"; Parkhill 1897, "bone clamp"; Lambotte, 1902, "lambotte. External fixator"; R.Hoffmann 1938, "Hoffmann external fixator", Judet 1956; Chalier 1917; Goossens (1939), Joly 1933, Andesson 1933, Cuendet 1933; Charnley 1948; Vidal-Adrey 1970; Aron (1976) and Cumming (1979) used dental methylmethacrylate to make external fixator splint Cotton (1979) and Burny 1979 used single Hoffmann frame and Edwards (1979) and Lawyer and Lobbers (1980) used double frame Hoffmann apparatus. King 1980 used the Day frame. Edge and Denham (1981) used the Portsmouth method of external fixation Evans et al (1988) used "Shearer External Fixator". Many workers developed Indigenous external fixator also. AO has also devoted itself to the problems of external skeletal fixation and devoloped different designs in which AO Tubular system brought with considerable improvements in the component parts. In our study we used AO tubular external fixator only in different mode i.e. compression, neutralization and distraction according to the need of fractures configuration. We used delta frame in 75 percent fractures, unilateral single tube frame in one fracture of tibia (case No 1), Bilateral frame, in one tibial fracture with bone loss (case No 2) and unilateral double tube frame in two fractures of femur.

During Management of Fractures, all type of frames provided better stability and rigidity good wound access, easy to perform any secondary procedure with fixator in place, avoided unnessessary trauma to healthy soft tissue, minimally or even never interfered with movements of joints, and allowed unencumbered partial and even full weight-bearing so patient easily performed day to day activities without dependancy. During study all pins for construction of frame were inserted via "safe corridor" of limb (Eycleshymer and Schoemaker, 1911). The building implants were, 4.5 mm Schanz screw 18 mm thread length with over all lengths of 100 mm to 200 mm and blunt tip to reduce the possibility of neuro-vascular injury, 4.5 mm Steinmann pin with a central 5 mm thread of 150 - 200 mm length for bilateral frame.

Over the years, external fixation has fascinated many surgeons with its apparent simplicity and untapped promise for solving puzzling problems. They have put external fixation on a solid clinical and mechanical basis. The recent education of the three basic components of fixator application and the identification of the variables that control mechanical frame properties (Behrens et al, 1985; 1989; 1983; Briggs and Chao 1982; Finlay et al 1987, and Behrens and Searls 1986), have eliminated iatrogenic injury to nerves, vessels and have greatly reduced secondary joint stiffness.

In majority of cases of external fixation, three schanz screws were passed above and below the fracture site (75%), in remaining 25% cases two to four Schanz screws and Steinmann pins were passed in proximal or distal fragments of fracture in this study Initially we put more pins but later on with experience and gradually developed experience, preferred to pass less number of Schanz.
screws and Steinmann pins according to the need of fractured fragment and stability. During insertion of screw or pin, we always considered about "safe corridor" for insertion and planned site and configuration of frame pre-operatively on the basis of pre-operative radiograph. In cases of construction of bilateral frame we always preferred pin insertion from lateral to medial to avoid or minimise the possibility of damaging neurovascular bundle and muscles of anterior compartment Vidal (1987) and Cotton (1979) recommended pin insertion from medial to lateral in order to prevent the pins from carrying small pieces of superficial tissue and muscle into the bone. Fischer (1979) preferred to pass the pins directly through the lateral musculature of leg to medial aspect. The reason being to insert the pins posteriorly in the tibia and yet anterior to the muscle, and secondly a great deal of pressure was exerted on the muscle by pin and the depressed muscle then acted as fulcrum and skin is forced down over the pin under tension despite adequate skin incision when the pin was passed, from medial to lateral.

In case of femur, precaution was always taken to prevent the injury to neurovascular bundle while passing the pins.

There is no region of the femur which innocuously accepts percutaneous pin fixation transfixation of soft tissues has predictable complications. Obviously, any structure present in the thigh can be transfixied, resulting in total or partial loss of function. Damage to a major nerve and vessel must be avoided at all costs. Avoidance of joint cavity invasion assumes secondary importance, followed by consideration of muscle belly transfixation and nursing care. The femoral nerve injury results from their relationship to the femoral artery in the adductor canal and the avoidance of this area when inserting pins. The Sciatic nerve enters the thigh posteromedial to the head of the femur and runs most of its course posterior to the shaft of the femur. Pins entering the femur posterior or those exiting posterior create such problem.

The superficial femoral artery travels with its accompanying veins through the femoral triangle and adductor canal on the medial aspect of the thigh. The proximal pole of the patella and the anterior superior iliac spine were used as bony reference points. The artery was posterior to the femur at 19.2 percent of the distance from patella to, and bisected, the femur at about 49.2 percent. So pin insertion in the coronal plane is less safe as one proceeds proximally but externally rotating the plane of the pin by 30° can increase the degree of safety. The use of half pins, entering laterally in this area or to perform an open placement of the pins is safest.

In case of fractures very near to knee joint, the super patellar pouch reaches an average about 1.3 times the length of the patella proximally and for lateral approach, pin should also pass just proximal to the adductor tubercle in order to avoid engagement of the collateral ligaments. When swelling has obscured the landmark, it is helpful to remember that it lies almost at the level of the proximal pole of the patella in relaxed and extended knee. During distal pin insertion, always flex the knee to avoid neuro-vascular injury behind the tibia distally. Pins tranfixing the muscle limit their exclusion and this affects proximal and distal joints. We experienced that more anterior insertion does.
hamper joint movements than the pins in the coronal plane

In the case of closed fractures, external fixation has an intermediate position between conservative and surgical treatment. In the case of open fractures, however, particularly those in which extensive additional damage to the soft tissue must be treated, external fixation is superior to all other methods of treatment. In our series, soft tissue healing duration ranged from 15 days to 120 days. The average duration of soft tissue healing was 45.67 days. Nine cases of all (56.25%) had significant soft tissue injury. Out of sixteen patients, only seven patients (43.75%) had soft tissue (12.50%) where soft tissue injury healed within 30 days had an average union time of 21 weeks. Five cases (31.25%) had average union time 34.8 weeks, having healing period of more than one month and too longer duration to unite (Table - 19 and 24). Thakur and Patankar (1991) treated 79 open tibial fractures by AO tubular external fixator and observed that the wound healed within four weeks in 66 patients (90.4%). In five patients the wounds healed in six weeks, in one patient in seven, and in one the wound did not heal until the tenth week.

Behrens and Searls (1986), studied 80 tibial fractures and non-union treated with an external fixator. Partial weight-bearing with the fixator in place was started after a mean period of 36 days. In 65 patients with 67 lesions (89.3%) six patients remained non-weight bearing in order to protect other injuries on the same side and two were never able to walk. Full, unsupported weight-bearing was started after a median period of 65 days in 52 patients (71.2%) while most of the other had a cast applied before they were ready to take full loads on the fixator. Thakur and Patankar (1991) treated open tibial fractures and allowed early weight-bearing. By the end of the first week, partial weight-bearing was achieved by all the patients. The mean time to full weight-bearing was 3.8 weeks (range 1 to 14). Anderson (1934) in pin and plaster and Naden (1949) in stader and Haynes splint started crutch walking from the day after external fixation. Karlstrom (1980) treated severe open fracture, the mean time for full weight-bearing without support was 29.6 weeks. Vincent et al (1969) and Burns (1979) allowed early weight-bearing in those cases where reduction was accurate. Other workers deferred full weight-bearing till there were evidences of clinical and radiological union. We started crutch walking without weight-bearing when the reaction to trauma subsided and the general condition of the patient allowed. Crutch walking Gradual weight-bearing was started after there were evidences of callus formation. In our series eleven patients (68.75%) showed mean partial weight-bearing time as 10.36 weeks (range 4 to 20). Ten cases (62.50%) showed full weight bearing from 6-36 weeks (mean 19.8 weeks).

Early partial and full weight-bearing added a new dimension of comfort and freedom for most patients and some have been able to return to demanding occupations with the fixator in place. As well as the psychological effect, the resultant increase in muscle activity and local blood flow may accelerate bone healing - as has been postulated for early weight-bearing in casts (Dehne et al 1961; Sarmiento 1974).

(range 11 to 40) after injury. They showed, the earlier dynamization 5 to 20 weeks, had shorter time to unite 11-28 weeks, and late dynamization 8 to 20 weeks had longer the period of bone healing 14 to 40 weeks. In our series 37 percent cases only dynamized in the mean time 28.65 weeks. Depending upon the dynamization of frame, radiological union occurred early (average 21.67 weeks) while in the 36 percent case, union occurred late (average 36 weeks) where dynamization not performed the dynamization accelerated union by cyclic loading at fracture site.

Gershuni et al (1983) left fixator on the tibia for an average of 3.1 months. When anatomic reduction of the fracture and stable fixation with compression was initially obtained, the fixator was maintained in situ until bone union & more rapid healing (2.5 months) and removed in less than 3.5 months. In our series, 12 fixator (75%) were removed between one to 40 weeks. The mean time of fixator removal was 25.64 weeks. Behrens et al (1986) removed fixator in 11 to 367 days (median 101 days). Karlstrom and Olerud (1983) removed external fixator in the mean time 4.1 months (range 2 to 10). Evans et al (1988) removed in mean time 16.5 weeks and Lawyer and Lubber (1980) after 23.2 weeks but Edwards (1979) removed the Hoffmann appliance when the wound healed and then applied functional weight bearing cast. We also some time applied patellar weight bearing cast just for support to avoid the risk of refracture.

In our series, the overall average time of radiological union was 25.09 weeks and clinical union was 34.6 weeks. The closed and Muller's type I fractures were shown to have good radiological union in average 17 weeks (range 12-48) and clinical union in an average 17.33 weeks range (14-20). The Muller's type III fractures took an average 36.75 weeks for radiological union and 44.67 weeks for clinical union (range 38-52). Lastly, non-union were united radiologically in 30.5 weeks and clinically 35 weeks range (34.38). Table No. 23 and) Nadan reported average period of union in closed fracture as 16.5 weeks and in open fractures 22 to 34 weeks in Vincent et al. (1969) series union time was 10.5 weeks where as Burny (1979) reported union time of 12 weeks for closed and 24 weeks for more Complicated cases. Lawyer and Lubber (1980) reported union time of 21.2 weeks for closed and 35.2 weeks for open fractures. Behrens and Sears (1986) reported clinical unions in open fracture (72%) median 211.5 days, closed fractures (25%) in 176 days and for non-union, infected (5%) 116 days while uninfected (3%) in 328.5 days. In their study, over all union time in 75 lesions (100%) was 186.0 days. Thakur and Patankar (1991) reported, bony union in Type I open fractures on average 16 weeks (range 11-28), and type II open fractures and average 18 weeks (range 14-20) nd type III open fractures an average 26 weeks (range 14-40). Chan et al. (1984) reported radiological as well as clinical union in 17 Muller's type III open tibial fractures an average 7 months (range 3 to more than 1 year) and an average 10-11 months (range 4 to 1 more than 15 month) respectively. Kotwal et al (1990) reported 74 compound tibial fractures, six open femoral fractures and 13 infected non-union (10 tibia and 3 femur) having average union 16.4 weeks (range 13-24) in 74 compound tibial fractures. Evans et al (1988) reported union in 20 closed tibial fracture and 30 open fractures. The average time to union was 8.7 months. Patients (20 cases) treated late by fixation took an average
9.5 months to unite while those treated by primary external fixation united in 8.2 months (30 cases).
Similarly, our study, five fractures (31.25%) were fixed within two weeks uniting in average 26 weeks
while rest 37.50% where fixation done more than two weeks of injury union took place in an average
time 31.67 weeks (Table No. 29).

They also reported, the average time to union for closed fractures in which reduction was
achieved by manipulation only as 6.7 months (16 Cases i.e.) 32 percent. The average time to union for
fractures which were open or which underwent open reduction was 9.6 months (68% i.e. 34 cases).
Eleven of these cases (22%) understand bone grafting and these united within an average of 10.5 months.
In our study, the average time to radiological union was 12 weeks in which reduction was achieved
by closed manipulation. The average time to union for fractures which were open or which
underwent open reduction or bone grafting was 30.8 weeks (Table No. 30).

Barquet et al (1988) reported mean union 7.5 months (range 4-11) in open fracture shaft
femur and mean union 9 months (range 5-11) in infected non-union of shaft femur. Statsis and
Paavrolainen (1985) reported union in average time 4.86 months in five cases of infected non-
union of the femur. Gottschalk et al (1985) reported an average radiological union time 6 months (range
4.5-8) in severely comminuted fractures of the femoral shaft using external fixator. In our study, we
noted an average radiological union in 23 weeks (range 19-30) for femoral fractures.

In this study, Eleven cases (68.75%) required many type of secondary procedure for
healing. Five cases (31.25%) required skin grafting, five cases (31.25%) bone grafting, three (18.75%)
loose pin removal and pin reinsertion and fibullectomy in four cases (25%) Behrens and Searls (1986)
reported 337 procedure in 75 tibial fractures. Gershuni et al 1985 reported skin grafting, bone-grafting etc.
In series of Edwards (1979) skin grafting was required in 48 cases, and bone grafting in 39 percent cases.
In Lawyer and Lubber (1980) series, each patient of grade II or grade II required at least one skin grafting.

Average period of post-operative hospital stay in our study was 36 days, varied from four
to 120 days. In this study most of the patients were discharged only when the wound had healed
completely or in such a condition which could be managed by dressing at home. Patients requiring
longer period of hospitalization were because of the following reasons -

- Poor general condition of the Patients
- Type III open fractures requiring frequent dressings
- Significant associated injuries which forced the patients to remain hospitalised

Thakur and Patankar (1991) reported post-operative hospital stay an average 1.4 weeks
(range 1-3.5) Gottschalk et al (1985) reported Average hospital stay 19 days (range 11-28) during which
the patients received physiotherapy and were taught to care for the screw sites and to continue their
exercises at home, during management of severely comminuted fractures of femoral shaft with external
fixator.
The incidence of non-union in Chan et al (1984) series was 30 percent with type III open tibial fractures. Hammer (1985) reported high incidence of non-union (38.1%) with the use of Hoffman-Vidal-Adrey External fixation system but none in Vincent et al (1969), Burny (1979) and Lawyer and Lubber (1980) series. We had one (Case No. 8) non-union in 12 assessable patients which failed to unite even after presence of fair amount of callus at the time of fixator removal. This patient was subsequently treated by P.T.B cast to accelerate union, but during next follow-up patient came with badly broken cast. Radiograph showed evidence of non-union i.e. rounding of the end.

The incidence of Superficial pin-tract infection in Gershuni et al (1983) series was 53.84 percent patients but only six patients (23.08%) required pin removal and/or replacement for major pin-tract infection. Chan et al (1984) series, superficial pin-tract infection was frequent complication in 94.12 percent cases and all patients showed some degree of loosening of some of the pins at various stages of the treatment process.

Behrens and Searls (1986) reported 12 percent cases with pin-tract infection and one (1.3%) patient developed a ring sequestrum. Gottschalk et al (1985) reported pin-tract infection only in one patient (14.28%). Thakur and Patankar (1991) reported minor pin-tract infection in 26 patients (35.6%) and major pin-tract infection in 96 percent cases requiring removal and replacement of the pin at another site. Barquet et al (1988) reported, Cannon et al (1985) reported pin-tract infection in five cases (16.67%); Behrens et al (1983) reported pin-tract infection in 16 percent cases. It is difficult to determine from a review of the literature the exact incidence of pin-tract sepsis. The reported incidence ranges from two to more than 50 percent. A major pin-tract infection requires removal of involved pin or removal of the entire fixator. Certain factors are considered likely to contribute to pin-tract infection; these factors include necrosis of tissue around the pin, excessive pressure at the pin-bone interface, thermal damage to bone during pin insertion, pin loosening or soft-tissue motion around pin. In our series, superficial or minor pin-tract infection occurred in nine cases (56.25%) and major pin-tract infection in three cases (18.75%) required removal as well as re-placement of pins at another site and only one ‘Ring sequestrum’ developed around pin with major pin-tract infection (Table No. 14 and 25).

Incidence of other complications like, secondary amputation, joint stiffness, flare up of infection and non-union was 6.25 percent and exposed part of bone developed into sequestrum in 25 percent cases. Per-operative complication, unsatisfactory closed-reduction observed in two cases; closed-reduction observed in two cases (12.5%) which was corrected by self-designed Modified-versatile-compression-destruction device (Plate No. 7).

There were five cases of shortening was found after fixator removal out of which in two cases the shortening was in other bones treated by conservative method simultaneously and in the rest three preoperative shortening did not vary after fixation except one case where the fracture in the other limb made the shortening unasseable. In literature, shortening was found in five cases of Naden (1949) and none in series of Burny (1979) and Lawyer and Lubbers (1980).