



Application of a type II external skeletal fixator with PMMA or carbon fiber as connecting rods for the repair of long bone fractures in goats

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ABSTRACT

A clinical study was conducted in twelve goats with long bone fractures. Goats were divided randomly into two equal groups. The fractures were treated with type II external skeletal fixator with External Skeletal Fixation with polymethyl methacrylate (PMMA) or carbon fibers as connecting rods in group I and II, respectively. Fractures were evaluated for clinical, radiological and biochemical parameters both pre-operatively and post-operatively on 0th, 15th, 30th, 45th and 60th day. Post-operatively, goats showed partial weight bearing on 0th day and contact of sole to ground within 8 days. Swelling and serous pin tract discharge were noticed during 2-5 days, which resolved by 1st week. The limb usage in both groups progressed from non-weight bearing on pre-operative day to complete weight bearing on 60th post-operative day. Radiographs revealed fracture healing with secondary callus formation with satisfactory alignment on 0th day, periosteal callus initiation on 15th day and apparently bridged fragments on 30th day. Osteolysis, periosteal reaction at pin-bone interfaces and barely visible to absent fracture line were observed on 45th day. Evident osteolysis and periosteal reaction at pin-bone interface and completely healed fracture with initiated cortico-medullary union and callus remodeling were evident on 60th day. Increased values of serum phosphorous and serum calcium and alkaline phosphatase were observed on 15th and 30th day when compared to pre-operative day and they were restored to normal by 60th day. All the biochemical values were recorded within physiological range. Intraoperative complications were minimal and post-operatively pin loosening, pin tract infection and fixator failure were observed. From the present study it was inferred that the closed reduction with minimally invasive technique provided satisfactory fracture fixation and early ambulation in goats. Carbon fibers offered advantages like earlier weight bearing, better alignment adjustment and better radiographic fracture site visibility. In addition, higher initial incurred costs, and the reusability of implants can mitigate long-term expenses.

Key words: Carbon fiber, Goats, Long bone fracture, PMMA, Type II ESF

Goats are highly adaptable and widely distributed species, which make them easy to manage in various conditions. Long bone fractures are a common orthopedic issue in goats, often results from traumatic incidents (Athira, 2018). Fracture fixation in goats poses economic constraints in veterinary practice. Various techniques are used for fracture fixation in goats, including: external coaptation (splints and casts), internal fixation and external skeletal fixation (ESF). ESF is a minimally invasive technique that preserves the fracture environment, promoting early callus formation and weight bearing (Van EE and Geasling, 1992). ESF offers advantages like shorter surgery duration and fewer complications (Gorse, 1998). This study aims to evaluate the effectiveness of Type II ESF

using PMMA or carbon fiber connecting rods with non-threaded transpiration pins for long bone fracture repair in goats. PMMA (Polymethylmethacrylate) and carbon fiber connecting rods offer benefits like economic viability and their versatility in application. The study will assess the efficacy of this technique in promoting fracture healing and lesser complications in goats.

MATERIALS AND METHODS

Twelve Osmanabadi goats with long bone fractures were included in this clinical study at Department of Veterinary Surgery and Radiology, Veterinary College, Bidar. The study aimed on fractures of the radius, tibia, metacarpal, and metatarsal bones, excluding humerus and femur due to anatomical constraints (Moores, 2008). The twelve goats were randomly divided into two groups. Group I included six goats treated with Type II External Skeletal Fixation (ESF) using PMMA as connecting rods whereas, group II included six goats treated with Type II ESF using carbon fiber rods as connecting rods with JESS clamps. The study was carried out to compare the effectiveness of PMMA

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Table 1. Pre-operative radiological findings and transfixation pins used in goats

Goat	Bone affected	Age (months)	Body wt. (kg)	Type of fracture	Size & no. of transfixation pins in prox. fragment	Size & no. of transfixation pins in distal fragment	Total pins used
Group I							
1	Right metatarsal	2	8	Simple transverse distal diaphysis	2mm- 2 pins	2mm- 2 pins	4
2	Right tibia	24	22	Simple long oblique distal diaphysis	2mm- 3 pins	2mm- 1pin 1.5mm- 1 pin as ancillary support	5
3	Right metacarpal	30	40	Simple comminuted mid diaphysis	2.5mm- 1pin 2mm- 1 pin	2.5mm- 2 pins 2mm- 1 pin	5
4	Right metacarpal	9	19.50	Simple short oblique distal diaphysis	2mm- 3 pins	2mm- 2 pins	5
5	Right metacarpal	24	27.50	Compound short oblique distal diaphysis	2.5mm- 3 pins	2.5mm- 2 pins	5
6	Left tibia	3	8	Simple short oblique mid diaphysis	2 mm- 2 pins	2mm- 2 pins	4
		15.00 ± 4.95 20.83 ± 4.98					
Group II							
1	Left metacarpal	7	25	Simple transverse mid diaphyseal	2mm- 2 pins	2mm- 2 pins	4
2	Left metacarpal	24	30	Compound transverse mid diaphyseal	2.5mm- 1 pin 2mm- 2 pins	2.5mm- 1 pin 2mm- 1 pin	5
3	Left metacarpal	4		Simple short oblique distal diaphysis	2mm- 3 pins	2mm- 2 pins	5
4	Right radius	3		Compound short oblique distal diaphysis	2mm- 3 pins	2mm- 2 pins	5
5	Right metatarsal	6		Simple transverse distal diaphysis	1.8mm- 2 pins	1.8mm- 2 pins	4
6	Left tibia	4		Simple long oblique distal diaphysis	2mm- 3 pins	2mm- 2 pins	5
		8.00 ± 3.26					

and carbon fiber as connecting rods in treating long bone fractures in goats (Table 1) for repair of fracture using ESF type II fixation technique which stabilizes the fracture and neutralizes the forces acting on fracture in a better way when compared to external coaptation technique.

All the goats of group I and II were operated under general anaesthesia for fracture repair. Feed and water were withheld for preoperative 12 hours. Ceftriaxone was injected intravenously at the dose rate of 10 mg/kg body weight one hour prior to surgery. Butorphanol at the dose rate of 0.05 mg/kg body weight and xylazine at the dose rate of 0.22 mg/kg body weight were injected intravenously 30 min and 10 minutes prior to induction as, respectively pre-anesthetic. Induction was done using ketamine at the dose rate of 11 mg/kg body weight intravenously. Maintenance of anesthesia was done using a mixture of ketamine and propofol (ketofol) in 1:1 ratio (v/v) till the completion of surgery.

The goats were restrained in lateral recumbency with fractured limb on lower side to facilitate easy access to the medial aspect of the bone for drilling through safe

corridors. Immobilization and reduction of fracture fragments were performed by closed approach after aseptic surgical site preparation. Temporary markings were done after reduction of fractured fragments for insertion of transfixation pins along the safe corridors. Non-threaded, trocar ended pins were used as transfixation pins, and their selected size being 25% of narrowest bone diameter of the fractured bone (Vogel and Anderson, 2014).

A nick incision of 1 mm was made at marked site along the longitudinal axis of fractured fragments before insertion of each transfixation pins. Pin was drilled with low-speed battery operated driller till it passes from near cortex to far cortex of bone fragments and then emerges out from other side of skin. The same procedure was followed for drilling of other transfixation pins both in proximal and distal fragments.

In group I, after drilling of all transfixation pins, a temporary scaffold was made using 20 mm corrugated electric wire cover. The acrylic mixture was instilled in corrugated wire cover. The setting time of 12 to 15 minutes was provided for hardening of PMMA. Sterile moist gauze

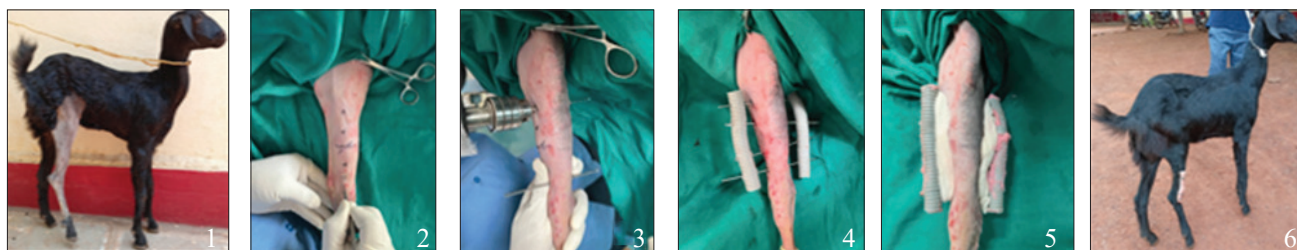


Fig. 1 Step wise surgical procedure for application of type II ESF with PMMA as connecting rod for repair of right tibia fracture in goat no.2 of Group I. 1. Goat showing fracture of right hind limb tibial fracture with non weight bearing lameness, 2. Marking on medial side of fractured bone for pin insertion, 3. Insertion of transfixation pin using Jacob chuck, 4. Bilateral placement of corrugated electric wire cover over all transfixation pin, 5. The PMMA mixture was instilled in to the corrugated electric wire cover, 6. Goat showing clinical weight bearing on 60th post- operative day with intact implant

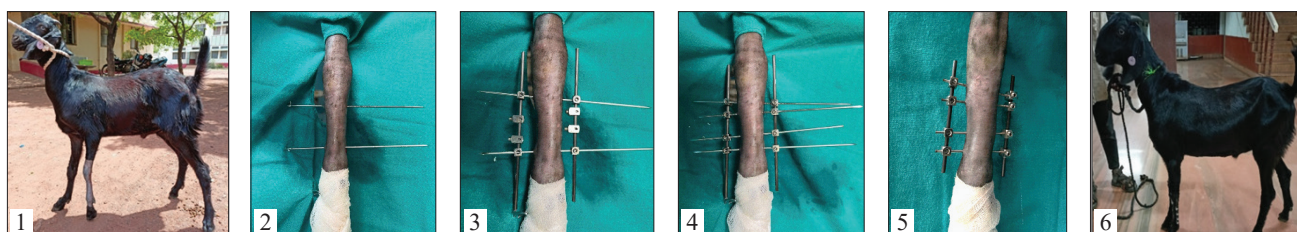


Fig. 2 Step wise surgical procedure for application of type II ESF with carbon fiber as connecting rod for repair of left metacarpal fracture in goat no.1 of Group II. 1. Goat showing fracture of left fore limb metacarpal fracture with non weight bearing lameness, 2. Insertion of two terminal transfixation pins in the respective fracture fragments, 3. The terminal transfixation pin ends were connected with carbon fiber as connecting rod carrying intended number of JESS clamps on both medial and lateral side of limb, 4. Additional transfixation pins were drilled through the intended number of clamps preplaced in the connecting carbon fiber rods, 5. The extra length of transfixation pins were cut close to all the JESS clamps, 6. Goat showing clinical weight bearing on 60th post- operative day with intact implant

mops were kept below the corrugated wire cover to avoid thermal necrosis of tissue. After hardening of acrylic, excess portion of the transfixation pins were cut close to the PMMA connecting rod (Fig.1).

In group II goats, similar surgical procedure was followed as in group I. After insertion of two terminal transfixation pins, the ends were connected with carbon fiber as connecting rod carrying intended number of JESS clamps on both medial and lateral side. Terminal clamps were tightened with Allen key to ensure the stabilization of fracture. The additional transfixation pins were drilled through the intended number of clamps preplaced in the connecting rods. All the clamps were tightened using Allen key after passing of transfixation pins. The extra length of transfixation pins were cut close to the JESS clamps (Fig.2).

In both the groups, the whole configuration was bandaged to minimize the risk of snagging on clothing or other objects (Julie, 2005). Post-operatively ceftriaxone was given at the dose rate of 10 mg/kg body weight intravenously for five days, along with meloxicam at the dose rate of 0.20 mg/kg intramuscularly for three days. Dressing of the surgical wound was done on alternate day. The fixators were removed after confirmation of clinical and radiological union of fractured fragments under proper antiseptics.

The operated goats were evaluated on pre-operative day and after operation (immediate) on 0th, 15th, 30th, 45th and

60th days to assess the wound healing and functional limb usage as per Fox *et al.* (1995) viz., Excellent - Functionally normal; Good - Slight lameness only after extensive exercise; Fair- Slight to moderate lameness but consistent weight bearing; Poor- Non-weight bearing lameness. Also, evaluation of grading of lameness described by Vasseur *et al.* (1995) is given in Table 2.

Post-operative radiographs were taken on similar intervals to assess the progress of bone healing and complications. Biochemical parameters such as serum calcium (mg/dL), serum phosphorous (mg/dL) and serum alkaline phosphatase (IU/L) were evaluated on 0th, 15th, 30th and 60th 45th day. The clinical and biochemical parameters were recorded at different time intervals within the group and between the groups and were analyzed using student

Table 2. Grading of lameness given by Vasseur *et al.* (1995)

GRADE I	Normal weight bearing on all limbs at rest and while walking
GRADE II	Normal weight bearing at rest, favours affected limb walking
GRADE III	Partial weight bearing at rest and while walking
GRADE IV	Partial weight bearing at rest and not bear weight on affected limb while walking
GRADE V	Does not bear weight on limb at rest or while walking

“t” test as described by Snedecor and Cochran (1994).

RESULTS AND DISCUSSION

All the goats with long bone fractures were presented with acute pain, non-weight-bearing lameness, and crepitation at fracture site. One goat of group I with metacarpal fracture and two goats of group II with metacarpal and radius and ulna fracture showed bleeding from the fracture site. Similar observations were observed by Athira (2018).

Five goats of each group showed swelling distal to the fracture site and serous pin tract discharge was observed from post-operative day 2-5, which resolved within a week. It was mainly attributed to normal inflammatory discharge due to soft tissue injury during pin insertion (Van EE and Geasling 1992; Basith *et al.*, 2018). Skin scaling was observed during 30th to 45th post-operative day and it was attributed to chronic usage of topical application of povidone iodine around the pin tract.

Goats of both the groups showed pointing of toe to the ground on first post-operative day. Group I goats showed contact of sole to the ground between 3 to 8 days whereas, group II goats showed between 1st to 8th post-operative day indicated the better weight transfer between the fragments (Aithal *et al.*, 2019) in the latter group.

In group I, fixator stability was good throughout the observation period however one goat showed displaced connecting rod on 45th post-operative day without affecting the functional usage and weight bearing on the affected limb. In contrary, Julie *et al.* (2007) reported the damaged PMMA fixator with loss of fracture reduction and affected functional limb usage in two cases (33.33%). In group II, fixator stability was compromised in 3 goats (50%) which

also affected the functional outcome in 2 goats (66.67%). In both of these goats, the carbon fibers were re-applied which showed improvement in functional outcome in one goat while complete failure of fixator occurred in second goat on 27th post-operative day. This fracture was managed with modified Robert-Jones bandage till complete weight bearing and healing of wounds. Canapp (2004) reported that pin loosening was associated with pin tract drainage and usage of non-threaded transfixation. In contrary, Phaneendra (2014) had not notice any fixator failure throughout the fixation period.

The details of post-operative grading of lameness of goats in groups I and II are given in Table 3. On pre-operative day, all goats of group I showed poor functional limb usage (Athira, 2018). Functional limb usage was found to be good as early as 15th post-operative day in one goat, 30th post-operative day in 4 goats and 45th post-operative day in one goat. At the end of the study, 5 goats achieved excellent functional usage; however, one goat had good functional outcome. This could be attributed to decreased inflammation at fracture site and initiation of bridging callus (Jahangirbasha *et al.*, 2019). Five out of six goats progressed to grade I lameness and one goat showed grade II lameness by 60th post-operative day.

On pre-operative day, all goats of group II showed poor functional limb usage. Functional limb usage was found good as early as 15th post-operative day in two goats, 30th post-operative day in 4 goats and 60th post-operative day in one goat. At the end of the study, 5 goats achieved excellent functional usage; however, one goat persisted as good grade due to implant failure. Five out of six goats progressed to grade I lameness and one goat showed grade II lameness by 60th post-operative day. This can be

Table 3. Post-operative grading of lameness of goats in groups I and II

Group	Goat no.	Pre -operative day	Post-operative days				
			Day 0	Day 15	Day 30	Day 45	Day 60
I	1	V	V	IV	III	II	I
	2	V	V	IV	III	II	I
	3	V	V	IV	II	I	I
	4	V	IV	III	III	I	I
	5	V	V	IV	III	I	I
	6	V	V	IV	IV	II	II
Mean±SE		5.00±00	4.84±0.17	3.84±0.17	3.00±0.26*	1.50±0.23**	1.17±0.17**
II	1	V	V	IV	III	I	I
	2	V	V	IV	V	IV	II
	3	V	V	IV	III	II	I
	4	V	IV	III	III	I	I
	5	V	IV	IV	III	I	I
	6	V	V	III	II	I	I
Mean±SE		5.00±00	4.67±0.22	3.67±0.22	3.17±0.41*	1.67±0.50**	1.17±0.17**

* Significant difference ($p \leq 0.05$) compared to pre-operative intervals within the group, ** Significant difference ($p \leq 0.01$) compared to pre-operative intervals within the group

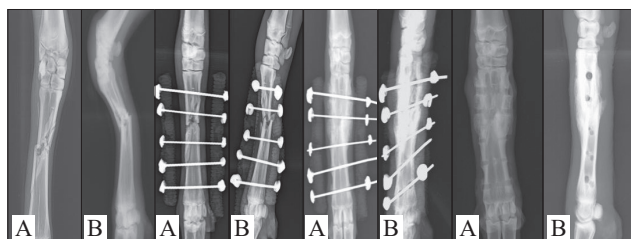


Fig. 3 Dorso-palmar (A) and Medio-lateral (B) radiographic views in Goat of Group I (PMMA) for mid-diaphyseal comminuted fracture of metacarpus on before operation, 0th, 60th and after removal of implants on 60th post-operative day showing invisible fracture line with initiation of callus remodelling, cortico-medullary union and radiolucent pin tracts.

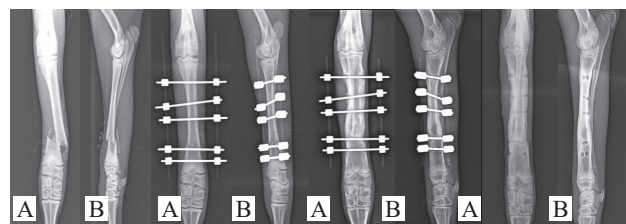


Fig. 4 Cranio-caudal (A) and Medio-lateral (B) radiographic views in Goat of Group II (Carbon fiber) for distal diaphyseal short oblique fracture of radius on before operation, 0th, 60th and after removal of implants on 60th post-operative day showing invisible fracture line and early cortico-medullary union with radiolucent pin tracts.

attributed to neutralized forces at fracture site and stable fracture fragments (Canapp, 2004). Group II tended to have comparatively lower Mean ± SE values for lameness grading, indicating a more rapid response to fixation along with rigid fracture fixation.

The fixations in both groups showed a progressive improvement in functional limb usage and lameness scores with surgical repair of fracture by using potential benefits of the chosen fixation systems in goats.

Post-operative radiographs of 5 goats in group I showed good implant stability at fracture site throughout observation period and PMMA rod displacement was observed in one goat at the end of study without affecting the functional limb usage. The fracture alignment in 5 goats showed adequate cortical contact and one goat showed less cortical contact between the fractured fragments, the gap was filled with hard callus in subsequent post-operative days. The periosteal callus formation was initiated on 15th post-operative day, callus density was increased till 45th post-operative day and the callus remodeling was seen on 60th post-operative day in all the goats (Fig.3). These findings were in accordance with Joy and Venugopal (2014a). In all the goats, osteolysis and periosteal reaction were noticed on 30th post-operative day onwards. Implants were removed on 60th post-operative day. Similarly, Julie *et al.* (2007) observed varied degree of osteolysis and periosteal reaction without affecting functional limb usage.

Post-operative radiographs of 4 goats in group II showed good implant stability at fracture site throughout observation

period. Broken carbon fibers were observed in one goat on 7th post-operative day and fixator failure was noticed on 27th post-operative day in another goat. The fracture alignment in 5 goats showed adequate cortical contact and one goat showed less cortical contact between the fractured fragments, the corrective surgery was carried on next post-operative day. The periosteal callus formation was initiated on 15th post operative day, callus density was increased till 45th post-operative day and the callus remodelling on 60th post-operative day in all the goats (Fig.4). In all the goats, osteolysis and periosteal reaction were noticed on 30th post-operative day and on subsequent days. Implants were removed on 60th post-operative day. The radiolucency of carbon fiber provided better visibility of fracture site in group II when compared to group I. Similarly, Phaneendra (2014) said that carbon fibers enabled better visualisation of fracture site to assess fracture healing.

The mean values for serum calcium, serum phosphorous and serum alkaline phosphatase in both the groups showed gradual increase from pre-operative day and reaching peak value on 30th post-operative day. The levels returned to normal values on 60th post-operative day in all goats (Table 4).

The increased serum calcium and serum phosphorous on 30th and 15th post-operative day, respectively could be attributed to enhanced osteoclastic activity, which leads to bone resorption at fracture site and then decreased values could be attributed to deposition of calcium at the fracture site. The findings were in accordance with Vinit (2017) and

Table 4. Mean ± SE values for Biochemical Parameters in goats

Biochemical Parameters	Groups	Pre-operative day	0 th Day	15 th Day	30 th Day	60 th Day
Serum calcium (mg/dL)	I	8.35±0.07	8.41±0.07*	8.50±0.05**	9.03±0.08**	8.24±0.06**
	II	8.33±0.06	8.46±0.06*	8.56±0.07**	9.08±0.09**	8.41±0.04*
Serum phosphorous (mg/dL)	I	6.13±0.06	6.29±0.07*	6.88±0.11**	6.32±0.05**	6.03±0.04*
	II	6.12±0.04	6.28±0.04*	6.69±0.04**	6.33±0.02*	6.05±0.04
Serum alkaline phosphatase (IU/L)	I	127.61±2.33	132.60±2.33*	142.09±2.20**	156.28±1.75**	138.27±3.41*
	II	129.06±1.86	134.03±1.89**	144.17±1.89**	156.94±1.26**	135.63±2.58*

* Significant difference ($p \leq 0.05$) compared to pre-operative intervals within the group, ** Significant difference ($p \leq 0.01$) compared to pre-operative intervals within the group

Table 5. Post-operative complications and treatment of group I and group II goats

Group I (type II ESF using PMMA as connecting rods)			Group II (type II ESF using carbon fiber as connecting rods)		
Goat No.	Post-operative complications	Treatment	Goat No.	Post-operative complications	Treatment
1	No complications noticed	-	1	Bent in carbon fiber and broken medial carbon fiber was noticed on clinical union of fractured limb	Corrective surgery was not taken, as goat functional limb usage was not affected
2	Transfixation pin loosening of proximal most pin and pus accumulation at medial aspect of proximal pin were observed	Proximal pin was removed on the same day and antiseptic dressing of pin tracts was carried out	2	Malalignment of fragments on the day of operation was noticed on initial period A sero-sanguinous discharge was noticed on proximal pins and complete loosening of implant was observed on later part of fracture healing However goat showed satisfactory weight bearing on affected limb during walking	corrective procedure was carried on next day of operation by removing one proximal most pin to adjust the fragments to apposition Removal of whole fixator was carried out on the same day and management of fracture with modified Robert-Jones bandage till fracture healing
3	Proximal pin loosening and medial displacement of lateral connecting rods and wound around the proximal pin site on lateral aspect of carpus due to pressure caused by connecting rod	Proximal pin was removed on the same day and antiseptic dressing of pin tract was carried out	3	No complications noticed	-
4	No complications noticed	-	4	No complications noticed	-
5	No complications noticed	-	5	No complications noticed	-
6	No complications noticed	-	6	Outward deviation of affected limb and broken carbon fiber was observed	Corrective surgery was carried out by replacing carbon fiber

Athira (2018).

The increased serum alkaline phosphatase (IU/L) activity in the present study could be attributed to increased osteoblastic activity at the fracture site which released large amount of alkaline phosphatase, and was also involved in bone matrix formation and mineralization of bone matrix. The findings were in accordance with Jahangirbasha *et al.* (2019) and Chimkode *et al.* (2024).

There were no major intra-operative complications noticed in goats of group I and group II. Post-operative complications of group I and II goats are given in Table 5. These complications were readdressed as per requirement.

In conclusion, Type II ESF using PMMA and carbon fiber connecting rods provided satisfactory immobilization for long bone fractures in goats. The radiolucent nature of carbon fiber enabled better post-operative radiographic visualization of fracture site in medio-lateral view. Dislodgement or displacement of ESF was seen more in Group II. However, Group II goats showed early weight bearing indicating superiority of carbon fiber to PMMA.

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