



Physical characters and economics of acrylic and epoxy polymers as frame components of external skeletal fixator

SURBHI KULDEEP TYAGI¹, HARI PRASAD AITHAL², PRAKASH KINJAVDEKAR³, AMARPAL⁴, ABHIJIT MOTIRAM PAWDE⁵ and IRAWATI POLESHWAR SARODE⁶

Indian Veterinary Research Institute, Izatnagar, Uttar Pradesh 243 122 India

Received: 20 August 2012; Accepted: 11 August 2014

ABSTRACT

Physical characters of acrylic and epoxy polymers used in constructing external skeletal fixator vis-à-vis economics were compared in the present study. The fixator constructs were prepared using acrylic/epoxy polymer, 1.5 mm K-wires and ultra high density polyethylene rods as a bone substitute. Observations on fabrication ease, weight, radiographic properties and economics of polymers were taken. The epoxy polymer being doughy, less heat producing and fumeless was easier to fabricate into constructs. Hardening time for acrylic was dependent on environmental temperature with an average of 11 min; whereas, epoxy putty hardened in about 22 min and the hardening was independent of environmental temperature. Acrylic fixators were radiolucent and significantly lower in weight. Preparation cost of epoxy constructs was significantly lower than acrylic constructs. Present study provides baseline benchmarks to choose polymers in constructing external skeletal fixators according to available resources, technical expertise and economics involved.

Key words: Acrylic, Epoxy, External skeletal fixators, Polymer

The polymers are also useful as components of fixation systems like external skeletal fixation systems. Generally, components of external skeletal fixators are made of a metal, mostly stainless steel (Kummer 1990); aluminium, titanium and carbon fibres are relatively light in weight but very costly (White *et al.* 2003). The major disadvantage associated with ESF made of metal is their heavy weight, relatively high cost, their fixed frames which offer less versatility in shape and direction and in addition their difficult availability, especially in Indian sub-continent. The size and shape of the side bars/rings remain the same. Also, the diameter of the transosseous pins is dictated by the size and location of the clamps or rings (Okrasinski *et al.* 1991). Several modifications were done to make external skeletal fixators (ESF) better for use in clinical situations such as replacement of the metallic connecting bars and clamps with the non-metallic polymeric substances. Polymethylmethacrylate (PMMA), epoxy putty and automotive body filler were also used to design ESF components for use in veterinary patients (Worth 2007). These free-form external skeletal fixators are light in weight, less expensive and the pin direction need not be influenced

by the direction and location of the connecting bar/ring. Also the pin diameter is not limited by the clamp size (Okrasinski *et al.* 1991) and these polymers can be moulded into a variety of shapes.

Biomechanical studies revealed that, compared with stainless steel equivalent, the acrylic fixator is stronger in axial, craniocaudal and torsional loads and as strong in mediolateral bending loads (Willer *et al.* 1991). Roe and Keo (1997) suggested that epoxy putty can be a suitable material for connecting pins in free-form external skeletal fixators. A recent biomechanical study showed that the ESF frames made of acrylic and epoxy polymers are at par (Surbhi 2011). The present study was therefore undertaken with the objective of comparing the 2 polymers namely acrylic and epoxy based on the observations on ease of fabrication into fixator components, weight, radiographic properties and economics.

MATERIALS AND METHODS

Manually construction of fixator constructs was done using acrylic and epoxy polymers as side bars of the ESF frames. The frames were constructed on ultra high density polyethylene (UHDPE) rods of 20 mm diameter. Length of the 2 segments of construct was kept 7 cm each. The pins (1.5 mm diameter K-wires) made of 316 L stainless steel were passed at 3 points both in proximal and distal segments. Side bars were constructed using either acrylic or epoxy polymer, at a uniform distance of 20 mm from the

Present address: ¹Assistant Professor (surbhiivri@gmail.com), College of Veterinary Science and Animal Husbandry, Navsari Agricultural University, Navsari. ², ⁴Senior Scientist (aithal@ivri.res.in, amarpal@ivri.res.in), ³, ⁵Principal Scientist (pk@ivri.res.in, apawde@ivri.res.in), ⁶Ph.D. Scholar (irawatisarode@rediffmail.com), Division of Surgery.

central plastic rod.

For acrylic fixators, self curing dental acrylic was used. Acrylic powder (polymer) and liquid hardener (monomer) were mixed in a glass beaker immediately before application. Acrylic in semi liquid state was poured into the side bars made of corrugated poly vinyl chloride (PVC) pipes of 20 mm diameter, and allowed to flow down the whole scaffold. The open ends of side bars were sealed with the help of adhesive tape. Acrylic was then allowed to polymerize and harden. For epoxy fixators, the epoxy-resin was mixed with the hardener for 1–2 min, till a uniform colour was achieved. The side bars of the fixator were constructed by moulding the epoxy on the pins by incorporating the bent pins within. The handling characters of both polymers, heat produced, fumes generated, time required for hardening of polymers and other technical difficulties encountered during construction of the ESF frames were noted down and compared.

Weight of UHDPE rods with the pins was taken as A. The total weight of the fixator construct was taken as B. Weight of filling material (acrylic or epoxy) used (C) was calculated by subtracting A from B and the weight was expressed in grams, as weight of filling material, $C = B - A$. Thus the average weight of each fixator ($n=28$) was measured and compared.

Per unit cost of acrylic and epoxy polymers used in fabrication of each fixator was calculated. On the basis of material used the cost of filling material (acrylic/epoxy) was calculated as A. The total cost of pins used was calculated as B, depending on the number of pins used in each design by adding the cost of pins and filling material, the total cost (C) of the fixator was calculated as: total cost in rupees, $C = A + B$. Thus, the cost of each design of acrylic or epoxy fixator was calculated and compared.

Statistical analysis: Standard descriptive statistical tools were used for analyzing various parameters. The means between 2 groups were tested for statistical significance using one-way ANOVA (Snedecor and Cochran 1994).

RESULTS AND DISCUSSION

Acrylics and epoxy are polymers which on hardening (polymerization) form a strong structure. In veterinary orthopaedics, these polymers have been used in construction of ESF components in dogs, cats and birds (Okrasinski *et al.* 1991, Willer *et al.* 1991, Worth, 2007, Aithal *et al.* 2010). As components of an ESF, the connecting rods, or sidebars, provide a bridge between the pin clamps and rings, unifying the bony fragments in the external fixator construct. The use of these polymers as connecting rods or side bars in ESF systems affords the surgeon greater latitude in fixation pin placement. This is because the fixation pins need not be aligned in a single longitudinal plane, in addition, fixation pins of any diameter may be used, and not just those that can be accommodated by a connecting clamp (Shahar 2000). Polymeric ESF offers the advantage of reduced cost, improved versatility, and simplified application technique when compared with Kirschner ESF (Okrasinski *et al.*

1991). In Indian conditions, these polymers are easily available and are economical as compared to their metal counterparts. In addition, the ESF made of polymeric components are light in weight, which may encourage an earlier return to function (Ross and Matthiesen 1993).

Amongst various acrylics available in the market, dental acrylic is relatively easily available and more economical, so was used in the present study. A number of epoxy putty (industrial grade) is available in the market. Because of the easy availability of M-seal in the market and better handling characters, it was selected in the present study. During standardization, all the 3 types of M-seal available in the market, viz. regular (red), fast curing (blue) and quick set (white) were tested. It was found that the regular M-seal took very long time to set (more than 80 min), whereas, the fast curing M-seal took about 20–25 min for setting. Further, the time of setting for quick set M-seal was less than 10 min, not giving enough time to mould and form the construct. Hence, on the basis of time taken for setting, fast curing M-seal was chosen and used for the construction of different designs of epoxy fixators.

When compared on the basis of ease of fabrication, the construction of epoxy fixators models was comparatively easier and less time consuming for epoxy fixators than acrylic fixator models (Table 1). During construction of the frames, acrylic has to be kept in flowing consistency, which makes its handling sometimes difficult as there are chances of leakage from the points of pin insertion in PVC tubes, whereas, the doughy consistency of epoxy facilitated its handling. The acrylic had to be mixed just before application, with continuous stirring, to maintain a flowing consistency. When delayed during application, it became hard and it had to be discarded and fresh mix had to be prepared. While pouring the acrylic into the pipe, leakage occurred in many fixator constructs at the pipe-pin interfaces or at pipe joints. When the room temperature was relatively higher ($>20-21^{\circ}\text{C}$), the mixing glass beaker had to be pre-cooled (to prevent early setting). The liquid contains methyl methyl acrylate polymer, which forms poly methyl methyl acrylate (PMMA), which was highly flammable, it had to be kept away from the source of ignition. Anderson (1988) reported that the fumes produced during polymerization are

Table 1. A comparison of acrylic and epoxy polymers based on their physical characters and radiographic properties

Parameters	Acrylic	Epoxy
State	Liquid to semisolid	Doughy
Relative handling	Difficult	Easy
Leakage while application	Possible	No
Exothermic reaction	More	Less/negligible
Fumes production	Yes	No
Time for hardening	Less	More
Relative weight	Less	More
Relative cost	More	Less
Radiographically	Translucent	Radiopaque

noxious and toxic. For polymerization and hardening a lot of heat was produced, and care had to be taken to prevent skin burns. Martinez *et al.* (1997) also reported such type of complications related to the use of acrylic. While mixing acrylic powder with liquid, noxious fumes were produced, which were irritating to eyes, respiratory system and skin. To avoid these complications, wearing of face mask and hand gloves is pre-requisite and is thus highly recommended.

For acrylic polymer, depending on the ambient temperature, the working time can vary in length up to the setting time of 12 to 15 min. The warmer the environment the faster the material will set (Hall 1981, Mascia 1982). In the present study also, during warm climate (summer) the acrylic hardened within 10–12 min. At low temperature (winter) acrylic took more than 20 min to harden. In order to accelerate the reaction, temperature controlled environment was created, so that hardening could occur at normal time. No such difference in time of hardening was recorded for epoxy fixators, which was independent of the ambient temperature. There was slight expansion of acrylic while hardening. Hardening time was less for acrylic (nearly 11 min) and once set it did not give any chance for even slight adjustments.

Epoxy also had to be prepared immediately before the use. The epoxy monomer was mixed with the resin, till it acquired a uniform colour. If a pin is pushed into the epoxy dough, a cavity forms in the epoxy putty, and it does not contact the entire pin surface, so it is necessary to squeeze the epoxy putty around the pin (Roe and Keo 1997). A similar procedure was followed in the present study to ensure that epoxy putty made a good contact with the pin surface. In contrast to acrylic polymer, there was no fume and negligible heat production during processing of epoxy polymer. The time for hardening (22 min) was comparatively more with epoxy; this long time for polymerization might be the reason for negligible heat production as heat must have dissipated gradually. The property—relatively long setting time allowed for minor adjustments in alignment of segments even after pin fixation—might offer an advantage in clinical situations.

The weight of the fixator is an important factor, which could influence the animals comfort and tolerance towards the fixator. An ideal fixator should be light in weight and strong. For the polymeric fixators having light weight components, the diameter and strength of the fixator can be increased without much increase in weight. Polymeric fixators are lighter in weight than stainless steel fixators of comparable diameter (Lewis *et al.* 2001, Julie *et al.* 2007). Among the acrylic and epoxy used in the present study, the acrylic was significantly lighter in weight (Table 2), which is an advantage over epoxy material.

Radiographically, acrylic is radiolucent and has an advantage in clinical situation as compared to epoxy and stainless steel fixators (Lewis *et al.* 1998). To avoid this complication in epoxy fixators, orthogonal views can be taken to prevent interference in radiographic interpretation.

Table 2. Values (mean±SE) of weight and cost of the ESF frames constructed with acrylic and epoxy polymers

Parameters	Acrylic (N=28)	Epoxy (N=28)
Weight of filling material (g)	132.50±10.20 ^a	405.35±29.18 ^b
Cost of filling material (₹)	254.40±19.59 ^a	83.09±5.98 ^b

The cost of the fixation device often dictates the selection of fixation technique, especially in animal patients. Overall, the cost of acrylic material per unit fixator (Table 2) was significantly lower than that of acrylic. The acrylic fixator was reported to be of lower cost than metal fixators (Lewis *et al.* 1998, Julie *et al.* 2007).

A range of variable size fixators can be custom made using acrylic or epoxy polymers, depending upon the patient's size and weight. Different gauges of tubing/PVC pipes can be used as moulds for application of acrylic fixators, whereas, epoxy polymer can be hand-moulded to various diameters. The epoxy polymer was easier to fabricate into fixator components due to its better fabricating ease and is comparatively more economical (about half the cost) than acrylic polymer, whereas, acrylic polymer is radiolucent and relatively lighter in weight, when compared to epoxy polymer. One can choose polymers in constructing external skeletal fixators according to available resources, technical expertise and economics involved.

REFERENCES

- Aithal H P, Kinjavdekar P, Amarpal, Pawde A M, Pratap K, Zama M M S, Surbhi, Monsang S W and Setia S C. 2010. Epoxy-pin external skeletal fixation for management of open long bone fractures in calves and foals. A review of 16 cases. 34th Annual Congress of ISVS. Veterinary College, Puducherry. 8–10 Dec 2010.
- Anderson D E and St Jean G. 1996. External skeletal fixation in ruminants. *Veterinary Clinics of North America Food Animal Practice* **12**: 117–52.
- Hall C. 1981. Polymers: molecular structure. *Polymer Materials. An Introduction for Technologists and Scientists*. Pp.1–91. (Ed.) Hall C. John Wiley and Sons, New York.
- Julie B, Swam K V, Rajankutty K, Venugopalan K and Sarada Amma T. 2007. Acrylic external skeletal fixator for treatment of long bone fractures in dogs. *Indian Journal of Veterinary Surgery* **28**: 6–10.
- Kummer F J. 1990. Technical note: Evaluation of new Ilizarov rings. *Bulletin of Hospital Joint Diseases* **50**: 88–90.
- Lewis D D, Cross A R, Carmichael S and Anderson M A. 2001. Recent advances in external skeletal fixation. *Journal of Small Animal Practice* **42**:103–12.
- Lewis D D, Bronson D G, Samchukov M L, Welch R D and Stallings J T. 1998. Biomechanics of circular external skeletal fixation. *Veterinary Surgery* **27**: 454–64.
- Martinez S A, Arnokzky S P, Flo G L and Brinker W O. 1997: Dissipation of heat during polymerization of acrylics used for external skeletal fixator connecting bars. *Veterinary Surgery* **26**: 290–94.
- Mascia L. 1982. *Thermoplastics: Materials Engineering*. pp.120–

79. Applied Science Publishers, Ltd. New York .
- Okrasinski E R, Pardo A D and Graehler R A. 1991. Biomechanical evaluation of acrylic external skeletal fixation in dogs and cats. *Journal of American Veterinary Medicine Association* **199**: 1590–93
- Roe S C and Keo T. 1997. Epoxy putty for free-form external skeletal fixators. *Veterinary surgery* **26**: 472–77.
- Ross J T and Matthiesen D T. 1993. The use of multiple pin and methylmethacrylate external skeletal fixation for the treatment of orthopaedic injuries in the dog and cat. *Veterinary Comparative Orthopaedics and Traumatology* **6**: 115–21.
- Shahar R. 2000. Relative stiffness and stress of type I and type II external fixators: Acrylic versus stainless-steel connecting bars-a theoretical approach. *Veterinary Surgery* **29**: 59–69.
- Snedecor G W and Cochran W G. 1994. *Statistical Methods*. 8th edn. Iowa state university press, Ames, Ia.
- Surbhi. 2011. 'Biomechanical and clinical studies on acrylic and epoxy-pin external skeletal fixation systems in dogs.' Thesis Doctor of Philosophy of Veterinary Surgery and radiology, Deemed University Indian Veterinary Research Institute.
- Willer R L, Egger E L and Hestand M B. 1991. Comparison of stainless steel versus acrylic for the connecting bar of external fixators. *Journal of American Veterinary Medicine Association* **27**: 541–48.
- Worth A J. 2007. Management of fractures of the long bones of eight cats using external skeletal fixation and a tied-in intramedullary pin with a resin acrylic bar. *New Zealand Veterinary Journal* **55**: 191–97.
- White D T, Bronson D G, and Welch R D. 2003. A mechanical comparison of veterinary linear external skeletal fixation system. *Veterinary Surgery* **32**: 507–14.