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Use of a pool-raft system for recovery of horses from general anesthesia: 393 horses (1984–2000)

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Objective—To describe the pool-raft recovery system protocol and to evaluate the clinical outcome in horses that underwent recovery from general anesthesia using this system.

Design—Retrospective study.

Animals—393 horses that underwent recovery from general anesthesia in the pool-raft system.

Procedure—Anesthetic records were examined from horses recovered from anesthesia in the pool-raft system between January 1984 and December 2000. Complete medical records of horses were examined when available. Information regarding the anesthetic and recovery period was recorded. Horses first recovered from general anesthesia in the pool-raft and, once awake, were transported to a recovery stall and lowered to the floor in a standing position.

Results—351 horses underwent 1 pool-raft recovery, and 42 horses underwent multiple pool-raft recoveries. Most horses were recovered from general anesthesia within the pool-raft system to safeguard repair of a major orthopedic injury. During 471 pool-raft recoveries, 34 (7%) horses had complications within the recovery pool and 62 (13%) had complications within the recovery stall. Deaths resulted from complete failure of internal fixation, pulmonary dysfunction, or a combination of pulmonary dysfunction and fixation failure in 2% (10/471) of horses that underwent pool-raft recoveries.

Conclusions and Clinical Relevance—The pool-raft system is a good option for recovery from general anesthesia. Although not a fail-safe system, it appears to decrease the complications of recovering horses in a high-risk category. Potential disadvantages of this system are added expense and manpower necessary in building, maintenance, and usage, as well as size limitations of the raft itself. (*J Am Vet Med Assoc* 2002;221:1014–1018)

Horses with orthopedic problems present many challenges, including recovery from general anesthesia. An increase in the duration of anesthesia, such as that experienced in horses undergoing major orthopedic surgery, has been implicated to predispose horses to postanesthetic complications.[1,2,a] Dr. Jacques Jenny et al[3] at the University of Pennsylvania originated the idea that a carefully designed pool-raft system would allow the horse to safely regain consciousness following anesthesia. Use of a raft within a pool system would allow the horse to float, avoiding negative pulmonary effects that develop with submersion.[4] The C. Mahlon Kline Orthopedic and Rehabilitation building was then designed and built to house the pool-raft system, which has been in use since 1972. Despite its long use, results of this recovery system have not been previously reported. The purpose of the study presented here was to describe the pool-raft recovery system protocol and to evaluate the clinical outcome in horses that underwent recovery from general anesthesia using this system.

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Criteria for Selection of Cases

Anesthetic records of all horses that underwent recovery from general anesthesia in the pool-raft system from January 1984 to December 2000 were evaluated. Complete medical records were also examined when available. Horses undergoing pool-raft recovery from general anesthesia were identified through use of a dedicated log maintained by operating room personnel. Horses were recovered using the pool-raft system at the discretion of the surgeon. Horses undergoing pool-raft recoveries were considered high risk because of the nature of the injury or anticipation of poor quality recovery. Horses recovered in the pool-raft system between 1972 and 1983 were not included, because records were unavailable.

Procedures

The C. Mahlon Kline Orthopedic and Rehabilitation indoor anesthetic recovery pool at the University of Pennsylvania is 6.7 m (22 ft) wide and 3.4 m (11 ft) deep. The recovery pool is surrounded by a cantilevered deck, with the diameter of the pool being 1.2 meters (4 ft) greater than the internal diameter of the deck. This circumferential overhang allows personnel access to the horse while preventing the horse's limbs from striking the pool wall during recovery. The pool holds 114,000 L (30,000 gal) of continuously filtered, brominated water, which is heated at a constant temperature of 36°C (96°F). The pH and bromine content are measured daily. When not in use, the recovery pool is covered with a solar cover to increase heating efficiency and minimize humidity. A raft used in conjunction with the pool allows flotation of the horse, preventing problems associated with partial submersion. The raft used for flotation is a US Navy 6-man life raft modified[b] to accommodate 4 horse limbs (**Fig 1**). Raft dimensions accommodate large juvenile and adult

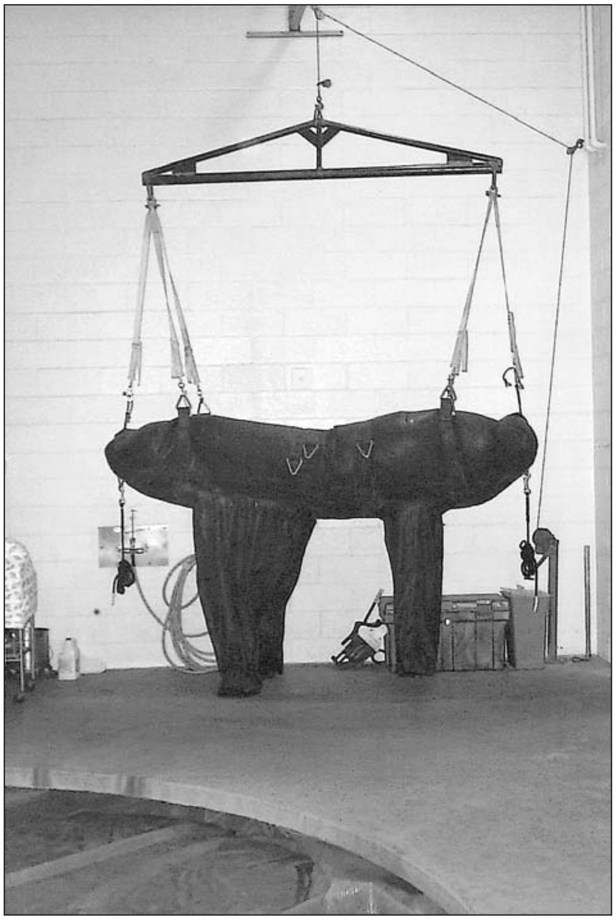

Figure 1—Photograph of the suspended recovery raft used for horses in the pool-raft system for recovery from general anesthesia. The raft's ability to accommodate horses is limited by the distance between the forelimb and hind limb allowances, which is 1.4 m (4.6 ft).

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The pool-raft recovery protocol has evolved over time, and the following is a general description of the procedure. Prior to surgery, a jugular venous catheter is placed. Horses are sedated in the recovery stall. A large animal sling,[c] suspended from an overhead monorail system, is loosely buckled around the horse in the standing position, and they are induced with injectable anesthetic. Following either oral or nasal tracheal intubation, horses are positioned on the operating table, and after the surgery and related procedures are completed, the horse is lifted in the sling and lowered into the recovery raft. Horses are sedated prior to transfer from the operating table to the pool-raft system if movement is anticipated as a result of inadequate anesthetic depth. The sling and raft are on independent 907 kg (1 ton) electric hoists, which can be transported to the recovery pool on an overhead monorail system 4.9 m (16 ft) above the floor. The horse and raft are then lowered into the pool, and the raft is secured to rings on the pool deck (**Fig 2**). Two ropes are used to control the horse's head over a smaller flotation raft[d] to prevent injury or aspiration of pool water. A nasotracheal tube

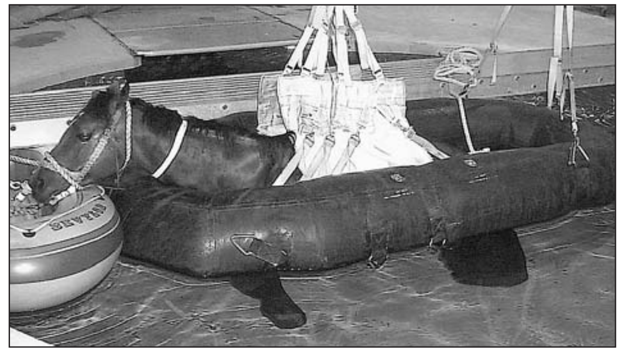

Figure 2—Photograph of a horse within the pool-raft system.

Figure 3—Photograph of the transfer of a horse from the pool-raft system to a recovery stall by overhead monorail system.

is placed, and oxygen supplementation is given at the discretion of the anesthetist if the horse is not breathing spontaneously or if their respirations are shallow or infrequent while in the pool raft. Horses are sedated or tranquilized if they became anxious early in the pool recovery phase. Personnel observe the horse for increasing periods of vigorous activity, and the horse is transferred from the pool once it remains alert without transient periods of somnolence. A sedative is given before removal from the pool and transfer to the recovery stall if the horse is excited. Horses that lift 1 or more limbs from the raft are also judged to be awake enough to stand and are immediately transferred to the recovery stall without attempts to replace these limbs

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back into the raft. A blindfold is placed over the eyes and cotton in the ears to minimize patient stimulation. A minimum of 7 people are required to transfer a horse from the pool to a recovery stall. The staff wears protective headgear as an added safety measure. The horse is hoisted in the sling out of the raft and taken by monorail to the padded recovery stall (**Fig 3**). Finally, the horse is lowered into the sling in a standing position until his feet just contact the floor of the recovery stall, and the blindfold is removed. Head and tail ropes assist the horse and maintain its orientation in the stall. The horse is allowed a few minutes to look around and is encouraged verbally and manually to stand. Immediately after the horse is bearing weight fully, the sling is removed. The horse is walked to its stall approximately 5 to 10 minutes later. If the horse cannot bear full weight or refuses to do so, an alternate method of recovery is chosen. Alternative recoveries include lowering the horse into lateral recumbency onto a thick foam mat, returning the horse to the pool-raft system, or transporting the horse to the stable via overhead monorail system and then lowering the horse into a recumbent position.

Anesthetic and medical records of horses undergoing pool-raft recovery were reviewed. Data collected from each record included signalment, type of injury and surgical procedure, position and measured values under general anesthesia, and events and complications surrounding the recovery event. Data describing the horse and recovery event were recorded and analyzed using descriptive techniques.

Results

We identified 486 pool-raft recoveries within our 16-year study period yielding a mean of 29 pool-raft recoveries performed each year, with a range of 15 to 55 pool-raft recoveries per year. Anesthetic records were available for 393 horses undergoing 471 pool-raft recoveries. In addition, within this population, complete medical records were available for analysis in 337 horses undergoing 397 pool-raft recoveries. Many of our patients underwent multiple pool-raft recoveries; 351 horses underwent 1 pool-raft recovery, 29 had 2 pool-raft recoveries, 4 had 3 pool-raft recoveries, 4 had 4 pool-raft recoveries, and 5 had 5 or more pool-raft recoveries. In our study group the highest number of pool-raft recoveries per horse was 10. The age of the horses ranged from 10 months to 26 years, with a mean age of 5 years. Among this group were 110 geldings, 115 colts or stallions, and 166 fillies or mares. Breed distribution included 281 Thoroughbreds, 62 Standardbreds, and 46 horses of another breed. Mean weight was 474 kg (1,043 lb), with a range of 300 to 696 kg (660 to 1,530 lb).

Admitting problems of horses were variable, but were predominantly major orthopedic injuries. Horses were placed into the pool-raft recovery system (287 recoveries) to safeguard repair of a long bone fracture, most commonly third metatarsal condylar fractures (130), medial or spiraling third metacarpal condylar fractures (45), and olecranon fractures (28), to prevent fracture in horses in which this event was estimated to be more likely (79), such as placement of the external skeletal fixation device (31), and for soft tissue procedures for which problematic recoveries were anticipated (22). Multiple recoveries (78) in the pool-raft system were performed for the following reasons: 32 recoveries for revision surgeries of a previous repair, 20 for cast changes, 18 for implant removals, and 8 to safeguard a previous repair following an unrelated surgical procedure.

In 97% (355/366) of pool-raft recoveries, anesthesia was induced with the horse in a sling. In 3% (11/366), horses came in unable to stand or were anesthetized against the table, and the sling was applied following induction. Ninety-four percent (440/469) of horses were placed on the operating table in lateral recumbency. After IV administration of induction agents, inhalants isoflurane (71%; 334/470), halothane (27%; 130/470), and sevoflurane (1%; 6/470) were used. Positive pressure ventilation was used in 97% (439/470) of horses. The mean anesthetic period was 156 minutes, with a range of 50 to 510. The mean surgical time was 95 minutes, with a range of 15 to 410 minutes. Direct **mean arterial pressure (MAP)** was routinely measured throughout each procedure with a mean value of 77.9 mm Hg. The lowest MAP of > 5 minutes duration was 66.9 mm Hg, and the mean time that the MAP was < 70 mm Hg was 33 minutes representing 21% (33/156 minutes) of the total anesthetic period. The mean value of MAP at the time of transfer to the pool-raft system was 84.2 mm Hg. Nasal, rectal, or inguinal body temperatures of horses were also recorded. For the anesthetic period, mean initial temperature was 36.7°C (98.1°F) and mean final temperature was 36.4°C (97.5°F).

Twenty-three percent (110/471) of horses were sedated prior to transfer from the operating table to the pool-raft system if movement was anticipated. Xylazine hydrochloride was the most common agent. Typical doses of xylazine, given IV, were 0.1 to 0.2 mg/kg (0.2 to 0.4 mg/lb). Analysis of recorded pool-raft endotracheal intubation revealed that 95% (270/283) of horses were intubated nasally, 1% (2/283) were intubated orally, and 4% (13/283) were not intubated. Analysis of recorded pool-raft oxygen supplementation revealed that oxygen was supplemented either via demand valve or insufflation. Fifteen percent (77/471) of horses received demand valve supplementation. Oxygen supplementation was not used in 83% (390/471) of horses. Twenty-four percent (111/471) were sedated or tranquilized early in the pool recovery phase, and the most common agent administered was acepromazine maleate. The mean time spent in the pool was 70 minutes, with a range of 15 to 260 minutes. The majority of horses (93%; 437/471) did not suffer complications while in the recovery pool. Pool complications consisted of loss of venous access (3%; 13/471), horses lifting 1 or both forelimbs out of the raft necessitating earlier-than-anticipated removal from the raft (2%; 10/471), respiratory tract complications (2%; 8/471), hoist dysfunction (1%; 4/471), and sling dysfunction (0.2%; 1/471). The IV catheter becoming dislodged caused loss of venous access. In each horse, the IV catheter was replaced, restoring venous access. Respiratory tract complications within the recovery pool included dislodging the endotracheal tube, apnea, aspiration of pool water, and severe dyspnea. If the endotracheal tube was dislodged, it was replaced to provide a patent respiratory tract for passive ventilation. Personnel treated transient periods of apnea, occurring immediately after transfer of the horse to the recovery pool and related to anesthetic depth, with active ventilation via oxygen demand valve. A horse that aspirated pool water later developed pulmonary edema. The horse's anxious demeanor was thought to contribute to complete breakdown of internal fixation in the recovery stall. A horse that developed severe dyspnea in the pool raft died; necropsy examination later revealed a diagnosis of tracheal collapse.

A sedative was given before removal from the pool and transfer to the recovery stall if the horse was excited; 40% (188/471) were sedated, with xylazine the most common agent. Typical doses of xylazine, given IV, were 0.1 to 0.2 mg/kg (0.2 to 0.4 mg/lb). The mean recovery time, including pool time, was 76 minutes with a range of 16 to 545 minutes. If the horse was unable to stand in the recovery stall, an alternate recovery method was then chosen. In 438 of 471 (93%) pool-raft recoveries, no alternate recovery method was used. Of the 471 pool-raft recoveries, 16 (3.4%) involved placement of the horse onto a deep foam mat in the recovery stall, 12 (2.6%) involved the use of an overhead monorail system for transportation of the horse to the stable, and 5 (1%) required placing the horse back into the pool for an additional period. In 87% (409/471) of pool-raft recoveries, complications were not observed within the recovery stall. Complications apparent in the recovery stall included generalized weakness (5%; 24/471), complete failure of fixation (2%; 10/471), wet bandage or cast (1.5%; 7/471), respiratory tract problems (1%; 5/471), temporary facial paresis (1%; 5/471), facial trauma (1%; 4/471), temporary radial neuropathy (1%; 4/471), pronounced epistaxis (0.4%; 2/471), partial failure of fixation (0.4%; 2/471), myositis (0.4%; 2/471), failure of the tail rope (0.4%; 2/471), and failure of the head rope (0.4%; 2/471). Wet casts or bandages during pool-raft recovery are caused by urination, sweating, excessive splashing, or raft leakage and may be underreported in the medical record. Respiratory tract problems evident within the recovery stall included most commonly dyspnea, caused by dislodging or obstructing the endotracheal tube or severe nasal edema, and a single instance of pulmonary edema. Horses experiencing complete fixation failure within the recovery stall included 3 horses with third metatarsal medial condylar fractures, 3 with olecranon process fractures, 2 with radius fractures, 1 with a proximal phalanx fracture stabilized using an external skeletal fixation device, and 1 horse that fractured his scapula following a scapular notch resection. Of the 337 horses for which information was available beyond the anesthesia recovery period, 292 (87%) were discharged from the hospital, and 45 (13%) were humanely destroyed or died. In this population, 10 (3%) horses were destroyed or died as a result of complications within the pool raft recovery system. One horse died of respiratory tract complications within the pool-raft, and the remaining 9 horses were euthanatized in the recovery stall as a result of complete failure of internal fixation. One of these 9 horses had pulmonary edema secondary to aspiration of pool water and resulting anxiety was thought to contribute to breakdown of internal fixation in this horse. The mean hospital stay was 17.4 days, with a range of 1 to 291 days.

Discussion

Most equine surgical facilities offer a modified recovery system for fractures at high risk of catastrophic breakdown. Modifications may include use of ropes to steady the head and tail, use of personnel within the stall to assist the horse, recovery within a sling or against an operating table, additional use of external coaptation, modified flooring, and sedation and mats within the stall to prolong recumbency before the first attempt to stand. To our knowledge, in the United States, 2 equine surgical facilities, in addition to New Bolton Center, have access to a pool recovery system. Other described pool recovery systems differ fundamentally from our system.[5] In these systems, horses are partially submerged and supported directly with a sling system versus a flotation device. The pool dimensions are smaller, and the floor is elevated at the termination of the recovery period to allow easy exit from the pool. In a study from Washington State University between 1997 and 1998, the primary complication encountered in pool recovery was pulmonary edema occurring in 10 of 60 recoveries, 1 resulting in fatality.[e] In our study, 1 of 393 horses developed pulmonary edema following aspiration of pool water. In this horse, pulmonary edema and related respiratory distress were thought to have contributed to an increase in the amount of anxiety, thrashing in the recovery stall, and failure of the internal fixation. The horse was later euthanatized as a result of this complication. Increased incidence of pulmonary complications in pool systems where horses are partially submerged, compared with flotation systems, could be expected, as hydrostatic pressure is known to directly compress the thorax, decreasing functional residual and vital capacity.[4]

Horses are placed into the pool-raft system at the discretion of the surgeon, and criteria for selection are constantly evolving. For example, prior to the year 1987, horses with medial femoral condylar cyst lesions debrided via arthrotomy were routinely recovered in the pool-raft system because of concerns regarding disruption of wound closure. After 1987, arthroscopy became the standard treatment alleviating these concerns. A second example is prior to the year 1990, many horses with dorsal cortical metacarpal fractures were recovered in the pool-raft system. After 1990, standing surgery became the standard approach, eliminating the need for a modified anesthetic recovery. Third, in a previous report from our hospital about medial condylar fractures of the third metatarsal bone, 6 of 9 horses undergoing internal fixation and recovering in a conventional system developed mid-diaphyseal fractures during or after recovery.[6] In the same report, 2 horses that underwent internal fixation and recovered in the pool-raft system had successful outcomes. Following this period, horses with medial metacarpal and metatarsal fractures and many lateral condylar metatarsal fractures were recovered in the pool-raft system to prevent losses in recovery. In this review, only 3 of 80 horses with medial metatarsal condylar fractures had fixation failure in recovery. Further modifications include trends to delay surgical intervention from time of admission to allow stabilization of the patient and use of fewer pharmaceuticals prior to transfer to the recovery stall area, both anecdotally improving recovery demeanor and outcome.

In conclusion, the pool-raft system is a safe option for recovery from general anesthesia. Several large studies have been conducted to investigate mortality in horses associated with general anesthesia. Mortality rates have been estimated to be 0.63,[7] 0.68,[2] and 1.6%.[8] Results of another study that evaluated equine emergency procedures other than gastrointestinal disease estimated the mortality rate to be 15.3%.[9] Unfortunately, the populations in these studies are not directly comparable to our population and the 2% mortality rate that we report. Potential disadvantages of the pool-raft system are added expense and manpower necessary in building, maintenance, and usage, as well as size limitations of the raft itself. Although not a fail-safe system, it appears to decrease complications of recovering horses in a high-risk category.

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[a]Young SS, Taylor PM. Problems associated with clinical anaesthesia (abstr). *Aust Equine Vet* 1990;8:159.
[b]Firestone Tire and Rubber Co, Akron, Ohio.
[c]Liftex Corp Large Animal Sling, Warminster, Pa.
[d]Sevylor USA Inc, XR56-GTX, Los Angeles, Calif.
[e]Tidwell S, Schneider RK, Ragle CR, et al. The use of a hydro pool system to recover horses following general anesthesia: 60 cases, 1997–1998 (abstr). *Vet Surg* 1999;28:404.

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