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Source: Journal of Wildlife Diseases, 34(3) : 547-554

Published By: Wildlife Disease Association

URL: https://doi.org/10.7589/0090-3558-34.3.547

Journal of Wildlife Diseases, 34(3), 1998, pp. 547–554

SURGICAL IMPLANTATION AND EVALUATION OF HEART RATE TRANSMITTERS IN CAPTIVE BIGHORN SHEEP

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ABSTRACT: A surgical approach was developed for implantation of transmitters to monitor heart rate of bighorn sheep (*Ovis canadensis*) with an objective of discrete long-term, long-range data collection. We surgically implanted Telonics model HR400 transmitters on the dorsolateral thorax of 15 captive adult bighorn sheep ewes in April-May and October-November 1995. No complications or marked impairment of function were associated with the surgery; however, a transmitter was passively expelled from one ewe 19.5 mo post-implantation. Twelve of 15 transmitters remained functional ≥1 yr, while three failed 3.5 to 4.5 mo following implantation. Heart rate data collected from the transmitters using a Lotek SRX_400 telemetry receiver/datalogger equipped with W9 EVENT_LOG accurately reflected heart rate as measured with electrocardiogram tracings. Line of sight signal range was at least 800 m in 95% (37/39) of collections made from standing ewes, while data could be collected reliably (74%; 29/39) to 600 m from bedded ewes. When a reliable long-lasting inconspicuous telemetry system is required, we believe that this approach holds promise for success in free-ranging as well as captive ungulates.

Key words: Bighorn sheep, heart rate, *Ovis canadensis*, surgical technique, telemetry.

INTRODUCTION

Remote collection of physiological data using telemetry can be a useful tool to wildlife biologists because it allows normal physiological responses to be measured without interference from physical or chemical restraint. Heart rate data have been collected remotely from wildlife to: determine baseline heart rate and associated natural variations (Moen, 1978; Kreeger et al., 1989), study and predict metabolic rate and relative energy expenditure (Holter et al., 1976; Nilssen et al., 1984; Chabot, 1991), and monitor disturbance and stress (MacArthur et al., 1982; Kreeger et al., 1990b; Weisenberger et al., 1996).

In our studies, we required a telemetry system to monitor heart rate as an indicator of disturbance in bighorn sheep (*Ovis canadensis*) at wildlife viewing areas. This application required a system that was inconspicuous and would function reliably over a long range (>0.5 km) for an extended period (≥1 yr). Implantable telemetry systems to monitor physiologic parameters have been reported for use in a variety of wildlife species (Skutt et al., 1973; Philo et al., 1981; Renecker and Hudson, 1985; Kreeger et al., 1989; Cassirer, 1990; Coates et al., 1990; Kreeger et al. 1990a; Wallace et al., 1992), but no system fully met our criteria for wild ruminants. Heart rate telemetry systems in ruminants have generally been short-lived due to battery depletion, transmitter or electrode failure, or expulsion from the body. Although a relatively successful system adapted from Bunch et al. (1989) using intra-abdominal implantation was used in bighorn sheep and mule deer by Wallace et al. (1992), problems associated with intra-abdominal placement and transmitter failure were reported. Further, signal range of the intra-abdominally placed transmitters was ≤0.5 km on flat terrain. Here, we tested an alternative approach by surgically implanting the Telonics model HR400 heart rate transmitter (Telonics, Inc., Mesa, Arizona, USA) on the dorsolateral thorax of captive bighorn sheep. We evaluated (1) the surgical procedure by monitoring morbidity and mortality in implanted bighorn sheep, and (2) transmitter function by measuring accuracy, longevity, and signal range from standing and bedded animals.

MATERIALS AND METHODS

Surgical technique

We implanted heart rate transmitters into 15 tractable bighorn sheep ewes held at the Colorado Division of Wildlife's Foothills Wildlife Research Facility, Fort Collins, Colorado (USA; 40°35′N, 105°10′W). Groups of ewes were maintained in about 3-ha pastures and received ad libitum quantities of grass/alfalfa hay, water, trace mineral block, and about 500 g/animal/day of a pelleted supplement (Baker and Hobbs, 1985). Surgeries were performed during April–May (n = 5) and October–November (n = 10) 1995. Ewes ranged in age from 1.5 to 13 yr and in body mass from 55 to 82 kg.

Ewes were isolated and fasted for about 48 hr prior to surgery. We induced anesthesia with intravenous (IV) administration of 1.4 mg/kg ketamine HCl (Ketaset, Fort Dodge Laboratories, Fort Dodge, Iowa, USA) and 0.15 mg/kg xylazine (Rompun, Miles Inc., Shawnee Mission, Kansas, USA). Ewes were intubated with an 11 mm endotracheal tube and surgical anesthesia was maintained using a rebreathing circuit with isoflurane (AErrane, Anaquest, Madison, Wisconsin, USA) at 1.0–2.0% concentrations in oxygen flows of 1–2 l/min. A 1.1 mm × 5.1 cm indwelling intravenous catheter (Deseret Medical Inc., Sandy, Utah, USA) was placed for fluid administration. Normal saline solution (0.9% sodium chloride; Baxter Healthcare Corp., Deerfield, Illinois, USA) was administered at a rate of 200 ml/hr. We monitored anesthetic depth by continuous visual inspection of mucous membrane color, jaw tone, respiratory rate, and pulse rate. Patient monitoring was assisted electronically with pulse oximetry (Nellcor Model 10, Nellcor Inc., Haywood, California, USA), end tidal CO_2 (Vet/Cap 7000 capnometer, Sensor Devices, Inc., Waukesha, Wisconsin, USA), electrocardiogram (ECG; model 420; Mennen Medical Inc., Clarence, New York, USA), and temperature probe (model 870, Datascope Corp., Paramus, New Jersey, USA).

Anesthetized ewes were prepared for surgery by clipping hair on the left lateral thorax from the scapula to the last rib. They were then carried to a designated surgery area, placed in right lateral recumbency, and the surgical site prepared using a standard surgical scrub. Using aseptic technique we implanted Telonics model HR400 heart rate transmitters (Telonics, Inc.), which had been previously sterilized using the Sterrad system (Sterrad 100, Advanced Sterilization Products, Irvine, California, USA), on the dorsolateral thorax. The transmitters were 11 cm length × 3.3 cm diameter, and weighed 120 g. Positive and negative leads were 15 and 50 cm in length, respectively. We first made a 15 cm paramedian skin incision 12 cm lateral to the dorsal midline and just caudal to the scapular cartilage. We elevated fat and made a 10 cm incision parallel to the fibers in the *latissimus dorsi* muscle. Deep fascia was incised parallel to the ventral lateral border of the *longissimus dorsi* muscle to allow for its elevation. The transmitter was placed, with leads exiting caudally, in the naturally occurring shelf between the ribs and *longissimus dorsi* muscle (Fig. 1). Initially (April–May 1995), no procedure was used to prevent the transmitter from migrating craniad under the scapular cartilage over time; however, in later surgeries (October–November 1995) we placed one or two far-far near-near sutures (2-0 Maxon; Davis & Geck Monofil Inc., Manati, Puerto Rico, USA) in the split fascia cranial to the transmitter to

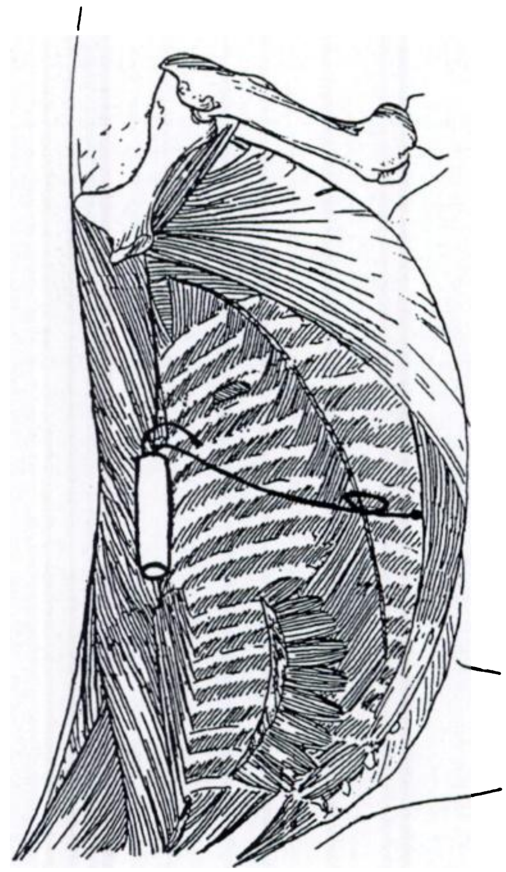

FIGURE 1. Placement of heart rate transmitter relative to deep musculature of the lateral thorax (caudal end toward top of page; adapted from Pasquini, 1982) of a bighorn sheep. The transmitter was placed in the naturally occurring shelf between the ribs and *longissimus dorsi* muscle.

deter migration. Two to four far-far near-near sutures (0 Maxon; Davis & Geck Monofil Inc.) were used to reattach the split fascial plane over the transmitter.

With the transmitter secured, the electrodes were then placed. The positive electrode was sutured to muscle fascia just ventral to the transmitter. The electrode was first tacked to the fascia, then surrounded by fascia using a staple suture. Excess lead wire was looped and tacked to the fascia using simple interrupted sutures. The negative electrode was threaded through a trocar (6 mm outer diameter × 36 cm long) that had been passed subcutaneously from the primary incision to a 4 cm incision on the ventral lateral thorax at the level of the antebrachiohumoral joint. The electrode and excess lead wire was sutured to superficial muscle as previously described for the positive electrode. Function and accuracy of the transmitter was confirmed by comparing ECG output to signal received using a Lotek model SRX_400 receiver/datalogger (Lotek Engineering Inc., Newmarket, Ontario, Canada). Incisions in the muscle layer were closed using a cruciate pattern, while the subcutaneous and skin layers were closed with simple continuous patterns (2-0 Maxon; Davis & Geck Monofil Inc.). Ceftiofur sodium (2.5 mg/kg IV; Naxcel, The Upjohn Company, Kalamazoo, Michigan, USA) was administered perioperatively. Phenylbutazone (4 mg/kg; Butatabs-E, Burns Veterinary Supply, Rockville Centre, New York, USA) was administered orally when the ewes had partially recovered from anesthesia.

Evaluation of transmitters

We monitored transmitter function at least once every 2 wk from the time of implantation until failure. We also developed a data acquisition system to collect and store large volumes of heart rate data using the Lotek receiver/datalogger with standard 128K byte data memory, equipped with EVENT_LOG (version 2.5x, W9; Lotek Engineering Inc.), and with a standard H antenna (Telonics, Inc., model RA-2A). The W9 EVENT_LOG package converts interpulse period of received signals to beats per minute (bpm). We programmed the package to determine heart rate based on sets of eight pulses before scanning to the next transmitter frequency. Data was downloaded in ASCII format via RS-232 serial port to a MS-DOS compatible computer.

We performed a calibration trial in July 1995 to determine the accuracy of the data acquisition system. Bighorn sheep implanted with heart rate transmitters ($n = 5$) were held in a 0.75 × 2 m stall while we elicited a range of heart rate responses (low, medium, high). Data were collected for three independent 1 min intervals from each animal under each of three heart rate responses. We initially sedated ewes lightly with about 0.15 mg/kg xylazine (Miles Inc.) IV and attached leads via clips to obtain a lead II ECG tracing. We then simultaneously collected heart rate data using ECG tracings on strip print-outs and using the data acquisition system. After collection of data under a period of low heart rate, heart rate was increased slightly by administering atropine sulfate (0.04 mg/kg IV; Vedco, Inc., St. Joseph, Missouri, USA). Heart rate was then further increased by administering yohimbine HCl (0.15 mg/kg IV; Wildlife Pharmaceuticals, Inc., Fort Collins, Colorado, USA) with or without 0.8 mg/kg ketamine (Fort Dodge Laboratories) IV and a mild human disturbance applied. We determined heart rate from the ECG by manually counting QRS complexes on the strip print-out and from the data acquisition system by calculating harmonic mean of heart rate data during the 1-min periods (Chabot et al., 1991). We analyzed data from this calibration trial using the method of least squares with the SAS statistical package (SAS Institute, Inc., 1988).

We also assessed the line of sight range of the signal from transmitters to the receiver on relatively level terrain. Bighorn sheep ($n = 5$) were sedated with ketamine and xylazine as described for surgical induction. Sedation was required so that the ewes could be placed consistently in the same location in a bedded or standing position with the right side of body facing the receiver. Data were collected during 1 min sampling periods from distances of 20, 100, 200, 300, 400, 500, 600, 700, and 800 m. Tests at distances >800 m were not attempted due to marked changes in topography of the land at our site. Two independent collections were made from each animal in each body position (bedded or standing) during September and November 1995; March and May 1996. We analyzed data using GENMOD and ANOVA procedures of the SAS statistical package (SAS Institute, Inc., 1988).

RESULTS

Surgical technique

No serious complications occurred during the surgical procedure. All parameters monitored remained within acceptable limits except for a period of decreased respiration rate lasting about 30 min in two bighorn sheep and associated mild arrhythmia in one. Intermittent positive pressure ventilation was applied during

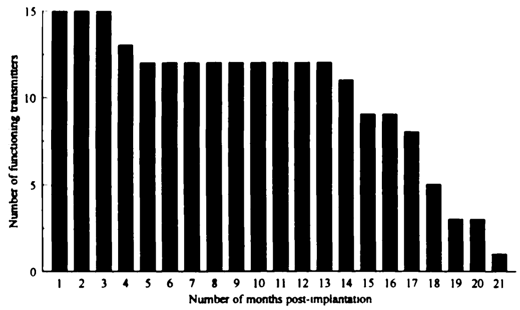

FIGURE 2. Functional duration of heart rate transmitters surgically implanted into captive bighorn sheep (n = 15).

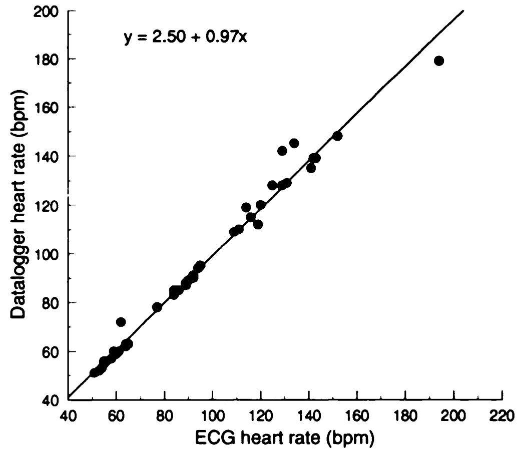

FIGURE 3. Correlation between heart rate data collected using the data acquisition system and heart rate determined using an ECG tracing was high (r^2 = 0.98; $\delta_{y/x}$ = 4.20) for bighorn sheep (n = 5) sampled over a range of heart rate responses.

these periods at a rate of 8 breaths/min until respiration rate returned to within normal limits. Mean surgery time was 54 min. Time to standing recovery was about 30 min in these tractable bighorn sheep.

Ewes were more sedentary for about 4 to 5 days following surgery, but no complications or impairment in function were observed. Two bighorn sheep received one additional dose of phenylbutazone about 2 mo post-operatively to decrease acute onset of moderate lameness. Lameness was associated with extension of the left forelimb and was apparently caused by the transmitter. Seromas associated with the transmitter occurred in two bighorn sheep, one about 2 mo post-operatively and the other about 6 mo post-operatively. Palpation indicated that the transmitter had migrated slightly craniad and partially under the scapula in the first ewe. Both seromas resolved without treatment. A transmitter was passively expelled from one ewe 19.5 mo post-implantation when a 2.5 cm diameter muscle/skin defect formed at the caudal end of the transmitter. No clinical signs of infection or pain associated lameness were noted in the ewe. The ewe was sedated for examination using ketamine and xylazine as described for surgical induction. The transmitter was removed by clipping the leads just below skin level. The defect was flushed with dilute betadine solution (The Purdue Frederick Company, Norwalk, Connecticut, USA) and closed using 2-0 Maxon (Davis & Geck Monofil Inc.) in cruciate and simple interrupted suture patterns. Prophylactic antibiotics (22,000 U/kg subcutaneous penicillin G benzathine and penicillin G procaine, Durvet, Inc., Blue Springs, Missouri, USA) and analgesics (4 mg/kg phenylbutazone per os, Burns Veterinary Supply) were administered. The ewe recovered without further complications.

Evaluation of transmitters

Twelve of 15 transmitters (80%) remained functional for at least 1 yr (Fig. 2). Three transmitters failed 3.5 to 4.5 mo following implantation. Failure was characterized by lack of signal transmission. Transmitters were not retrieved to determine cause of failure. The calibration trial indicated a strong, positive linear relationship (r^2 = 0.98; $\delta_{y/x}$ = 4.20; P < 0.001) between heart rate as indicated by the ECG tracing and heart rate determined using the data acquisition system (Fig. 3). In assessing line of sight signal range, we performed two independent collections from each of five bighorn sheep in two body positions over four sampling periods between September 1995 and May 1996, except that the transmitter of one ewe failed prior to the second collection in

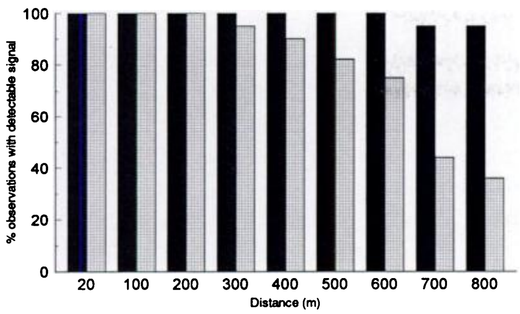

FIGURE 4. Percent of observations with a detectable telemetry signal (n = 39 observations from each distance) collected from bighorn sheep at line of sight distances of 20 to 800 m, September 1995 to May 1996. A solid bar indicates standing position and a stippled bar indicates bedded position.

May. At our study site, line of sight signal range from standing ewes was at least 800 m in 95% of the collections (37/39; Fig. 4). Although signal range decreased ($P < 0.001$) when ewes were bedded, signals were recorded from 74% (29/39) of the collections at 600 m (Fig. 4). Transmitter function varied ($P < 0.001$) between individual ewes.

DISCUSSION

We developed a safe and reliable technique for remotely monitoring heart rate in captive bighorn sheep. The Telonics model HR400 heart rate transmitter was successfully implanted in 15 captive, adult bighorn sheep. With the exception of one transmitter that was passively expelled after 19.5 mo, we observed no complications or impairment of function that would likely have affected survivability in free-ranging bighorn sheep. We attribute much of this success to the design of the Telonics transmitter, optimal anesthetic regimen, strict aseptic technique, and site of implantation. The dorsolateral thorax proved to be an ideal site for implantation from the perspective of both surgical technique and transmitter function. By placing the transmitter in a natural depression and covering it with superficial musculature, as well as subcutaneous tissue and skin, pressure on the incision line was minimized and dehiscence was avoided. Complications associated with intraperitoneal placement (Wallace et al., 1992) also were avoided and transmitter function was enhanced because the dorsal location likely increased signal range of the transmitter. Signals from temperature-sensitive transmitters were received for markedly greater distances when implanted on the back of the neck than when placed intra-abdominally in grizzly bears (Philo et al., 1981). The strong signal emitted from these transmitters should allow data to be collected at ranges that do not alter behavior or physiological response of animals under study. Additionally, because the lateral thorax is an area of minimal movement, interference from spurious signals (Jacobsen et al., 1981) is minimized.

We believe that this technique could be applied to other species of ungulates as well; however, a minimum body size for successful implantation of a transmitter this size likely exists. In this study, all ewes were ≥55 kg. In smaller animals, the shelf between the ribs and *longissimus dorsi* muscle may not be large enough to accommodate placement of the transmitter without pressure on the overlying tissues. Although all elements of a surgical procedure are important, the most critical aspects for success using this procedure appear to be strict aseptic technique and positioning of the transmitter well caudal to the scapular cartilage. Ample space should be allowed to accommodate range of motion of the scapula without interference with the transmitter. Addition of sutures to close the split fascia cranial to the transmitter in later surgeries apparently aided in preventing migration of the transmitter toward, or under, the scapular cartilage. This cranial migration was the most likely cause of the eventual expulsion of the transmitter from one ewe. The cranial end of the transmitter under the scapular cartilage likely served to increase the motion and angle of the transmitter (deeper at the cranial end under the scapular and more superficial at the caudal end). Based on the location of the muscle/skin defect, it appeared that pressure and mechanical trauma exerted by the caudal end of the transmitter was responsible for the tissue damage and consequent expulsion. In addition to the cranially placed stop sutures, the expulsion also may have been prevented by anchoring the transmitter to the deep fascia and *longissimus dorsi* muscle using a nylon surgical mesh. Alternatively, this complication could be avoided by surgically removing transmitters upon their failure.

Transmitters remained functional for an extended period. Because our intent was not to perform multiple surgeries on an animal, we were unable to determine cause of transmitter failures. We assume that the cause of three early failures most likely was due to leakage of body fluid into the transmitter because the units simply quit producing a signal. Transmission of a mortality signal, as would occur with lead breakage or inability to detect electrical activity of the heart, was not observed with any transmitter failure. We suspect that subsequent failures were due to battery depletion. Calculated battery life was 18.5 mo at 60 bpm (B. Burger, pers. commun.); however, because a bighorn sheep's heart rate is frequently >60 bpm, expected battery life is shorter.

Unfortunately, it is difficult to compare longevity of transmitters in this study with others because results of long-term evaluation have rarely been reported. Longevity of intra-abdominal heart rate transmitters was noted to be about 40 days in fox (Kreeger et al., 1989) and ≥180 days in wolves (Kreeger et al., 1990a). Heart rate transmitters implanted subcutaneously in a domestic and a bighorn sheep functioned 30 and 14 days, respectively, prior to expulsion following tissue necrosis (Coates et al., 1990). Transmitters implanted subcutaneously on the neck of elk functioned 5 to 9 mo (χ = 7 mo; Cassirer, 1990). Bunch et al. (1989) did not report longevity of transmitters placed intra-abdominally in two bighorn sheep; however, Wallace et al. (1992) used a similar technique to ours with good, although variable, success. In that study, seven transmitters failed due to lead breakage or disconnection ≤38 days post-implantation, seven transmitters short-circuited after seepage of body fluid between 126 and 509 days post-implantation, nine were functional when they were removed from live or dead animals 90 to 153 days post-implantation, and two were functioning at study termination 328 and 456 days post-implantation (Wallace et al., 1992). Because all of the transmitters in the current study continued to function >110 days post-implantation and 80% functioned to meet our criterion of ≥1 yr (Fig. 2), we believe that this approach may be more reliable for long-term monitoring when compared to other alternatives currently available.

Implantation of HR400 transmitters using this surgical approach met our criteria for success. The reliability and longevity of the Telonics transmitter implanted on the lateral thorax appeared to be an improvement over previously reported telemetry systems used in ruminants. The system did not detract from the aesthetic value of the animal because the implanted transmitter was not visible following regrowth of hair on the skin. Although a transmitter was expelled from one ewe, overall the technique was safe and humane to experimental animals. We believe that this technique could be successfully used in a field application; however, transportation of free-ranging animals to a base camp with aseptic surgical facilities would be required. Wallace et al. (1992) had limited success in capturing, transporting, and surgically placing transmitters intra-abdominally in free-ranging bighorn sheep. Although two of eight animals in that study died during or immediately following transport, modifications were made to the handling protocol to improve success over the period of animal captures. This finding highlights the importance of safe capture (Kock et al., 1987), transport, and anesthetic protocols in addition to use of a tested surgical technique for transmitter implantation. Although less invasive methods for monitoring heart rate in wild ruminants may be appropriate in some situations, when a reliable, relatively long-lasting inconspicuous telemetry system is required, we believe that this approach holds promise for success in free-ranging as well as captive animals.

ACKNOWLEDGMENTS

We thank P. E. Bleicher, A. L. Case, J. L. Schaefer, and L. A. Wallick for excellent surgical assistance and animal care; B. Burger for technical advice; L. D. Bowser for assistance with data management; and D. C. Bowden for advice on statistical analyses. Our work was supported by the Colorado Division of Wildlife Watchable Wildlife Program and Federal Aid to Wildlife Restoration Project W-153-R-8. The manuscript was prepared in partial fulfilment of the Ph.D. degree at Colorado State University (Wild). Helpful comments on earlier drafts were made by K. Giesen, H. J. Harlow, W. R. Lance, P. N. Lehner, B. A. Wunder, and two anonymous reviewers.

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Received for publication 3 May 1997.