STUDIES ON THE PHYSIOPATHOLOGY OF CHRONIC OBSTRUCTIVE PULMO-NARY DISEASE IN THE HORSE. II. RIGHT HEART HAEMODYNAMICS

A. LITTLEJOHN and FELICITY BOWLES, Equine Physiology Research Division, Department of Physiology, Pharmacology and Toxicology, Faculty of Veterinary Science, University of Pretoria, Onderstepoort 0110

ABSTRACT

LITTLEJOHN, A. & BOWLES, FELICITY, 1980. Studies on the physiopathology of chronic obstructive pulmonary disease in the horse. II. Right heart haemodynamics. *Onderstepoort Journal of Veterinary Research*, 47, 187–192 (1980).

Pressure curves obtained by cardiac catheterization of the pulmonary artery, right ventricle and right atrium of 9 horses and ponies with chronic obstructive pulmonary disease (COPD) were compared with those similarly recorded from 6 clinically normal control subjects.

The mean pulmonary peak systolic, pulmonary minimum diastolic and ventricular peak systolic pressures of the COPD subjects were significantly higher ($P<0,01$) than the corresponding mean pressures of the clinically normal control subjects.

The mean pressures calculated from pressure curves obtained from 8 Thoroughbreds in training did not differ significantly from those of the clinically normal subjects not in training.

Résumé

ÉTUDES SUR LA PHYSIOPATHOLOGIE DE LA MALADIE PULMONAIRE OBSTRUCTIVE CHRONIQUE DES CHEVAUX. II. HAEMODYNAMIQUES DU COEUR DROIT

Des courbes de pression obtenues par cathétérisme cardiaque de l'artère pulmonaire, du ventricule droit et de l'oreillette droite de 9 chevaux et poneys atteints de la maladie pulmonaire obstructive chronique (COPD) ont été comparées avec celles enrégistrées similairement de 6 sujets témoins cliniquement normaux. L'apogée pulmonaire systolique moyen, le minimum diastolique pulmonaire et l'apogée ventriculaire des pressions systoliques: des sujets COPD furent significativement plus élevés ($P<0,01$) que les pressions moyennes correspondantes des sujets témoins cliniquement normaux. Les pressions moyennes calculées à partir de courbes de pression obtenues de 8 chevaux pur sar g à l'entraînement ne diffèrèrent pas significativement de celles de sujets cliniquement normaux n'étant pas à l'entraînement.

INTRODUCTION

Intracardiac pressure measurements were first introduced as a clinical physiological tool in man by Forssman (1929). According to Ross (1962), the technique made an important contribution to the elucidation of cardiovascular physiology and pathology; in particular, measurements of pressures in the chambers of the right heart provided direct quantitative assessments of the degree of pulmonary vascular hypertension. The first reports of cardiac catheterization in the horse were given by Bernard (1876) and by Marey (1859), (cited by Geddes, McCrady & Hoff 1965). In this century, Spörri & Schlatter (1959), Fisher, Detweiler & Paterson (1963), Eberly, Tyler & Gillespie (1964), Gabel, Hamlin & Smith (1964), Eberly, Tyler & Gillespie (1966), Mordohovich (1971), Beltran (1973), Bergsten (1974), Amend, Garner, Rosborough & Hoff (1975), Brown (1977) and Dixon (1978) have utilized the technique in a variety of breeds of horses for various purposes. Bergsten (1974) noted that the use of tranquillizers by some of the above authors may have influenced their results. However, the effect of tranquillizers on intracardiac blood pressures in horses does not appear to have been reported.

The effect of chronic lung disease on cardiac function has been recognized in human medicine for many years. White (1951) introduced the term 'cor pulmonale' to denote ventricular hypertrophy as a result of pulmonary disease. Ettinger & Suter (1970) believed the term should be used in its widest sense in veterinary medicine, viz. right heart enlargement secondary to pulmonary vascular or parenchymal disease. The pulmonary hypertension which accompanies lung disease is the result of 2 processes. The first is the simple mechanical limitation of flow by the diseased pulmonary vascular bed (Berglund, 1968), and the second is the pulmonary vasoconstriction induced by hypoxaemia and hypercapnia (Fishman, Fritts &

Cournand, 1960). The mechanism of the second process is unknown.

Cor pulmonale was first reported in horses by Salutini (1959). Eberly *et al.* (1966) did not consider it a feature of the series of horses with pulmonary emphysema which they investigated, although the mean pulmonary arterial pressure of their series was higher than that of their control group. The above authors concluded that much remained to be learned about the effects of chronic obstructive pulmonary disease (COPD) on the pulmonary circulation of horses. However, both Bergsten (1974) and dixon (1978) reported that horses with COPD had pulmonary hypertension.

According to Berglund (1968), left heart pressures are rarely altered by COPD in man. This would appear to be the case in horses also, since no significant changes in systolic or diastolic pressures in the carotid artery were reported by either Eberly *et al.* (1966) or Bergsten (1974).

The purpose of the study reported here was to compare the pressures determined in the right heart and pulmonary artery of COPD horses with those of clinically normal horses. The right heart pressures of Thoroughbred horses in training were also investigated.

MATERIALS AND METHODS

Subjects

Three groups of subjects were investigated, namely, (a) clinically normal, consisting of 4 hacks and 2 riding ponies, (b) COPD, consisting of 5 riding ponies, 1 Lippizaner stallion, 1 Boerperd stallion and 2 hacks, and (c) 8 Thoroughbreds in training, of which 6 raced on the flat and 2 were event horses.

The clinically normal and COPD subjects were not in training for any competitive event. All subjects were maintained under identical conditions and were subjected to the same procedures in the same examination clinic.

Cannulae

Polyethylene tubing of outer diameter 1,2 mm and inner diameter 0,85 mm* was used to cannulate the heart. Lengths of 120 cm were notched in V-shape at one extremity to prevent occlusion of the orifice and placed in a 0,4% solution of chlorhexidene* overnight for sterilizing. A blunted 19 gauge needle was inserted in the other end for attachment to the transducer.

Analgesic solution

Lignocaine hydrochloride** 2% solution was used to induce analgesia at the site of cannulation.

Surgical instruments

A 14 guage needle, scalpel, dressing forceps and haemostat were sterilized by autoclaving.

Pressure transducer

The pressure transducer used was a Statham EMT 35***. Transducers of this type transform pressure variations applied to it into an electrical signal via a differential capacitor. Transducer EMT 35 was designed to measure intravascular pressures in the range −300 to +300 mm Hg and is highly sensitive to pressure variations of 1 mm Hg.

Electromanometer and writing device

The electromanometer EMT 31*** was used to amplify and calibrate the electrical signal. EMT 31 is a modular unit which plugs into the Mingograf 81*** recording system, and is designed for use in conjunction with transducer EMT 35. Input impedance of this unit was 3 megohm with an input signal of approximately 3 volts for maximum pressure.

The Mingograf 81 physiological recording system which was used to provide permanent records of pressure readings was fitted with ink jet galvanometers, giving simultaneous ink tracings from 5 different inputs.

Pressure curves were recorded at a paper speed of 50 mm per second.

Calibration

The EMT 31 electromanometer incorporates an internal calibration device whereby the desired range of pressure is marked on the chart paper by means of an electrical signal. This internal calibrator was regularly checked for accuracy with a mercury manometer.

Calibration was carried out in the 0–100 mm Hg range so that 1 cm on the chart paper equalled a pressure change of 20 mm Hg. Atmospheric pressure delineated the base line of the tracing and all readings were made with the transducer at the level of the shoulder joint. Mean values from several consecutive pressure curve tracings were calculated.

Procedure

The site chosen to introduce the cannula was in the lower 5th of the jugular furrow, over the jugular vein.

Local analgesic solution (0,5 mℓ only) was injected subcutaneously at this point. Approximately 4 minutes was allowed for desensitization, after which a puncture wound sufficiently large to allow passage of a 14 gauge needle was made. The jugular vein was raised by thumb pressure and the needle was inserted into the lumen.

Aseptic technique was routinely used in passing the cannula through the needle into the vein and thence into the heart chambers. When all but 20 cm of the cannula was passed through the needle, the cannula was flushed with heparinized 0,9% saline solution and connected to the transducer, and a tracing was made on the Mingograf-81. In most instances it was, found that the tip of the cannula was in the pulmonary artery, which in all cases produced a typical pressure curve in the approximate range 15–45 mm Hg. If the tip of the catheter was in the right ventricle (as evidenced by a typically "square-shaped" curve in the range 0–45 mm Hg), the cannula was manipulated by repeated retraction, rotation and re-insertion, until the tip was carried through the pulmonic valves into the pulmonary artery. When a satisfactory pulmonary arterial pressure curve was obtained, successive careful withdrawals of the cannula were made, thus recording pressure curves in the right ventricle and right atrium.

The transducer was held by means of a rigid stand and clamp at the level of the point of the shoulder of the subject throughout the recording. Care was taken to calibrate the transducer before and after recording by means of the electromanometer, which was standardized against a mercury manometer every 3 weeks.

Simultaneous EKG tracings were made with each, recording, so that pressure curves were correlated with the electrophysiological behaviour of the heart muscle. The 'Y' lead of the semi-orthogonal (S-O) system of Holmes & Else (1972) was used to record EKG tracings.

Floor insulation

A mat of woven rubber strips 3,50×0,92 m in size was used for all subjects. A sheet of copper gauze of similar size was placed under the mat. An earth wire of the Mingograf-81 Recording System was attached to this gauze with a crocodile clip.

RESULTS

Pulmonary arterial, right ventricular and right atrial pressures

Mean values and standard deviations of the above pressures in mm Hg obtained from measurements of the pressure curves in 6 normal and 9 COPD subjects are shown in Table 1. Pulmonary arterial and ventricular peak systolic pressures of the COPD subjects were found to be significantly higher than those of the normal subjects. The pressures of Thoroughbred horses in training (Table 2) did not differ significantly from the riding horses not in training. Examples of pressure curves are shown in Fig. 1.

DISCUSSION

Pulmonary arterial pressures

The mean systolic and diastolic pulmonary arterial pressures of 9 normal horses were similar to those recorded by other authors, viz.

Fisher *et al.* (1963) systolic 39, diastolic 16 mm Hg

Eberly *et al.* (1966) mean pulmonary 34 mm Hg

Gall (1967, cited by Bergsten, 1974) systolic 36, diastolic 21 mm Hg

Beltran (1973) systolic 33, diastolic 10,6

Bergsten (1974) systolic 45 and diastolic 22 mm Hg

Dixon (1978) systolic 45 and diastolic 22 mm Hg.

---

* Intramedic No. 7425, Clay Adams, New Jersey
** Versicaine, Maybaker, South Africa
*** Elema-Schönander, Sweden

TABLE 1 Pulmonary arterial, right ventricular and right atrial pressures of normal and COPD subjects

	Normal n=6 mm Hg	(kPa)*	COPD n=9 mm Hg	(kPa)	Difference of means mm Hg	Significance
Pulmonary peak systolic...............						t=3,55
Mean...............................	38,6	(5,13)	59,4	(7,90)	20,8	P<0,01
SD±...............................	5,7	(0,76)	13,0	(1,73)		
Pulmonary minimum diastolic............						t=4,65
Mean...............................	17,4	(2,31)	28,7	(3,82)	11,3	P<0,001
SD±...............................	5,7	(0,76)	3,2	(0,43)		
Ventricular peak systolic................						t=3,28
Mean...............................	41,5	(5,52)	58,2	(7,74)	16,7	P<0,01
SD±...............................	5,9	(0,78)	11,0	(1,46)		
Ventricular minimum diastolic...........						t=0,26
Mean...............................	2,9	(0,39)	2,1	(0,28)	0,8	NS
SD±...............................	1,2	(0,16)	7,1	(0,94)		
Atrial 'a' wave.........................						t=0,92
Mean...............................	15,3	(2,03)	17,9	(2,38)	2,6	NS
SD±...............................	4,3	(0,57)	5,6	(0,74)		
Atrial 'c' wave.........................						t=0,72
Mean...............................	11,7	(1,56)	14,0	(1,86)	2,3	NS
SD±...............................	6,0	(0,80)	5,7	(0,76)		

* kPa=kilopascals=mm Hg×0,133

NS=Not significant

P=Probability

Neither Fisher *et al.* (1963) nor Gall (1967) recorded the zero point they used for their determinations. Eberly *et al.* (1966) used the elbow joint and Beltran (1973) and Bergsten (1974) the shoulder joint. Pulmonary arterial pressures of this study were higher than those reported by Brown & Holmes (1978).

Both Eberly *et al.* (1966) and Bergsten (1974) obtained significantly higher mean values for pulmonary arterial pressures in horses with COPD. The mean pulmonary arterial systolic pressure of 60 mm Hg in Bergsten's (1974) 12 subjects with emphysema, compared with his normal mean value of 45 mm Hg, was highly significant. The mean end-diastolic pressure of 28 mm Hg in the pulmonary artery was not significantly higher in the above 12 horses with emphysema than in Bergsten's (1974) normal subjects.

In the COPD subjects of the present study, the mean pulmonary peak systolic and the mean pulmonary diastolic pressures were significantly higher in the COPD horses than in the clinically normal group. Nevertheless, the results were in general agreement with those of Eberly *et al.* (1966), Bergsten (1974) and Dixon (1978) in that pulmonary hypertension was associated with COPD in horses to a significant degree. Both Beltran (1973) and Brown & Holmes (1978) also reported that pulmonary hypertension was associated with chronic pulmonary disease in horses.

Fishman, Fritts & Cournand (1960) reviewed the literature on the response of the pulmonary circulation to acute hypoxia and concluded that experiments in both man and animals had shown that the pulmonary pressor response to hypoxia was consistently reproducible, although a pulmonary pressor response to hypercapnia had not been consistently demonstrated. There are, however, major differences between experimental procedures designed to measure the acute effects of breathing a 12–14% oxygen mixture

as in the experiments of Fishman *et al.* (1960), and the present studies, in which both groups of subjects breathed atmospheric air of a PO_2 of 125 mm Hg (calculated from the barometric pressure of *c.* 650 mm Hg at our altitude of 1300 m).

Firstly, the ideal alveolar PO_2 values in the Group (a) and Group (b) subjects of the present series were almost identical (Littlejohn, 1978). Secondly, human experiments were concerned with acute hypoxic situations, not chronic ones. The results of Lloyd (1965) showed that the pressor response did not persist indefinitely, and the same may be true of horses with pulmonary disease. Thirdly, the observations discussed by Littlejohn (1978) indicated that the arterial hypoxaemia displayed in the COPD subjects was largely associated with venous admixture.

The evidence of the present investigation therefore suggests that the pulmonary hypertension of COPD may be associated with mechanical factors in the lung as well as, or even instead of, a pressor response due to hypoxaemia. The fact that the intrathoracic pressure, which is determined by the elasticity of the lung, was shown to be increased in COPD subjects of this study (Littlejohn, 1978) also suggests that increased pulmonary arterial pressures may be associated as much with changes in lung architecture as with hypoxaemia.

Fishman *et al.* (1960) concluded that the autonomic nervous system was not involved in the pulmonary pressor response to hypoxia in man. However, they suggested that the response involved a change in the dimensions and the distensibility of some part of the pulmonary vascular tree, and admitted that the exact site and mode of action of the hypoxic stimulus remained unknown. It may be that the pulmonary hypertension of COPD involves a similar change as a result of pathological processes in the pulmonary vascular tree.

TABLE 2 Pulmonary arterial, right ventricular and right atrial pressure of Thoroughbred horses in training

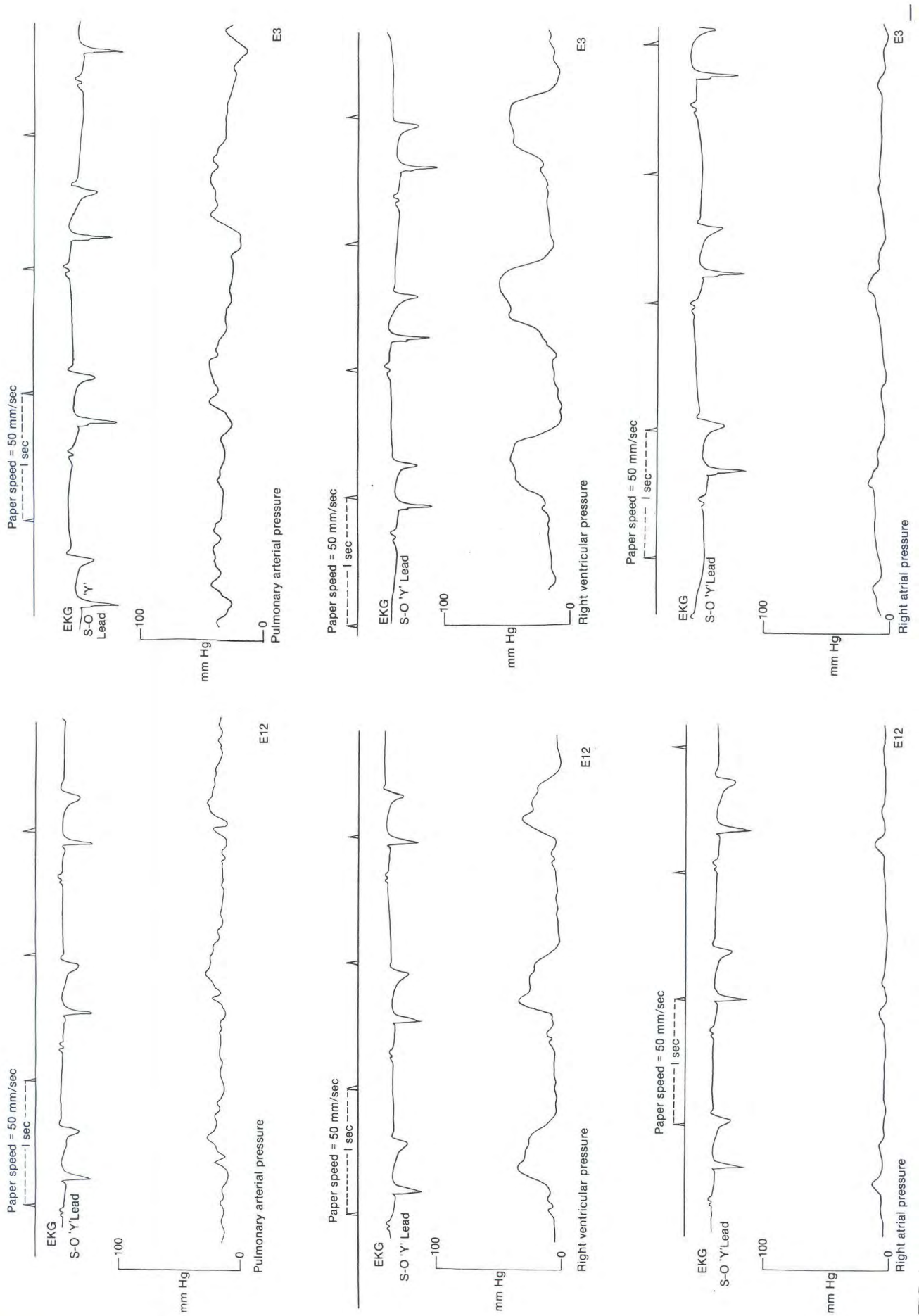| Identification	Age (yrs)	Pulmonary peak systolic		Pulmonary minimum diastolic		Ventric. peak systolic		Ventric. minimum diastolic		Atrial 'a' wave		Atrial 'c' wave	
		mm Hg	(kPa)*	mm Hg	(kPa)	mm Hg	(kPa)	mm Hg	(kPa)	mm Hg	(kPa)	mm Hg	(kPa)
Bay filly	(2)	38	(5,05)	20	(2,66)	36	(4,79)	6	(0,80)	8	(1,06)	8	(1,06)
Bay colt	(3)	40	(5,32)	—	—	31	(4,12)	0	(0,0)	14	(1,86)	8	(1,06)
Grey colt	(3)	34	(4,52)	14	(1,86)	41	(5,45)	2	(0,27)	12	(1,60)	8	(1,06)
Brown colt	(3)	34	(4,52)	21	(2,79)	34	(4,52)	2	(0,27)	16	(2,13)	—	
Bay gelding	(6)	49	(6,52)	24	(3,19)	49	(6,52)	10	(1,33)	14	(1,86)	9	(1,20)
Bay gelding	(11)	49	(6,52)	21	(2,79)	49	(6,52)	4	(0,53)	12	(1,60)	9	(1,20)
Black gelding	(4)	29	(3,86)	17	(2,26)	29	(3,86)	5	(0,67)	11	(1,46)	8	(1,06)
Grey gelding	(4)	42	(5,59)	20	(2,66)	42	(5,59)	10	(1,33)	14	(1,86)	12	(1,60)
Mean SD±		39,4 7,2	(5,24) (0,96)	19,6 3,2	(2,61) (0,43)	38,9 7,7	(5,17) (1,02)	4,9 4,0	(0,65) (0,53)	12,6 2,4	(1,68) (0,32)	8,9 1,5	(1,18) (0,20)

* kPa=kilopascals=mm Hg×0,133

190

FIG. 1 Pulmonary arterial, right ventricular and right atrial pressure curves of a normal subject (E12) and a COPD subject (E3). EKG tracings were recorded simultaneously

Right ventricular pressures

Peak systolic pressures in the right ventricle recorded by Eberly et al. (1964) and by Gillespie & Tyler (1969) were 59 and 64 respectively, and their end-diastolic pressures were 13, 14 and 15 mm Hg. However, the above authors used the elbow joint as a zero point, whereas the zero point used in the present studies was the shoulder joint. Since the positoin of the transducer when placed at the shoulder is higher than when at the elbow joint, readings of heart pressures with zero point at elbow joint will be higher than those with zero point at shoulder joint by an amount corresponding to the distance in cm H_2O between elbow and shoulder joints (Brown, 1977).

This difference in position of the transducer was calculated to be equivalent to 5–15 mm Hg, and it explains the difference between our results and those of the above authors.

Spörri (1962) obtained values in normal horses of 39,5 mm Hg and −1,5 mm Hg for right ventricular systolic and end-diastolic pressure respectively, using the shoulder joint as a zero point.

Since Neither Fisher et al. (1963), Gall (1967) (cited by Bergsten, 1974), nor Mordohovich (1971) specified their zero points, it is difficult to compare results, They obtained mean values of 46, 49 and 36 mm Hg, respectively, for right ventricular peak systolic pressure and 1,14 and 22,8 mm Hg, respectively, for end-diastolic pressure. The rather widely different values for right ventricular pressures reported by various authors suggest that the apparatus and techniques employed require more exact standardization than is presently the case. In the present investigation, values lie towards the lower limit of the reported ranges for peak systolic pressure and towards the upper limit of the reported ranges for end-diastolic pressure.

The present studies showed the mean ventricular peak systolic pressure and the mean ventricular minimum diastolic pressure of the COPD subjects were significantly higher than those of normal subjects, a result which confirmed the findings of Bergsten (1974) and Dixon (1978).

Right atrial pressure

The 'a' and 'c' waves of the right atrial pressure curve were clearly defined in all the recordings obtained. These waves presumably coincide with atrial systole and the onset of ventricular systole, respectively, as in human cardiology (Guyton, 1971). Bulging of the A-V valves into the atria as well as the pull exerted by the ventricular myocardium are considered to be factors responsible for the 'c' wave (Guyton, 1971). The 'v' wave of the human atrial pressure curve was not clearly defined in the present se ies of recordings, and consequently it was not measured.

Mean values for the 'a' and 'c' waves of the normal subjects were 15,3 and 11,7 mm Hg, respectively. These figures correspond fairly closely to the values recorded by Beltran (1973) and by Brown & Holmes (1978). In man, the 'a' wave has a range of 2–14 mm Hg, according to Altmann & Dittmer (1971).

• No significant differences in these parameters were observed in the COPD subjects investigated. However, the mean values were slightly higher for each measurement than the corresponding mean values for normal subjects. This suggests that the systemic circulation was beginning to exhibit the effects of pulmonary hypertension. These effects, which have been summarized by Guyton (1971), result in shifts of blood from the pulmonary circulation to the systemic circulation, and thus cause systemic congestion.

REFERENCES

ALTMANN, P. L. & DITTMER, D. S., 1970. Respiration and circulation, p. 316. Bethesda, Maryland: Federation of American Societies for Experimental Biology.
AMEND, J. F., GARNER, H. E., ROSBOROUGH, J. P. & HOFF, R. E., 1975. Hemodynamic studies in conscious domestic ponies. Journal of Surgical Research, 19, 107–113.
BELTRAN, L. E., 1973. A critical evaluation of right heart catheterisation in the horse. Ph.D. Thesis, London.
BERGLUND, E., 1968. The pathophysiology of chronic respiratory failure. Scandinavian Journal of Respiratory Diseases, Supplement, 72, 14–18.
BERGSTEN, G., 1974. Blood pressure, cardiac output, and blood gas tensions in the horse at rest and during exercise. Acta Veterinaria Scandinavica, Supplement 48, Stockholm.
BERNARD, C., 1876. Leçons sur le chaleur animale. Paris: Bailliére.
BROWN, C. M., 1977. A micromanometer study of intracardiac pressures in the horse. Ph.D. Thesis, Bristol.
BROWN, C. M. & HOLMES, J. R., 1978. Haemodynamics in the horse: 1. Pressure pulse contours. Equine Veterinary Journal, 10, 188–194.
DIXON, P. M., 1978. Pulmonary artery pressures in normal horses and in horses affected with chronic obstructive pulmonary disease. Equine Veterinary Journal, 10, 195–198.
EBERLY, V. E., TYLER, W. S. & GILLESPIE, J. R., 1964. Cardiovascular parameters in the Thoroughbred horse. American Journal of Veterinary Research, 25, 1712–1716.
EBERLY, V. E., TYLER, W. S. & GILLESPIE, J. R., 1966. Cardiovascular parameters in emphysematous and control horses. Journal of Applied Physiology, 21, 883–889.
ETTINGER, S. J. & SUTER, P. F., 1970. Canine cardiology. Philadelphia: W. B. Saunders.
FISHER, E. W., DETWEILER, D. K. & PATERSON, D. F., 1963. Equine medicine and surgery, 1st Edition, p. 367. California: American Veterinary Publications, Inc.
FISHMAN, A. P., FRITTS, H. W. J. & COURNAND, A., 1960. Effects of acute hypoxia and exercise on the pulmonary circulation. Circulation, 22, 204–215.
FORSSMAN, W., 1929. Die Sondierung des rechten Herzens. Klinische Wochenschrift, 8, 2085–2087.
GABEL, A. A., HAMLIN, R. & SMITH, C. R., 1964. Effects of promazine and chloral hydrate on the cardiovascular system of the horse. American Journal of Veterinary Research, 25, 1151,1158.
GEDDES, L. A., McCRADY, J. D. & HOFF, H. E., 1965. The contributions of the horse to knowledge of the heart and circulation. II. Cardiac catheterization and ventricular dynamics. Connecticut Medicine, 29, 864–874.
GILLESPIE, J. R. & TYLER, W. S., 1969. Chronic alveolar emphysema in the horse. Advances in Veterinary Science, 13, 59–99.
GUYTON, A. C., 1971. Textbook of medical physiology, 4th ed. Philadelphia: W. B. Saunders.
HOLMES, J. R. & ELSE, R. W., 1972. Further studies on a new lead system for equine electrocardiography. Equine Veterinary Journal, 4, 81–88.
LITTLEJOHN, A., 1978. Studies on the physiopathology of chronic obstructive pulmonary disease in the horse. D.V.Sc. Thesis, University of Pretoria.
LLOYD, T. C., 1965. Effect of alveolar hypoxia on pulmonary vascular resistance. Journal of Applied Physiology, 19, 1086–1093.
MORDOHOVICH, D., 1971. Untersuchungen uber die Herzdynamik bei Pferd, Rind und Schwein. Inaugural Dissertation, Zurich.
ROSS, D. N., 1962. A surgeon's guide to cardiac diagnosis. Part 1. The diagnostic approach, p. 60. Berlin: Springer Verlag.
SALUTINI, E., 1959. Cuore pulmonare cronico e bolsaggine. Nuova Veterinaria, 35, 101–104.
SPÖRRI, H., 1962. The study of cardiac dynamics and its clinical significance. Advances in Veterinary Science, 7, 1–41.
SPÖRRI, H. & SCHLATTER, C., 1959. Blutdruk-erhohungen im Lungenkreislauf. Schweizer Archiv für Tierheilkunde, 101, 525–541.
WHITE, P. D., 1951. Heart disease, pp. 499–516. New York: MacMillan.