 Canad. Med. Ass. J.
Aug. 27, 1966, vol. 95

Radio Telemetry of the Electrocardiogram, Fitness Tests, and Oxygen Uptake of Water-Polo Players

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During competitive water polo, heart rate in six subjects was monitored by cupped plastic and silver electrodes glued to the skin. Minimum rates during the game averaged 156 beats/min.; maximum rates averaged 186 beats/min. Mean maximum rate with bicycle exercise was 188 beats/min. Maximum oxygen (VO_2 max.) with bicycle exercise of 14 water-polo players was 53.3 ml./kg. Physical working capacity (PWC 170) was 1310 kilopond metres per square metre (k.p.m./sq. m.). PWC 170 correlated well with VO_2 max. in this small group ($r = 0.77$).

Oxygen uptake was measured at three speeds of swimming and four levels of work on a bicycle ergometer. VO_2 max. of swimming was 88% of that obtained on bicycle exercise. The slope of the oxygen uptake vs. pulse rate curves was less for the swimming than for cycling, so that for a given oxygen uptake below the maximal, pulse rate was less in the swimmers. At near-maximal swimming, respiratory quotient was 0.95 compared with 1.27 for cycling, suggesting that the swimmers were underbreathing.

Chez six joueurs de polo aquatique participant à un match, on a étudié à distance le rythme cardiaque au moyen d'électrodes de plastique et d'argent en forme de cupule et collées à la peau. Le rythme minimum pendant le match a été en moyenne de 156 battements/min., le maximum de 186 battements/min. Au cours d'un exercice sur bicyclette, le rythme moyen maximum était de 188 battements/min. La fixation maximum d'oxygène (VO_2 max.) pendant un exercice à bicyclette de 14 joueurs de polo aquatique a été de 53.3 ml./kg. La capacité de travail physique (CTP 170) a été de 1310 k.p.m./m. carré. La CTP de 170 correspondait bien à la VO_2 max. parmi ce petit groupe ($r = 0.77$).

La fixation d'oxygène a été mesurée à trois vitesses de nage et à quatre vitesses en vélo par un ergomètre de bicyclette. La VO_2 max. de nage a été de 88% de celle obtenue au cours de l'exercise sur bicyclette. La pente de la fixation d'oxygène par rapport à la courbe du pouls a été moindre pour la nage que pour l'exercice à bicyclette, de sorte que pour une fixation d'oxygène donnée inférieure au maximum, le pouls était moindre chez les nageurs. A la vitesse de nage proche du maximum, le quotient respiratoire a été de 0.95, contre 1.27 pour le cyclisme, ce qui laisse supposer que les nageurs avaient une respiration déficiente.

ELECTRONIC advances have made it possible to transmit various physiologic parameters by means of radio signals and receive these at remote points. One common application of this is the monitoring of heart rate from the telemetered electrocardiogram during various forms of physical activity. The size and weight of the radio transmitters now available permit participation in various athletic events with very little hindrance from the apparatus itself.

The telemetry of heart rate has implications beyond knowledge of heart rate alone. With bicycle exercise, the pulse rate increases in a linear fashion with increases in the intensity of the exercise load, as does the oxygen uptake. This is also true for treadmill exercise.

Knowing the oxygen uptake *versus* pulse rate relationship from bicycle exercise, it has been postulated that the oxygen demand of a given exercise can be inferred from the pulse rate alone. This postulate assumes that, because pulse rate and oxygen uptake bear a constant relationship to the workload for bicycle or treadmill exercise, the same will hold true for other types of exercise. The present report deals with radio telemetry of heart rate in water-polo players, showing how heart rate can be monitored underwater without special attire; and introduces the problem of pulse rate *versus* oxygen consumption relationships in the swimmer. Maximal and submaximal working capacity tests were also obtained in water-polo participants as a measure of their cardiorespiratory fitness.

METHODS

The standard Telemedics radio electrocardiographic transmitter and receiver was used. The bandage-type electrodes supplied with this equipment were not suitable for underwater use. We used silver electrodes 1.0 cm. in diameter, placed in small plastic cups so that the skin-to-electrode contact was entirely dependent on conduction through the electrode jelly. The cups were glued to skin, prepared by scuffing and rubbing with alcohol, with Eastman 910 adhesive. After placing the electrode on the skin, the electrode site was sprayed with a surgical adherent to add to the waterproofing effect of the glued cup electrode itself. No electrode positions will eliminate the muscle artifact of all types of swimming. We have tried four positions: both mid-axillary lines in the sixth interspace; mid-sternum to mid-back; medial end of the right clavicle to the V_5 or V_6 position; and manubrium sterni to xiphisternum. The latter was the best for the majority of swimmers (Fig. 1).

We placed the radio transmitter in a clear plastic box. A plastic or rubber bag would probably be less cumbersome, but the clear box had the advantage of allowing early detection of any leaks. None of the swimmers complained of the added weight or size.

The radio and electrodes were put in place before game time and the player was advised to go out

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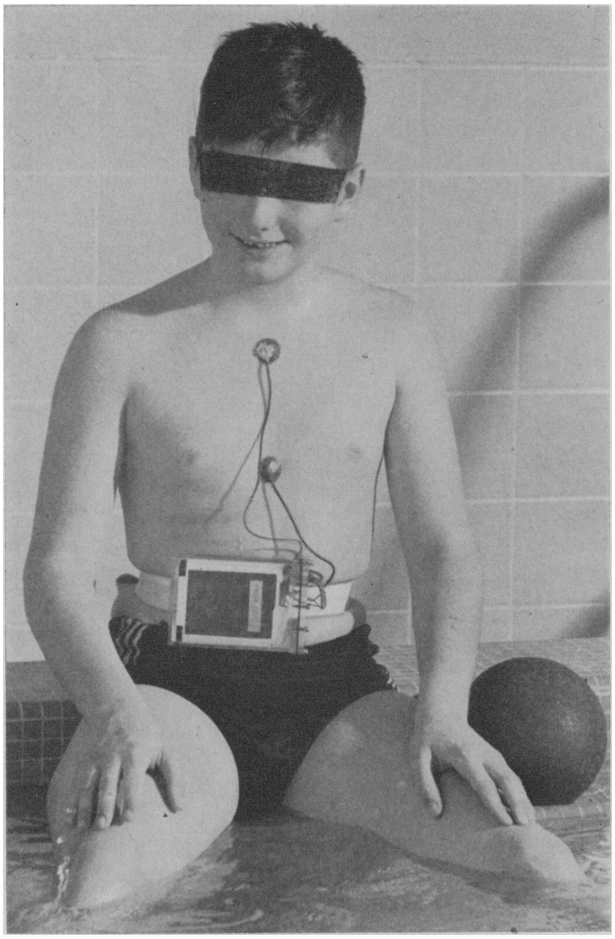

Fig. 1.—Radio transmitter in clear plastic case with belt around waist. Electrodes in position on chest.

and play his normal game. The electrodes were ripped off during the game in two out of eight tests. Electrocardiographic tracings were obtained frequently during the game and at rest periods, and heart rate was obtained by measuring the interval between five beats. No transmitting antenna was required even with the subject totally underwater.

The physical working capacity at a pulse rate of 170 beats/min. (PWC 170) measured in kilopond metres per minute (k.p.m./min.) was determined on an electronically braked bicycle ergometer by methods previously described[1, 2] in 14 water-polo players. The workload was then increased to an intensity such that the subject could barely continue the cycling for an additional three minutes. Expired air was collected from the second to the third minute of this maximal exercise for the determination of maximal oxygen uptake. The collected air was analyzed for oxygen using the Beckman paramagnetic oxygen analyzer and for CO_2 using the same instrument.[3] Gas volume was measured with a dry test meter.

Oxygen uptake *versus* pulse rate and workload curves during bicycle exercise was obtained in five of the above subjects on a separate day. Each subject cycled for five minutes at four different loads of increasing severity, and expired air was collected from the fourth to the fifth minute for oxygen uptake measurements. Pulse rates during this study were obtained from an electrocardiogram.

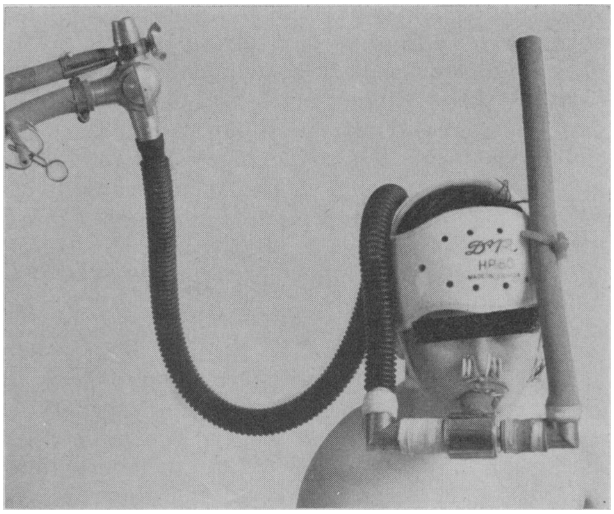

Fig. 2.—Hockey helmet to support air intake and outlet hoses.

Oxygen uptake was also measured in these five water-polo players by collecting expired air during swimming. A "snorkel" was connected to the intake of a two-way air valve (Fig. 2), the subject's nose

Fig. 3.—Air collection in Douglas bag during swimming.

was clamped, and expired air was collected from the outflow side of the two-way valve in a Douglas bag by going along with the swimmer at pool side (Fig. 3). The swimmer performed at three speeds, slow, medium and near maximum. Pulse rates were monitored during this swimming by the previously described radio technique. The swimmers travelled 50 yards with the mouth piece in and nose clamped before air was collected and 50 yards (or less if unable) for the air collection.

RESULTS

Successful radio telemetric studies were obtained in six of eight players tested during competitive regular league water-polo games. The pulse rates during the various situations of the game are given in Table I. Water polo was played in a 25-yard pool with a deep and shallow end with four five-minute periods and a two-minute break between periods. No attempt was made to have the player at complete rest just before the game as the anticipative tachycardia from the sport itself, plus an unavoidable excitement from wearing the radio, could not be eliminated.

TABLE I.—PULSE RATES DURING WATER-POLO GAME

Subjects	Pulse rates—beats/min. 1	2	3	4	5	6	Means
Situation:							
1. Resting before game......	127	83	121	117	99	109	109
2. End rest period between periods..............	159	156	175	173	170	—	167
3. Initial sprint to centre....	172	156	167	171	168	188	170
4. Potential score play......	181	188	179	177	183	188	183
5. Offensive ball handling....	179	193	175	181	194	193	186
6. Defensive pursuit........	181	175	170	175	193	191	181
7. Cruising on offence.......	175	192	181	177	194	156	179
8. Cruising on defence......	179	181	170	175	177	181	177
9. Shallow-end pause........	168	166	—	168	170	164	167
10. End of game............	140	191	179	166	179	—	171
11. Resting rate in laboratory.	66	91	84	84	72	82	80
12. Morning rate at home....	47	71	57	58	48	52	56
13. Maximal rate bicycle ergometer............	193	194	186	186	183	186	188

The maximal pulse rates of 180 to 195/min. were usually obtained during actual scoring or potential scoring plays on offence where the player would be expected to be going all-out, as well as during key defensive plays. The rate during defensive plays tended to be slightly less than for offensive plays, suggesting that most players did not go all-out on defence. However, throughout the entire game, pulse rates remained above 150/min. Even at times of relative inactivity, such as remaining in position in the shallow end resting the feet on the bottom, the pulse rates were over 160/min. At the end of the rest period between periods, pulse rates ranged from 156 to 170 with a mean of 167 beats/min., still far above the pre-game mean of 109 beats/min. Two minutes of recovery was really no better than a slack period in the middle of the game in allowing pulse rate to return towards normal.

It is noted that during the initial sprint to the centre of the pool mean pulse rate increased from 109 beats/min. just before to 170 beats/min. in the period of eight to 15 seconds. This rapid mobilization of cardiac reserve is typical of the trained athlete. The mean maximal heart rates for water polo and for bicycle exercise was similar, 186 and 188 beats/min., respectively.

Mean pulse rate immediately after the contest was still above 170 beats/min.

Mean morning minute pulse rate, taken by the subject at home shortly after arising, was 56 (range: 47 to 71), the slow resting rates being in keeping with the above-average fitness of the subjects. Mean resting heart rate in the laboratory after a 20-minute rest was 34 beats/min. greater than the resting rate at home. The mean resting rate just before the start of water polo competition was 29 beats/min. greater than the resting rate in the laboratory and 53 beats/min. greater than the early morning rate at home.

The maximal oxygen uptake and physical working capacity at a pulse rate of 170 of the 14 water-polo players are given in Table II. The maximal oxygen uptake is the best measure of overall fitness available, although there is not complete agreement on how best to express this value. A common method is to give the maximal oxygen uptake in ml./kg. body weight, but the swimmer, who may be more fleshy than the runner, is perhaps unfairly penalized by using weight.

TABLE II.—WORKING CAPACITY AND MAXIMUM OXYGEN UPTAKE OF WATER-POLO PLAYERS

Subject No.	*Age (years)*	*Height (cm.)*	*Weight (kg.)*	*PWC 170 (k.p.m./min.)*	*VO_2 max. l./min.*	*ml./kg.*	*l./min. (standard temp. and pressure) max. vent.*	*Maximum respiratory quotient*	*Maximum pulse rate beats/min.*
1	25	173	66	1270	3.32	50.0	120.9	1.24	193
2	28	183	82	1230	3.74	45.6	137.4	1.22	194
3	23	180	75	1110	3.47	46.3	126.4	1.22	186
4	19	180	76	1380	4.74	62.4	143.8	1.30	186
5	19	180	75	1422	4.54	60.6	156.3	1.33	183
6	26	183	70	1219	4.04	52.7	136.7	1.33	186
7	26	173	93	1570	4.35	46.7	117.8	1.47	186
8	22	185	95	1365	4.66	49.1	135.8	1.28	190
9	19	180	71	1185	3.82	53.7	146.3	1.25	195
10	35	180	80	1390	4.16	52.0	116.2	1.25	181
11	23	185	69	1322	4.46	64.6	143.1	1.08	195
12	25	178	68	1069	3.50	51.5	136.8	1.32	191
13	37	190	91	1615	4.56	50.2	154.9	1.37	183
14	18	175	61	1191	3.74	60.8	120.1	1.15	196
Mean.................	25	180	76	1310	4.07	53.3	135.1	1.27	189

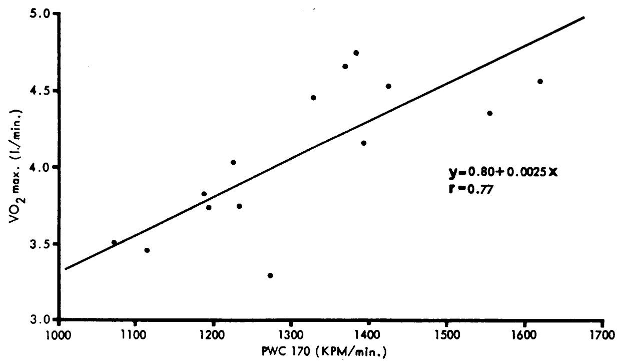

Fig. 4.—Maximum oxygen uptake *vs.* physical working capacity at a pulse rate of 170 beats/min. (PWC 170). Calculated straight line relationship. Work load is expressed in kilopond metres per minute (k.p.m./min.).

The maximal oxygen uptake of these amateur athletes compares favourably with those of fairly well-trained men in other sports—values of over 50 ml./kg. being quite acceptable. Some of the subjects, particularly those who were a little overweight, had maximal oxygen uptake values below this figure. Four subjects were above 60 ml./kg. and four were below 50 ml./kg. The two oldest subjects tested (aged 35 and 37 years) both had maximum oxygen uptakes over 50 ml./kg., and both had maximal pulse rates within the same range as the younger subjects.

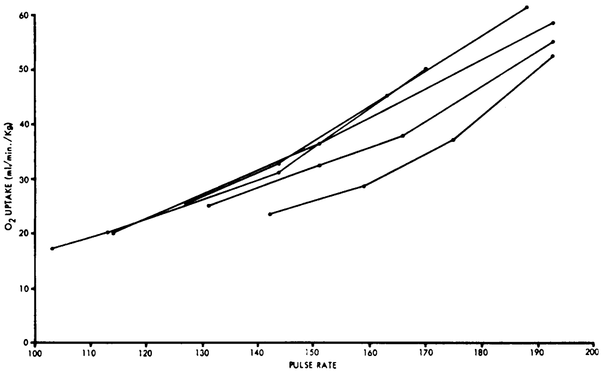

Fig. 5.—Oxygen uptake *vs.* pulse rate for bicycle exercise, five subjects; nearly straight line relationship.

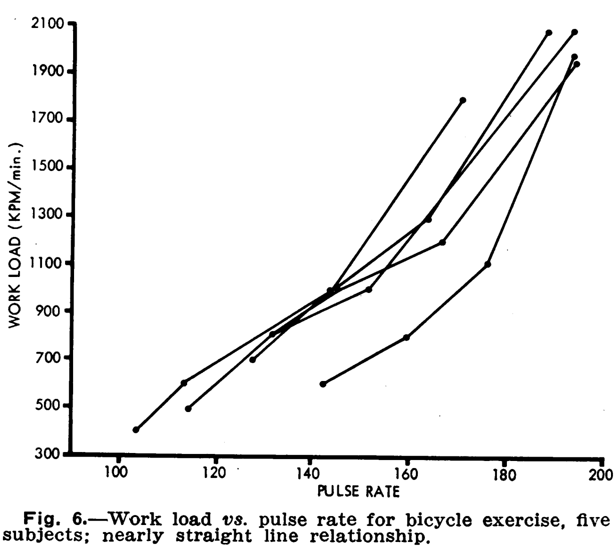

Fig. 6.—Work load *vs.* pulse rate for bicycle exercise, five subjects; nearly straight line relationship.

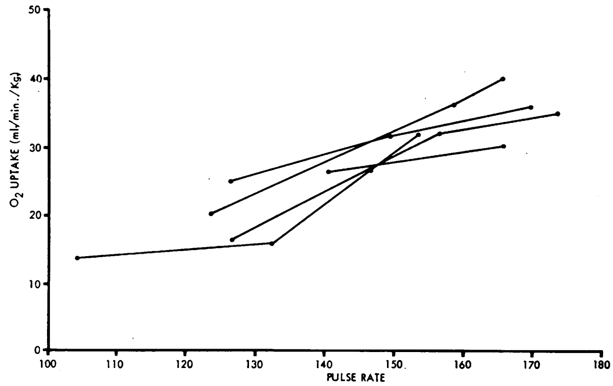

Fig. 7.—Oxygen uptake *vs.* pulse rate for swimming, five subjects.

The relationship between maximal oxygen uptake and PWC 170 is shown in Fig. 4. The correlation coefficient value (r) was 0.77. This high correlation of PWC 170 to maximal oxygen uptake in a select group of athletes where the differences between individuals were small is similar to that obtained in a large group of over 500 school children.[4]

Five subjects underwent the extra tests of oxygen uptake to pulse rate relationships with bicycle exercise and swimming. The results of the bicycle test are shown graphically in Figs. 5 and 6. There is an almost linear relationship between oxygen uptake and workload, and between oxygen uptake and pulse rate.

The oxygen uptake/pulse rate relationships during swimming for each of the five subjects are plotted in Fig. 7. A straight line relationship was present between these two variables in four of the five subjects. The mean peak pulse rates were 187

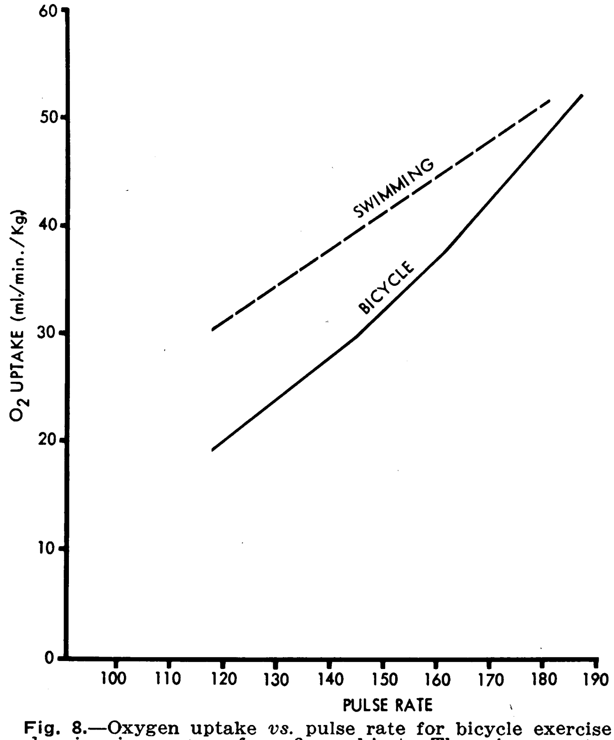

Fig. 8.—Oxygen uptake *vs.* pulse rate for bicycle exercise and swimming—means from five subjects. There is a greater oxygen uptake for a given pulse rate with swimming.

for bicycle exercise and 175 for swimming. The mean peak oxygen uptakes were 56.4 ml./kg. for bicycle work and 49.7 ml./kg. for swimming. Because of technical difficulties of air collection, an absolutely maximal effort was not possible with swimming.

Astrand *et al.*[5] were able to get maximal oxygen uptakes in girls during swimming almost equal to their uptakes with cycling, and we plan to modify our air-collecting apparatus.

DISCUSSION

The mean oxygen uptake/pulse rate ratios, calculated from the above data, are plotted against pulse rate for both the swimming and bicycle exercise in Fig. 8.

It is seen that at lower pulse rates more oxygen is used during swimming. The oxygen/pulse ratio at the slower swimming speeds is greater than that for bicycle exercise.

Our subjects were experienced swimmers, but the breathing apparatus and test procedure were just as new to them as the bicycle exercise, so that the emotional factors should have been similar in the two tests. Why then was swimming associated with a relatively lower pulse rate for a given oxygen uptake?

Factors considered were supine *versus* upright exercise; a smaller breathing valve with a longer connecting tube; during swimming "weightlessness" produced by water submersion; temperature effects of water; leg *versus* arm plus leg exercise; differences in blood gases; rate and depth of breathing. Another major difference in methodology was that measurements were made after four minutes at each load for cycling, compared to 60 to 120 seconds with each load for swimming. Further investigations are required in this area.

Goff *et al.*[6] and Tuttle and Templin[7] have studied the change in "resting" pulse rate occurring with immersion in water of varying temperatures. In most subjects submerged in water of swimming pool temperature, resting pulse rate declined 10 beats/min. Exercise rates were not obtained. Scholander has studied the heart rate response in diving seals and in man. In the seal, submersion of the nose alone causes a marked and abrupt reflex bradycardia. Cardiac slowing occurs more gradually in man and may be related to changes in blood gases. The relationship of the cardiac slowing under diving conditions to the increased oxygen/pulse ratio of swimming is not clear. Theoretically, cardiac slowing allows more efficient cardiac action with longer diastolic recovery time, which may be an important consideration in reconditioning programs in cardiac patients.

The high pulse rates obtained during competitive water polo reveal that this sport demands from 75 to 100% of maximal effort from the players throughout the game. When it is considered that the oxygen uptake studies during swimming revealed relatively low pulse rates except at near-peak swimming efforts, the rapid heart rates observed during the water polo are indicative of near-maximal metabolic demands.

Sports medicine is looking more and more into physiologic functions in athletes during training and during actual competitive events, and the field of sports medicine is no longer limited to athletic injuries. The elements of suspense and surprise can never be taken away from athletic competition, but the training of athletes is losing its aura of mystery. Development of techniques to measure accurately the physiologic demands of athletic events will help in the development of new methods of athletic training, and in the assessment of conditioning programs.

SUMMARY

A method for monitoring heart rate during water polo has been developed. During the game, rate is seldom below 150 beats/min., often above 170 beats/min. A comparison of bicycle exercise and swimming showed that there was a difference in the slope of the heart-rate oxygen-uptake curves. There was a slower heart rate for a given oxygen consumption during swimming.

We are indebted to the water-polo players who participated in this work and the Manitoba Water Polo Association for their fullest co-operation. Help with the apparatus was obtained from Mr. Walter Jones of the University of Manitoba and the Maintenance Department, Winnipeg Children's Hospital. We are also indebted to the Physical Education Department, University of Manitoba, for the use of their pool facilities.

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PAGES OUT OF THE PAST: FROM THE JOURNAL OF FIFTY YEARS AGO

PROVINCIAL NEWS

Maritime Provinces.—Seven hundred and ninety-nine patients were admitted to the Moncton General Hospital during the year ending May 31, 1916—559 private patients and 240 public patients. The number of patients discharged cured was 629, those improved 47, not improved 19, incurable 10. Seventeen patients were not treated and 45 died.

Ontario.—The following cases of communicable disease were reported in the province during the month of June: smallpox, 44 cases; scarlet fever, 121 cases, 2 deaths; diphtheria, 165 cases, 17 deaths; measles, 2039 cases, 14 deaths; whooping cough, 135 cases, 7 deaths; typhoid fever, 35 cases, 7 deaths; tuberculosis, 153 cases, 86 deaths; infantile paralysis, 2 cases, 1 death; cerebro-spinal meningitis, 11 cases, 9 deaths.

British Columbia.—The new Kootenay Lake General Hospital, Nelson, is to be commenced at once.—News, *Canad. Med. Ass. J.*, 6: 745, 1916.