A preliminary report on predicted urine production and food ingestion rate and salt balance of the common minke whale (Balaenoptera acutorostrata) off Iceland.

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Abstract

In August and September 2003 blood and urine samples were obtained from 30 common minke whales (*Balaenoptera acutorostrata*) caught off the coast of Iceland for scientific purposes. Both blood and urine samples were obtained from 16 of these animals, 4 nonpregnant females and 12 males. The animals weight was derived from their length, which gave a mean weight (standard deviation) of 4571 kg (1337). Na^+, K^+, Cl^-, Mg^{++}, Ca^{++}, creatinine, urea, and uric acid were measured in blood and urine as well as pH and osmolality. Utilizing allometry of creatinine clearance in relation to body weight and the serum and urinary concentrations of creatinine the average urine volume was predicted to be 214 L/day. From this volume and the known water content of the ingested food the average daily food ingestion was estimated to be about 280 L. This is considerably greater volume than reported earlier by most workers. Energy calculations suggest considerable heat loss as the metabolic rate is over three times that of an equally heavy terrestrial mammal. Concentrations of electrolytes in urine are compatible with the fact that the minke whale is a piscivorous animal and are quite different from those of the krill eating fin whale. The high sodium and magnesium levels in urine suggest some sea water ingestion.

Key words: Osmoregulation, urinary salt concentration, creatinine, creatinine clearance, euryphagous, piscivorous, feeding rate

Introduction

The North Atlantic minke whale (common minke whale; *Balaenoptera acutorostrata*) is a euryphagous animal, feeding on zooplankton (krill) as well as several species of fish (Haug et al 1995). It is also the most abundant baleen whale off the Icelandic coast with estimated number of 56.000 individuals according to a recent estimate (NAMMCO 1998). Man has exploited minke whales commercially as well as most of the species of fish which it preys upon, such as herring (Clupea harengus), capelin (Mallotus villosus), cod (Gadus morhua), haddock (Melanogrammus aeglefinus) and saithe (Pollachius virens) (Jonsgård 1982, Haug et al 1995, Nordoy et al. 1995, Sigurjónsson et al. 2000). To assess interspecies reactions and the ecological changes produced by man's exploitation of one of the top predators of fish, the minke whale, it is of great importance to know the average quantity of fish taken by individual minke whales per unit of time. No satisfactory methods have been available to predict the daily feeding rates of the big baleen whales.

A recent paper (Kjeld 2003) described a method that appears to approximately predict the food ingestion of two baleen whales, the fin (Balaenoptera physalus) and the sei (Balaenoptera borealis) whales. The method is based on the allometry of creatinine clearance (Ccr) related to weight and the measurement of serum and urinary concentrations of creatinine in the species. By inserting these values and the average weight of the whales into the general clearance equation of creatinine the urine volume is found. If it is known what food the animals are eating and its water content, the quantity of food ingested can be predicted. In this paper the above method has been applied to the common minke whale species caught in coastal waters around Iceland.

Also, since the common minke whale is a piscivorous animal and its food very different from the stenophagous, krill eating fin whale it was of interest to measure some electrolytes in blood and urine to compare them in the two species.

Materials and Methods

Whales and samples

As a part of a scientific program the minke whales were caught all around the coast of Iceland in August to September 2003. Samples from thirty animals (19 males, 11 females) were available but only 16 of them (12 males, 4 females) had both blood and urine samples. Blood samples were collected from the jugular vein immediately after the animal had been taken aboard the whaling boat some 25 min after the killing. The blood sample was spun down aboard the boat and the serum collected and kept frozen in plastic tubes at -20°C until measured 4 months later. Specimens with gross hemolysis or high Mg^{++} concentration (> 4.0mmol/L, sea contamination) were discarded. Urine specimens were obtained by puncturing the urinary bladder with a 19 G needle and aspirating the sample into plastic syringes which were then kept in universal polystyrene containers at -20°C until measured. The weight (W; kg) of the common minke whales was derived from their length (L; m) by the equation $W = 8.148 \times L^{3.163}$ (Lydersen et al. 1991, Folkow and Blix 1992).
The ingested food of the present whales' stomach has not been analyzed yet, so we made use of results from other reports on the type of food of the common minke whale off Norway and Iceland (Nordøy et al. 1995, Hauge et al. 1995,

Sigurjónssonand Víkingsson 1997, Sigurjónsson et al. 2000). As seen in Table 1, on which values we have based our calculations, there is a considerable variation in the water and energy content of the whole body of the different species that the minke whale preys on (Steimle and Terranova 1985, Nordoy et al. 1995).

Analytical methods

The measurements of the electrolytes and other constituents were measured by standard methods in laboratory medicine and have been described recently (Kjeld 2001). Briefly, sodium and potassium were measured by flame photometry, chloride by an electrometrical chloride meter, magnesium by atomic absorption. By continuous flow methods urea was measured by the diacetyl monoxime reaction, creatinine by the Jaffe (alkaline picrate) method, calcium by the o-cresolphthalein complexone complexometry and uric acid by enzymatic method (Boehringer Mannheim, Germany). Osmolality was assayed by freezing point decrease (micro osmometer, Advanced Instruments Inc., Norwood, Mass., U.S.A.).

Allometry and creatinine clearance

The allometric equation relating creatinine clearance and body weight (Ccr) used here has recently been described (Kjeld 2003). The equation (Ccr, ml/min = $4.458W^{0.815}$) was based on 50 mostly recent papers on endogenous creatinine clearance in mammals. The specific Ccr (Ccr, ml/min/kg) derived for the minke whale is then used in the equation for renal endogenous Ccr:

$$\text{renal endogenous Ccr, ml/min/kg} = \frac{UV \bullet UC}{PC \bullet t \bullet W} \qquad [1]$$

where UV is urine volume (ml) during the collection period, UC is urinary creatinine concentration, PC is plasma creatinine concentration (same units as for UC), t is collection period (min) and W is the body weight (kg) of the animal(s) under study.

Statistics

Student's t test was used for comparing groups by their means. The level of significance was set at 0.05. Allometry (scaling) equations were used for prediction by interpolating (predicting weight from length) and extrapolating (predicting Ccr from weight).

Results

Male (12) and female (4) minke whales used in the allometry (assays on both serum and urine) were of similar length and consequently of similar weight. All the male animals were sexually mature except one but three of the females were sexually immature and one probably mature but not pregnant. The mean weight, obtained from the length by the equation given in the Materials and Methods chapter, of the16 animals from which both serum and urine samples were analyzed, was 4571.3 kg (Table 2).

This mean weight (4571 kg) was then used for insertion into the allometric formula, Ccr, ml/min = $4.458W^{0.815}$. A graph of Ccr values of a broad range of terrestrial mammals plotted on a log-log scale against their respective body weights is shown in

Fig. 1. This figure is taken from a paper by Kjeld (2003), showing the extrapolated Ccr values for the fin and sei whales, but has been modified by adding to it the extrapolated Ccr of the minke whale. This gives a predicted Ccr of 4297 ml/min for the 4571.3 kg average minke whale weight or a specific Ccr of 0.940 ml/min/kg. Inserting this and the serum and urinary creatinine concentrations from Table 3 and Table 4 into the Ccr equation [1], a urine volume of 214 L per 24 hr is obtained for our present average minke whale.

The average water content of the food of the euryphagous minke whale varies depending on what type of food it eats (Table 1). In Table 5 two volumes of daily food ingestion have been calculated from the predicted urinary volume, one (A) with equal parts of cod, haddock, saithe and sandeel giving 285 L volume and the second (B) with 60% fish (as in A) and 40% krill giving 275 L volume ingested. These quantities will be slightly larger if the loss of water in feces is accounted for. The whales' fecal volume is not known. Carnivores, however, produce much less fecal volume than herbivores (2.0 – 2.5% of body mass). If the fecal volume of the minke whale is put at 0.4% of the body weight with a moisture content of 50%, the added ingestion volume would be about 11 L. This indicates an average feeding rate for the minke whale of approximately 280 kg per day when feeding as suggested in Table 5.

With predicted ingestion volumes and an approximate knowledge of the combination of the food the energy balance of the average minke whale can be calculated. This is shown in Table 5 where the two combinations of food, volumes A and B above, are converted into energy and two assumptions made, i. e. that the assimilation of the food is about 80 % and that the average fat deposition is 15 kg per day. For comparison a standard metabolic rate (SMR) for a terrestrial mammal of equal size as the present average minke whale (4571 kg) has been derived by Kleiber's allometry equation on metabolic rate (MR; Kleiber 1975), kcal/day = $68W^{0.756}$.

The mean serum concentrations of the electrolytes and the nitrogenous constituents, urea, creatinine and uric acid, together with their variations are shown in Table 3. The serum levels of the fin whale (Kjeld 2001) have been inserted in parentheses after the mean values for comparison. The mean urinary concentrations of the electrolytes and the other constituents and their variation indices are shown in Table 4. Again the respective concentrations of the fin whales are inserted in parentheses for comparison. The CVs of the urinary values are higher than those of the serum indicating the added variability of the urine production.

Discussion

Do to circumstances at sea there were only 12 males and only 4 females in the group of animals that had both blood and urine specimens taken. Their mean lengths and weights were not significantly different (Table 1), and neither were any of the serum parameters (Fig 2) in the two sexes, even when all the animals with acceptable specimens (15males and 11 females) were included (results not shown).

The use of postmortem serum specimens has been discussed in a recent paper (Kjeld 2001) and of the constituents measured here only the potassium levels changed (increased) rapidly after death (~ 75%/h). The levels of serum potassium (7.3

mmol/L, Table 2) could therefore have been overestimated in this study by about 15 – 20% which would mean that the levels were similar to those found in the fin whales (Kjeld 2001) but lower than those reported earlier for minke whales (Tryland and Brun 2001) and bowhead whales (*Balaena mysticetus*) (Heidel et al. 1996) of 8.2 and 9.3 mmol/L, respectively.

The other serum results of the minke whale in Table 2 were similar to levels reported by the above authors except for low uric acid levels in the fin whale already discussed (Kjeld 2001) and calcium and creatinine levels agreeing well for the two minke whale studies but lower than those in the bowhead whale. Serum creatinine levels vary in different animals which are probably related to their muscle mass. Calcium levels, however, would be expected to be similar in related mammals because of their fundamental physiological importance both inside and outside the cells.

The results of this paper highlight two major points. Firstly, the common minke whale (Balaenoptera acutorostrata) is predicted by a study of its water balance to ingest about 2.5 times more food during the feeding season than most of the earlier estimates predicted (Sergeant 1969, Nordoy et al. 1995, Sigurjónsson and Víkingsson 1997). Secondly, as seen in Table 3 the concentrations of electrolytes in the minke whale's urine are quite different from those of the fin whale (Kjeld 2001), thus reflecting a totally different type of food ingested by the two species.

Several studies on the common minke whale have assumed the daily ingestion rate to be around 100 kg (Sergeant 1969, Nordoy 1995, Sigurjónsson and Víkingsson 1997) but others have stressed the view that the metabolic rate (MR), and therefore the food ingestion rate, is a matter of circumstances such as the heat loss to the environment and the daily activity. Most of the MRs reported for cetaceans and otariid seals are not obtained under basal (Kleiber 1975) conditions and have been up to two to three times higher than in terrestrial mammals (Lavigne et al. 1986, Innes et al. 1987, Hinga 1979). Armstrong and Siegfried (1991) studied several possible ingestion rates in Antarctic minke whales (*Balaenoptera bonaerensis*) caught by Japanese whalers. These animals were 1.7 times heavier than those presented in this study. When their calculations were based on respiratory data by Folkow and Blix (1992) of the common minke whale together with assumptions such as 30kg fattening per day, their estimated ingestion rate became similar to the one presented here. Also, if the Antarctic minke whales were assumed to fill their stomach capacity with krill (0.884% of their weight, Oshumi 1979) three times during the day, their ingestion rates seemed to be comparable to the present ones.

The present results show 3.6 and 3.1 times higher daily energy use by the minke whales than by that predicted for an equiponderate terrestrial mammal (Table 5). If, however, the heat loss through the body surface is calculated according to Brodie (1975) with a 2 cm blubber thickness and 20% added through loss in respiration the above ratios become 3.4 and 3.0, respectively. Probably the relative heat loss is greater in the minke whale, which is about 8 to 10 times smaller than the fin whale on which Brodie based his calculations. If there is for instance during feeding a significant heat loss through the big mouths of the baleen whales, then that might be proportionally greater in the smaller animals. The study of Folkow and Blix (1992) indicated an inverse relationship between heat loss and body size in the minke whales but the heat loss calculated by these authors appears too small to agree with our ingestion data. However, our energy results agree well with those reported by Hinga (1979) who based his studies mainly on the feeding rate of cetaceans in captivity in various institutions and those of Kanwisher and Sundnes (1965) who studied the common harbour porpoise (*Phocaena phocaena*).

The total amount of fat stored (fattening) during the summer feeding season is of importance in the energy budget of the minke whale and is obtained from three different reports, that of Armstrong and Sigfried (1991) and those of Nordoy et al. (1995) and Næss et al. (1998). The first assumes about 30kg fattening per day for the 1.7 times larger Antarctic minke whale and the latter two about 5 to 8 kg per day for the common minke whales of similar average size as those here presented. The 15 kg fattening per day chosen here for the energy calculations is therefore a compromise between the ones reported so far.

The concentrations of electrolytes in the minke whale's urine are quite different from those of the fin whale (Table 4) and this is in good agreement with earlier reports that the minke whale's food (Haug et al. 1995, Norday 1995, Lindstrøm et al. 1997, Sigurjónsson et al. 2000) is indeed very different from that of the habitually stenophageous, krill eating fin whale off Iceland (Víkingsson 1997). Chloride, and sodium levels in the minke whale's urine are two thirds and half those of the fin whale. Magnesium levels are one third those of the fin whale, whereas potassium levels are about 25 percent higher in the minke whale. The average concentrations of calcium, magnesium, sodium and potassium in the prey (flesh of cod and haddock; data from Agricultural Handbook no. 8, U. S. Dept. Agriculture) are 4.1 (3.0), 11 (6.0), 26 (165) and 88 (76) mmol/L. The urinary concentrations of the minke whales (Table 4) have been inserted in parenthesis after the prey values. Values for sodium are much higher in urine than in the prey and magnesium values about twice those of the prey. This probably indicates some sea ingestion. In the krill eating fin whale the sea ingestion was predicted to be about two to four per cent (Kjeld 2003). At the present the salt concentration of the whole body of the fishes preyed on is not known. Na^+ and Cl^- are mainly extracellular ions and K^+ and Mg^{++} mainly intracellular. After measuring the whole body concentrations, including all extracellular spaces in blood vessels, entrails, gills etc., such balance studies can be done.

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Table 1. Percent water content and energy density in the species* which constitute the bulk of the food eaten by the minke whales.

Species	H_2O (%)	Wet weight KJ/g	Wet weight Kcal/g
Cod (*Gadus morhua*)	78	4.2	1.01
Saithe (*Pollachius virens*)	74	5	1.20
Haddock (*Melanogrammus aeglefinus*)	78	4.5	1.08
Sandeel (*Ammotydes americanus*)	69	6.8	1.63
Capelin (*Mallotus villosus*)#		6.6	1.58
Krill (*Meganyctiphanes norvegica*)	82	3.4	0.82

*Data from Steimle and Terranova (1985) and #Nordoy et al. (1995).

Table 2. Mean length (m) and weight (kg) of the male and female minke whales of which both serum and urine chemistries were measured as well as the means for the whole group.

	Mean	SD	Range
Males (12)			
Length	7.35	0.62	5.7-8.1
Weight	4572	1049	1971-6066
Females (4)			
Length	7.21	1.4	5.3-8.4
Weight	4569	2214	1554-6832
Whole group (16)			
Length	7.3	0.81	5.3-8.4
Weight	4571.3	1337	1554-6832

Table 3. Serum electrolytes, urea, creatinine, uric acid (mmol/L), pH and osmolality in serum of minke whales. Mean serum values for fin whales (Kjeld 2001) are inserted in parenthesis for comparison.

	N*	Mean	SD	Range
Na^+	16	161.3 (164)	8.0	142-175
K^+	13	7.3 (6.1)	1.20	5.7-9.8
Cl^-	16	116.5 (121)	8.2	101-138
Mg^{++}	14	1.35(1.33)	0.69	0.87-3.6
Ca^{++}	14	2.24 (2.3)	0.22	1.9-2.6
Urea	16	24.8 (24.3)	2.74	21.4-29.9
Uric acid	16	0.11(0.03)	0.06	0.03-0.20
Creatinine	16	0.23 (0.13)	0.08	0.15-0.41
pH	16	7.23 (?)	0.33	6.6-7.7
Osmol	16	382 (364)	26.4	333-429

*Two samples inadvertently taken into K^+EDTA and one with hemolysis.

Table 4. Electrolytes (mmol/L), urea, creatinine, pH and osmolality in urine of 16 minke whales. Mean urinary values for fin whales (Kjeld 2001) are inserted in parenthesis for comparison. In the last column average seawater concentrations are shown.

	mean	SD	range	Seawater concn.*
Na^+	164.6 (303)	49.2	82-273	470
K^+	76.1 (60.9)	21.5	38-117	10
Cl^-	201.9 (306)	51.5	115-286	548
Mg^{++}	6.0 (19.4)	2.5	2.8-11.9	54
Ca^{++}	2.95 (?)	1.2	1.02-5.33	10
Urea	488 (419)	147	307-763	-
Creatinine	6.76 (4.3)	4.2	2.8-18.6	-
pH	5.6 (6.6)	.20	5.4-6.06	-
Osmol	1067 (1040)	203	740-1387	-

*Average concentrations, inserted for reference (Barnes 1954; Prosser 1973).

Table 5. Energy balance for a 4571-kg minke whale producing 214 L of urine, A: eating 285 kg/day of food consisting of fish only (even parts: cod, haddock, saithe, sandeel) and, B: eating 276 kg/day of 60% fish (as in A) and 40% krill (Meganyctiphanes norvegica).

	A kcal/day	B kcal/day
Ingested food/day, A = 285 kg, B = 276 kg	350960	329856
80% assimilation efficiency	280768	263885
Fat stored during summer, 15 kg/day	-139500	-139500
Energy used per day	141268	124385
*SMR of "4571-kg terrestrial mammal" predicted by allometry	39765	39765

*The ratio of energy per day for minke whales to that for terrestrial mammals is 3.6 for the A type of food and 3.1 for the B type.

Figure legend.

Figure 1. A modification of a graph by Kjeld (2003) is shown which depicts the plot of an allometric equation for creatinine clearance (Ccr) against body weight on a log-log scale. The equation (Ccr, ml/min = $4.458W^{0.815}$) was based on 50 recent papers on endogenous creatinine clearance in mammals. By inserting the mean weight of the present minke whales into the above equation a Ccr value is obtained and plotted as a four point star on the extrapolated (broken line) part of the regression line together with the sei (18100 kg) and the fin whale (37000 kg) as five point stars.

Figure 1.