Limitations in the Assessment of Dietary Energy Intake by Self-Report

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Development of the doubly-labeled water method has made it possible to test the validity of dietary intake instruments for the measurement of energy intake. Comparisons of measured energy expenditure with energy intake from either weighed or estimated dietary records against energy expenditure have indicated that obese subjects, female endurance athletes, and adolescents underestimate habitual and actual energy intake. Individual underestimates of 50% are not uncommon. Even in non-obese adults, where bias is minimal, the standard deviation for individual errors in energy intake approaches 20%. Two investigations of the validity of self-reported dietary records for measuring change in dietary intake also indicate large underestimates of the actual change. Because of bias and imprecision, self-reported energy intakes should be interpreted with caution unless independent methods of assessing their validity are included in the experimental design.

INTEREST IN THE assessment of dietary intake is probably as old as society itself; however, the science of measuring dietary intake of individuals outside of the metabolic ward has been traced by Bingham[1] to the 1930s and 1940s. Widdowson et al[2,3] used the weighed-food record to survey dietary intake among men and women. Subjects were asked to weigh each item of food, as well as all unconsumed portions of food, and to write down these weights for all items of food and beverage consumed. This was followed by the use of household units by Youmans et al,[4] who asked individuals to record the amount of food eaten for 7 days using standard household measures such as cups, teaspoons, and linear measures, or the number of whole items such as fruits. The use of diet-recall surveys based on interviews was reported at about this same time by Wiehl,[5] who asked subjects to report food consumed during the previous 2 days, and Turner,[6] who extended the reporting period in pursuit of a typical dietary pattern. Both investigators used food models to aid in the determination of portion sizes. Wiehl and Reed[7] also introduced the food-frequency method in which subjects were asked to report the frequency with which they consumed specific foods over a 5-day period.

All of these methods, with various modifications, have been used to measure energy intake for the study of energy balance and body weight. For this purpose, measured or estimated portions of each food are converted to energy units using food tables. Depending on the study, these techniques were used either to measure actual intake over the period of study or to estimate habitual energy intake or the dietary energy consumed by an individual over some longer period.

However, each measure of dietary energy is subject to random variation, which as used here refers to the scatter about the mean value, and to systematic error or bias, which as used here refers to the difference between the mean value and the true value. Historically, random variation has been assessed for these methods by performing repeat measurements using the same dietary instrument. Although there are differences between subjects and studies, it is generally accepted that a major source of random variation in dietary energy is the individual's day-to-day variation in energy consumption. The average daily within-subject coefficient of variation or random variation for energy intake is 20% to 30%.[1] This random variation decreases as the square root of the number of study days increases, such that it is approximately 10% for a 7-day record.

IS SELF-REPORTED ENERGY INTAKE ACCURATE?

Although all these techniques have been used and are continuing to be used to measure dietary energy intake, little was known about the accuracy of dietary intake analysis until recently. This lack of knowledge was due to the absence of reference techniques for measuring dietary intake in free-living subjects. However, various indirect methods had raised concerns about the accuracy of the methods.

The greatest concern about accuracy has been raised with regard to recall methods.[1] Comparison of intake against direct, covert observation had indicated that individuals tend to forget items that were consumed and thus underestimate intake.[8] Furthermore, portion sizes tend to be underestimated when large and overestimated when small, which leads to a "flat slope" between reported intake and observed intake.[9]

Accuracies of diary methods using either common household units or weighing had also been questioned. From a household-intake perspective, careful analysis of household trash had determined four major sources of reporting error: rounding errors and other random errors in package sizes, upward distortions of high-status items, downward distortions of items that are viewed as "bad," and substitution errors where one item is reported in the place of an unreported item.[10] From an individual point of view, comparison of reported intake with 24-hour nitrogen excretion in the urine had detected systematic underestimation of dietary intake, especially in obese subjects, whose reported nitrogen intake was half the nitrogen intake estimated from urinary nitrogen excretion.[11]

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USE OF ENERGY EXPENDITURE TO VALIDATE ASSESSMENT OF ENERGY INTAKE

As indicated earlier, it had proven difficult to assess the accuracy of intake methods in free-living subjects because of the lack of reference methods. However, recently, advances in the use of stable isotopes to measure total daily energy expenditure have made it possible to compare the accuracy of self-reported dietary energy intake against energy expenditure. In subjects who are stable with respect to weight and body composition, energy intake equals energy expenditure and thus the two measures should compare. Such stability does not exist on a day-to-day basis, but over moderate periods of time, small daily changes in body energy stores are averaged out and energy expenditure should equal habitual energy intake.

Total daily energy expenditure can be measured in free-living subjects using the doubly-labeled water method.[12] The basic premise of the method is that after a loading dose of water labeled with the stable isotopes ^{18}O and deuterium, the ^{18}O will be eliminated from the body as water and carbon dioxide and deuterium will be eliminated as only water. The difference between the two elimination rates will therefore be proportional to the rate of carbon dioxide production. In essence then, after administration of doubly-labeled water, body water acts as a metabolic recorder that maintains a record of carbon dioxide production for a period of 7 to 21 days. Total energy expenditure is then calculated from carbon dioxide production and an estimate of the respiratory ratio.[13]

The doubly-labeled water method has been extensively validated against gas exchange in small animals and humans.[14,15] In so doing, the doubly-labeled water technique has been shown to be accurate to 1%, with a coefficient of variation of 2% to 8% depending on isotope dose and length of the elimination period. In addition, the method has been validated against measured dietary intake when the subject's food was provided entirely by the investigator. In these validations, dietary energy intake agreed within 5.5% with energy expenditure, and the coefficient of variation was 9%.[16,17] The doubly-labeled water method can therefore be used as a reference method for validation of dietary energy intake. Assuming a coefficient of variation for energy intake of 10% for a 7-day period[1] and a coefficient of variation for energy expenditure of 9% (unpublished data, October 1994), the coefficient of variation for comparison of the two measures should be approximately 13%.

POPULATION STUDIES

Two early investigations of the validity of dietary intake were performed in subjects who had low reported intakes and thus were thought to be energy efficient. Livingstone et al[18] reported results from 31 subjects who had been part of a previous study of dietary intake. Male and female subjects were selected to include the entire range of energy intake from very low to high. Dietary intake was determined for 7 days by weighed dietary record, and energy expenditure was measured concurrently with doubly-labeled water. Comparison with energy expenditure indicated that the average subject underestimated habitual energy intake by 18%, with a coefficient of variation of 22%. The greatest underestimate of energy intake occurred in the "small eaters," or the tertile with the lowest self-reported intake, with only the upper tertile of subjects demonstrating good agreement with reported intake and measured energy expenditure. In the second study, Singh et al[19] attempted to validate dietary energy intake measures in Gambian women, a population in which very low energy intakes had been observed in previous studies. Dietary intake was obtained using a combination of weighing and recall. Field workers weighed the consumed portion of each meal for 11 days and determined between-meal intake by recall. This recall was performed at 3- to 4-hour intervals and only involved a limited number of available snacks. Energy expenditure was measured by doubly-labeled water for a 14-day period. Energy intake averaged only 50% of energy expenditure in four nonpregnant, nonlactating women (6.1 ± 2.0 *v* 12.2 ± 2.8 MJ/d). The discrepancy was even greater in nine lactating women with intake averaging only 41% of measured expenditure, which does not even include the energy transferred from the mother through milk output. Because this study was performed at the height of the agricultural season, some discrepancy was expected due to a negative energy balance. However, the average weight loss during the study period was only 29 ± 58 g/d, which could only account for approximately 0.8 MJ/d, assuming a composition of 75% fat. Thus, the change in body energy stores could account for less than one sixth of the discrepancy, and it was concluded that intake was grossly underestimated. However, the reason for the underestimate could not be identified despite considerable effort on the part of the investigators.[19]

EFFECT OF OBESITY ON ACCURACY

Several investigators have also used the doubly-labeled water method in an attempt to validate self-reported dietary intakes in obese subjects. These studies differ from those described earlier in that the subjects were selected on the basis of body size and composition rather than a previous measurement of low dietary intake. Bandini et al[20] attempted to validate 14-day dietary diaries in common household units in 28 non-obese and 27 obese adolescents by comparing energy intake with energy expenditure measured concurrently with doubly-labeled water. Reported energy intake was consistently less than measured energy expenditure in this group of 12- to 18-year-old children. Reported energy intake averaged only 59% ± 24% of energy expenditure in obese subjects. The discrepancy was smaller in the non-obese group (81% ± 19%), but reported intake was still significantly less than expenditure. To determine whether the discrepancy resulted from underreporting or from subjects' decreasing their intakes below maintenance requirements, the investigators monitored weight change during the 14-day period. Both the obese and non-obese groups gained weight (0.4 ± 1.0 and 0.1 ± 0.7 kg, respectively), which indicates that the discrepancy was due to underreporting. The degree of underreporting, expressed as a percentage difference between reported intake and measured energy expenditure, increased with both body weight (for males, $r = .35$ and $P < .07$; for females, $r = .66$ and $P < .001$) and body fatness (for males, $r = .39$ and $P < .05$; for females, $r = .64$ and $P < .001$). Also of note, reported energy intakes did not differ between obese and non-obese groups (8.1 ± 3.0 and 9.2 ± 2.6 MJ/d, respectively) despite a significantly greater energy expenditure in the obese.

Prentice et al[21] also attempted to validate self-reported intake in nine obese and 13 non-obese subjects; however, this study used a 7-day weighed dietary record and was performed in adult women. Similar to the findings reported by Bandini et al,[20] reported energy intakes in obese subjects did not differ from those of non-obese subjects (6.7 ± 1.9 and 7.8 ± 1.7 MJ/d, respectively) despite a significantly greater energy expenditure in obese subjects (10.2 ± 1.4 *v* 7.4 ± 0.7 MJ/d, respectively). In this study, reported energy intakes in the non-obese group were similar to measured energy expenditures, with intake averaging 98% ± 15% of measured expenditure. However, in the obese group intake was significantly less than expenditure, averaging 83% ± 16% of expenditure ($P < .05$). Weight changes were also monitored in this study, although their interpretation is complicated because intake was recorded for only 7 to 14 days of the 14- to 31-day period of measuring energy expenditure by doubly-labeled water. The non-obese group maintained weight and thus were accurately reporting both actual and habitual energy intake. However, the obese group tended to lose weight in an amount that could account for approximately half the discrepancy between reported intake and expenditure, and thus appeared both to underreport actual intake and to consume less than their habitual intake. Thus, although the discrepancy in reported energy intake between the obese and non-obese was similar in the studies reported by Prentice et al[21] and Bandini et al,[20] the proportions of the discrepancy due to underreporting and undereating differed.

Underreporting of energy intake in obese subjects has also been reported by Lichtman et al[22] during attempted weight loss through diet restriction. In this study, 10 subjects were selected on the basis of previous inability to lose weight on a prescribed hypocaloric diet and thus described as diet-resistant subjects. Dietary intake was recorded for 14 days to the nearest ounce or number of items consumed. When compared with energy expenditure measured by doubly-labeled water and adjusted for weight loss during the measurement, the degree of underreporting of energy intake was 47% ± 16%, which is greater than either of the previously mentioned studies and probably reflects criteria for subject selection. For comparison, six obese subjects who were not diet-resistant only underreported dietary intake by 19% ± 38%, which is not statistically significant and is similar to the degree of underreporting found by Prentice et al.[21] Tests of the subject's ability to estimate portion sizes using food models indicated that both groups could accurately estimate the dimensions of the models, and thus underreporting probably was not due to errors in estimates of portion size. Psychological and behavioral tests indicated moderate depression by the Beck Depression Inventory and cognitive restraint, disinhibition by the Eating Inventory in both groups. Of note, the diet-resistant group indicated significantly greater cognitive restraint and less disinhibition, as well as lower levels of perceived hunger, than the control group. Despite the ability to accurately estimate portion sizes, the diet-resistant group also underreported the amount of food consumed in a test served 24 hours earlier under standardized laboratory conditions, whereas the control group could accurately recall the amount they ingested. Finally, diet-resistant subjects reacted with surprise when results of their underreporting were revealed to them. Although none of the findings of these additional investigations could clearly identify the cause of underreporting of energy intake, they do suggest (but do not prove) that underreporting is not due to a conscious effort to delude the investigators, but rather to some inability to perceive true dietary intake.[23]

EFFECT OF AGE ON VALIDITY

Despite the differences between subjects, protocols, and techniques used for dietary analysis, all three studies discussed, as well as a recent study reported by Westerterp et al,[24] are uniform in their findings of underreporting of dietary energy intake among obese subjects. However, the findings of Bandini et al[20] and Prentice et al[21] disagree with respect to validity of self-reported energy intakes in the non-obese group, and it is not clear whether the difference reflects the use of a weighed dietary record in place of a diet record based on common household units and estimated portion sizes, or whether it reflects differences in the ages of the subjects. A recent study reported by Livingstone et al[25] indicates that it is probably the latter. In this study, 7-day weighed dietary records of energy intake were obtained from 12 children each at the ages of 7, 9, 12, 15, and 18 years. These were compared with energy expenditure measured over 10 to 14 days. Dietary records were recorded by the parents for the 7- and 9-year-old children, whereas the 12-, 15-, and 18-year-old children took greater responsibility for their own records. Despite the use of weighed dietary records, Livingstone et al[25] also found that non-obese adolescents underreported dietary intake. Underreporting of dietary energy averaged 20%, which is identical to that reported by Bandini et al[20] for non-obese adolescents. Thus, the degree of underreporting by dietary record in non-obese adolescents is independent of the use of weighing or household measures. Interestingly, energy intakes for 7- and 9-year-old children that were recorded by the children's parents were accurate when compared with measured energy expenditure; however, the coefficients of variation were relatively large (25% for 7-year-olds and 15% for 9-year-olds). In a small number of obese children in this young age group, we have also found that parent-reported energy intakes agree well with measured energy expenditure (unpublished data, May 1994).

The study reported by Livingstone et al[25] also included dietary assessment using a diet-history questionnaire and is the only study to date to investigate the accuracy of a diet-history instrument using energy expenditure as the reference measure. The food-frequency questionnaire was administered by a single investigator using photos of food portions to estimate serving size during a 1- to 2-hour interview. This interview was performed 2 to 4 weeks before or after the weighed record was obtained to minimize any carryover effect. The diet history was found to be relatively accurate in each of the age groups from 3 to 18 years, with a slight bias toward overestimating energy intake. Energy intake by diet history averaged 108% of energy expenditure. It should be noted that children are normally in positive energy balance because of the requirements for growth, but this is only 1% to 2% of intake. Despite the good agreement between diet history and energy expenditure for the entire group, individual agreements were marginal, with individual overestimates and underestimates ranging up to 50%. The average coefficient of variation was nearly 20%.

EFFECT OF PARTICIPATION IN ATHLETICS ON ACCURACY

In addition to the bias toward underreporting of energy intake among overweight or obese individuals, there is also strong evidence that trained athletes underreport dietary intake. Recently, Schulz et al[26] compared 6-day diet records using estimated portions in common household units against expenditure by doubly-labeled water in nine elite female athletes engaged in endurance training. Reported energy intake was less than expenditure in eight subjects, averaging 80% ± 15% of energy expenditure. These subjects tended to lose weight at a rate that could account for 60% of the difference between reported energy intake and measured expenditure. Thus, both undereating and underreporting appeared to occur, with undereating being the predominant factor. In a similar study using similar methodology, Edwards et al[27] reported that dietary records underestimate habitual energy intake by 30% ± 18% in trained female endurance runners. They also administered the Food Attitudes Questionnaire to the subjects of this study and found that underestimation of energy intake was most prevalent in heavier subjects and that these subjects tended to have a negative body image. Thus, there is an indication that the bias in reported intake was associated with a concern with body weight, although none of these runners would be classified as overweight by normal standards.

ASSESSMENT OF CHANGE IN INTAKE

In addition to the attempts to validate instruments for energy intake, several investigators have also studied the ability of self-reported intakes to reflect changes in dietary energy intake. Results, unfortunately, have been discouraging. Westerterp et al[28] studied 13 previously nonexercising men and women before and at the end of a 40-week endurance-training intervention. Energy intake was obtained from 7-day records using common household units, and energy expenditure was measured concurrently by doubly-labeled water. Although not actively engaged in sports, subjects were non-obese and energy intakes reported before the exercise intervention were in good agreement with energy expenditure (−5% ± 28%). However, during the last few weeks of the 40-week intervention, energy expenditure had increased by 21%, or 2.3 MJ/d. In contrast, reported intake only increased a few percentage points, and thus the discrepancy between reported intake and expenditure was −19% ± 17%. The subjects did lose weight and fat mass during the 40-week intervention, but the most rapid loss occurred early. By the end of the intervention, undereating could only account for approximately 0.2 MJ/d, or 10% of the discrepancy. Thus, dietary records were poor at measuring the change in dietary intake associated with an exercise intervention. In a dissimilar situation, Goldberg et al[29] evaluated 12 women throughout pregnancy. Weighed 7-day dietary records and doubly-labeled water results were obtained before and at 6-week intervals during pregnancy. Intake records grossly underestimated energy intake as determined from expenditure plus the increase in body energy stores, but reported intakes did increase by an amount equivalent to 1.7 MJ/d during pregnancy. This increase could account for approximately half the cumulative increase in energy expenditure plus body energy stores, and thus the increase in reported energy intake was probably half the true increase. Taken together, these two studies indicate that self-reported dietary records using either weights or common household units grossly underestimate change in dietary energy intake.

SUMMARY

In summary, attempts to validate self-reported dietary energy intakes by comparing them against energy expenditure measured by doubly-labeled water generally confirmed many of the concerns about bias raised by Bingham.[1] The bias is greatest in obese individuals, and there is no indication that valid estimates of dietary energy can be obtained by self-report in obese subjects over 12 years of age. Bias is dramatically reduced in non-obese subjects, but can still be large in weight-conscious individuals, such as demonstrated by female endurance athletes. Studies have found that some instruments are more biased than others. Specifically, the diet-history instrument demonstrates much less bias in adolescents than dietary records. However, a recent abstract indicates that the diet history is also subject to bias in weight-conscious individuals[30] and thus will not solve the problem of obtaining accurate dietary intake data in obese individuals. It is also unlikely that simpler forms of intake instruments such as 24-hour recall or short food-frequency questionnaires will out-perform diet records, since previous studies have already raised concern about errors associated with these instruments.[1]

Even in the non-obese where bias is minimal, the ability to measure dietary energy intake in individuals is marginal. Coefficients of variation are on the order of 20% to 25%, which, even after removal of the 9% variability in energy expenditure by doubly-labeled water, suggests a 95% confidence interval for an individual's energy intake of approximately 40%. Furthermore, diet records also underestimate changes in dietary energy intake.

Underestimates of dietary energy intake among obese individuals, female athletes, and other weight-conscious individuals, as well as the tendency to underestimate dietary change using self-reported dietary intake instruments, tend to flatten the range of apparent dietary energy intakes. This reduces the utility of dietary intake instruments in epidemiologic research by making it difficult to detect a relationship between energy intake and health outcomes. For example, the regression coefficient between reported intake and expenditure and hence habitual energy intake in the 31 adults studied by Livingstone is only .55. In studies of obese and non-obese subjects where results are biased, regression coefficients are even smaller ($r = .28$ for women reported by Prentice et al,[21] and $r = .1$ for adolescents reported by Bandini et al[20]).

Further studies are warranted for better definition of the errors in self-reported dietary intake. Current findings suggest that it will not be possible to identify a single correction factor that can be applied to self-reported energy intake; however, identification of the causes of low estimates of energy intake and even lower sensitivity to detecting change in intake is needed. Such knowledge might make it possible to improve the design of dietary intake instruments. Without specific knowledge of the factors that lead to the bias in self-reported energy intake, dietary intakes must be interpreted with caution, unless independent measures are included in study protocols to validate the intake data.[1]

REFERENCES

1. Bingham SA: The dietary assessment of individuals: Methods, accuracy, new techniques and recommendations. Nutr Abst Rev (Ser A) 57:705-742, 1987
2. Widdowson EM: A study of English diets by the individual method. I. Men. J Hygiene 36:269-292, 1936
3. Widdowson EM, McCance RA: A study of English diets by the individual method. II. Women. J Hygiene 36:293-309, 1936
4. Youmans JB, Patton EW, Kern R: Surveys of the nutrition of populations. Am J Public Health 32:1371-1379, 1942
5. Wiehl DG: Diets of a group of aircraft workers in Southern California. Milkbank Mem Fund Q 22:5-40, 1942
6. Turner D: The estimation of the patient's home dietary intake. J Am Diet Assoc 16:875-881, 1940
7. Wiehl DG, Reed R: Development of new or improved dietary methods for epidemiological investigations. Am J Public Health 50:824-828, 1960
8. Acheson KJ, Campbell IT, Edholm OG, et al: The measurement of food and energy intake in man—An evaluation of some techniques. Am J Clin Nutr 33:1147-1154, 1980
9. Madden JP, Goodman SJ, Guthrie HA: Validity of 24 h recall. J Am Diet Assoc 68:143-147, 1976
10. Rathje WL: "Where's the beef?": Red meat and reactivity. Anim Behav Sci 28:71-128, 1984
11. Warnold I, Carlgren G, Krokiewski M: Energy expenditure and body composition during weight reduction in hyperplastic obese women. Am J Clin Nutr 31:750-763, 1978
12. Lifson N, McClintock R: The theory and use of turnover rates of body water for measuring energy and material balance. J Theor Biol 12:46-74, 1966
13. Black AE, Prentice AM, Coward WA: Use of food quotients to predict respiratory quotients for the doubly-labeled water method of measuring energy expenditure. Hum Nutr Clin Nutr 40C:381-391, 1986
14. Nagy K: CO_2 production in animal: Analysis of potential errors in the doubly labeled water method. Am J Physiol 238:466-473, 1980
15. Schoeller DA: Measurement of energy expenditure in free-living humans by using doubly labeled water. J Nutr 118:1278-1289, 1988
16. Bandini LG, Schoeller DA, Edwards J, et al: Energy expenditure during carbohydrate overfeeding in obese and non-obese adolescents. Am J Physiol 256:E357-E376, 1989
17. Riumallo JA, Schoeller DA, Barrera G, et al: Energy expenditure in underweight free-living adults: Impact of energy supplementation as determined by doubly labeled water and indirect calorimetry. Am J Clin Nutr 49:239-246, 1989
18. Livingstone MBE, Prentice AM, Strain JJ, et al: Accuracy of weighed dietary records in studies of diet and health. Br Med J 300:708-712, 1990
19. Singh J, Prentice AM, Diaz E, et al: Energy expenditure of Gambian women during peak agricultural activity measured by the doubly-labelled water method. Br J Nutr 62:315-329, 1989
20. Bandini LG, Schoeller DA, Cyr HN, et al: Validity of reported energy intake in obese and nonobese adolescents. Am J Clin Nutr 52:421-425, 1990
21. Prentice AM, Black AE, Coward WA, et al: High levels of energy expenditure in obese women. Br Med J 292:983-987, 1986
22. Lichtman SW, Pisarka K, Berman ER, et al: Discrepancy between self-reported and actual caloric intake and exercise in obese subjects. N Engl J Med 327:1893-1898, 1992
23. Danforth E Jr, Sims EAH: Obesity and efforts to lose weight. N Engl J Med 327:1947-1948, 1992 (letter)
24. Westerterp KR, Verboeket-Van de Venne WP, Meijer GA, et al: Self-reported intake as a measure for energy intake: A validation against doubly labelled water, in Aihaud G (ed): Obesity in Europe 91. London, UK, Libbey, 1991, pp 17-22
25. Livingstone MB, Prentice AM, Coward WA, et al: Validation of estimates of energy intake by weighed dietary record and diet history in children and adolescents. Am J Clin Nutr 56:29-35, 1992
26. Schulz LO, Alger S, Harper I, et al: Energy expenditure of elite female runners measured by respiratory chamber and doubly labeled water. J Appl Pysiol 72:23-28, 1992
27. Edwards JE, Linderman AK, Mikesky AE, et al: Energy balance in highly trained female endurance runners. Med Sci Sports Exerc 25:1398-1404, 1993
28. Westerterp KR, Meijer GAL, Janssen EME, et al: Long-term effect of physical activity on energy balance and body composition. Br J Nutr 68:21-30, 1992
29. Goldberg GR, Prentice AM, Coward WA, et al: Longitudinal assessment of energy expenditure in pregnancy by the doubly labeled water method. Am J Clin Nutr 57:494-505, 1993
30. Black AE, Jebb SA, Bingham SA: Validation of energy and protein intakes assessed by diet history and weighed records against energy expenditure and 24 H urinary nitrogen excretion. Proc Nutr Soc 50:108A, 1991 (abstr)