The Question of Declining Sperm Density Revisited: An Analysis of 101 Studies Published 1934–1996

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In 1992 Carlsen et al. reported a significant global decline in sperm density between 1938 and 1990 [Evidence for Decreasing Quality of Semen during Last 50 Years. Br Med J 305:609-613 (1992)]. We subsequently published a reanalysis of the studies included by Carlsen et al. [Swan et al. Have Sperm Densities Declined? A Reanalysis of Global Trend Data. Environ Health Perspect 105:1228-1232 (1997)]. In that analysis we found significant declines in sperm density in the United States and Europe/Australia controlling for age, time, and semen collection method. The declines in sperm density in the United States (approximately 1.5%/year) and Europe/Australia (approximately 3%/year) were somewhat greater than the average decline reported by Carlsen et al. (approximately 1%/year). However, we found no decline in sperm density in non-Western countries, for which data were very limited. In the current study, we used similar methods to analyze an expanded set of studies. We added 47 English language studies published in 1934-1996 to those we had analyzed previously. The average decline in sperm count was virtually unchanged from that reported previously by Carlsen et al. (slope = -0.94 vs. -0.93). The slopes in the three geographic groupings were also similar to those we reported earlier. In North America, the slope was somewhat less than the slope we had found for the United States (slope = -0.80; 95% confidence interval (CI), -1.37-0.24). Similarly, the decline in Europe (slope = -2.35; CI, -3.66-1.05) was somewhat less than reported previously. As before, studies from other countries showed no trend (slope = -0.21; CI, -2.30-1.88). These results are consistent with those of Carlsen et al. and our previous results, suggesting that the reported trends are not dependent on the particular studies included by Carlsen et al. and that the observed trends previously reported for 1938-1990 are also seen in data from 1934-1996. Keywords: epidemiology, geography, regression analysis, semen quality, sperm density, trend. Environ Health Perspect 108:961-966 (2000). [Online 5 September 2000] http://ehpnet1.niehs.nih.gov/docs/2000/108p961-966swan/abstract.html

In 1992 Carlsen et al. (1) stated that...reports published worldwide indicate clearly that sperm density has declined appreciably during 1938-1990. Subsequently, this conclusion has been supported by findings from some studies (2–4), but not by others (5–7). The critical issues raised concerning this study fall, broadly, into three categories. Some authors suggested that poor or highly variable data invalidated any inference about trends in sperm counts (8,9). Others questioned the validity of the statistical methods used in this analysis (8,10,11). Bias due to changing study populations (12 or confounding by factors such as age and abstinence time (time between sample collection and last ejaculation) were also suggested (4,8).

We conducted several analyses designed to examine these concerns. The first, published in 1997, reanalyzed the studies used by Carlsen et al. (1) to examine model selection, confounding, and selection bias (13). In that paper, we noted that estimates of mean sperm density from the United States and Europe declined somewhat more rapidly than had been reported by Carlsen et al. (1). In other parts of the world, where studies were few and most were quite recent, there was insufficient data to evaluate this question. We also found that controlling for confounding bias, to the extent possible, provided additional support for the conclusions of Carlsen et al. (1) rather than reducing the estimated decline in sperm density. In the second analysis, published in 1999, we looked at sperm counting methods and the reliability of measurements from these historical studies (14). We found no evidence that counting methods changed appreciably or that counts from older studies were less reliable than those from recent studies.

The current study extends our previous analyses in three ways. First, we conducted an independent literature review to evaluate possible bias in the selection of studies used by Carlsen et al. (1). Second, we examined the robustness of the models utilized in that analysis (and ours) by applying these models to an expanded data set. Finally, we assessed the consistency of post-1990 data with trends in sperm density from studies published before 1990.

Methods

Analysis of Carlsen et al. study. Carlsen et al. (1) screened studies published from 1930 to mid-1990 to identify studies that included estimates of sperm density. They excluded studies that included men in infertile couples, men who were referred because of genital abnormalities, and studies that selected men on the basis of their sperm count. Studies that used nonmanual methods for counting sperm were also excluded. Carlsen et al. (1) included 61 studies published between 1938 and 1990. The authors estimated the rate of change in mean sperm density as a function of publication year by fitting a simple regression model.

Current analysis. The current analysis includes 54 of the 61 studies analyzed by Carlsen et al. (1). As in our previous paper (13), we excluded three non-English language studies (15–17) because it was not practical for us to systematically review the non-English language literature on this subject. We also excluded two studies that included men who conceived only after an infertility work up (18,19), studies that did not meet the eligibility criteria of Carlsen et al. (1). Finally, we did not include any studies with less than 10 subjects, which resulted in two additional exclusions (20,21). The most recent study in Carlsen et al.'s analysis (1) and our 1997 reanalysis (1) was published in June 1990. To extend the study period, we conducted a search of Medline (National Library of Medicine, Bethesda, MD) for English-language studies published between 1990 and 1996 and found 19 that met these eligibility criteria. We also conducted a less systematic search of the 60-year period 1930–1990 and identified 28 additional eligible studies. Therefore, the current analysis is based on 101 English-language studies published in 1934–1996 (54 “Carlsen” studies and 47 “non-Carlsen” studies), each with at least 10 men and all satisfying the eligibility criteria published by Carlsen et al. (1). The 47 “non-Carlsen” studies are summarized in the Appendix.

Each of these 101 studies was reviewed independently by two of us to systematically...


...mple linear model. For comparison with Carlsen et al. (1), we first replicated their simple linear regression. As shown in Table 3, the slope for the regression line in the expanded data set (–0.94 × 10^6 mL/year; p < 0.0001) is very similar to that found for the original 61 studies (–0.93 × 10^6 mL/year; p < 0.0001). These estimates differ only slightly from the slope we reported in our 1997 analysis (13): (–0.95 × 10^6 mL/year, p < 0.0001).

Assessing confounding and interaction. To select variables for our analyses, we initially included all variables for which we had abstracted data and we noted the percent change in the slope that resulted when we removed them one at a time. Several of these were unrelated to sperm density or publication year (change <10%) and were dropped from further analysis. These variables were the number of samples per subject, whether the years of sample collection were reported, whether the arithmetic mean was reported, and purpose of the study. Although removing age changed the slope by only 1.2%, we included this variable in the final model because it is a basic demographic variable.

### Table 1. Publication year of studies in three analyses.

| Publication year | Carlsen et al. (1) | Swan et al. (13) | New studies in current analysis | All studies in current analysis |
|------------------|-------------------|-----------------|-------------------------------|-------------------------------|
| 1930–1959        | 10 (16%)          | 8 (14%)         | 2 (4%)                        | 10 (10%)                      |
| 1960–1979        | 17 (28%)          | 14 (25%)        | 3 (6%)                        | 16 (16%)                      |
| 1980–1989        | 33 (54%)          | 33 (59%)        | 23 (49%)                      | 55 (54%)                      |
| 1990–1996        | 1 (2%)            | 1 (2%)          | 19 (40%)                      | 20 (20%)                      |
| Total            | 61                | 56              | 47                            | 101                           |

*Includes one study with <10 subjects that was excluded from the current analysis.

### Table 2. Geographic distribution of studies in three analyses.

| Region            | Carlsen et al. (1) | Swan et al. (13) | New studies in current analysis | All studies in current analysis |
|-------------------|-------------------|-----------------|-------------------------------|-------------------------------|
| North America     | 28 (46%)          | 27 (48%)        | 18 (38%)                      | 43 (43%)                      |
| Europe            | 17 (28%)          | 15 (28%)        | 20 (43%)                      | 35 (35%)                      |
| Other             | 16 (26%)          | 14 (25%)        | 9 (19%)                       | 23 (23%)                      |
| Total             | 61                | 56              | 47                            | 101                           |

*Includes two studies with <10 men that were excluded from the current analysis.

*Includes one Australian study included in “other” in the current analysis.

### Table 3. Results of fitting a simple linear regression model in three analyses.

| Factor             | Carlsen et al. (1) | Subset of Carlsen in current analysis | All studies in current analysis |
|--------------------|--------------------|------------------------------------|--------------------------------|
| Number             | 61                 | 54                                 | 101                            |
| Publication years  | 1938–1990          | 1938–1990                          | 1934–1996                      |
| Slope              | -0.93              | -0.95                              | -0.94                          |
| p-Value            | <0.0001            | <0.0001                            | <0.0001                        |
| R²                 | 0.36               | 0.36                               | 0.22                           |

*Excludes non-English language studies and those with <10 men.
often included in analyses of sperm density. The method of counting sperm was also included (although removing it changed the slope by only 6%). In this expanded set of studies, recruiting criteria and the percent of men with proven fertility were highly correlated, so only one of these variables (fertility) was retained for further analyses. The following variables were included in all subsequent multiple regression models: geographic region, age, abstinence time, percentage of men with proven fertility, method of counting sperm, and method of sample collection (Table 4). Of these, all but the method of counting sperm had been included in our previous analysis (13). Because one of the goals of this study was to examine the effect of adding new studies, we also kept a variable that indicated whether the study had been included by Carlsen et al. (1), even though removing it from the model had little effect on the slope. Despite the incompleteness of data on many covariates, the inclusion of the variables contained in Table 4 did improve model fit. When the simple linear model was compared with the multivariate linear model, including these covariates, the adjusted R² increased from 0.22 to 0.59.

In addition to including these covariates singly, we examined interaction terms to allow for different slopes in the three geographic regions. In our previous analysis (13), the three slopes that we estimated differed considerably (−1.50, −3.13, and +1.56, respectively, for the United States, Europe/Australia, and other countries). In the current analysis the European slope (−2.35) still differed from that for North American (difference in slopes = −1.55; CI, −2.90−0.21), indicating significant interaction (Figure 2). Although we did include the slope of the best fitting line for other countries (−0.60), the fit to a linear model for data from these countries was not good and the confidence interval was very broad. Given the limited data, there was no evidence that this slope differed appreciably from those from other regions (Table 5).

**Nonlinear models.** We also fit a number of nonlinear models (quadratic, spline, and step) using the same set of covariates that were used for the linear model (Table 4). Olsen et al. (8) suggested that these models were preferable to Carlsen’s simple linear model (1). In our 1997 analysis (13), we showed this was not the case, once geographic region and the interaction of region and year were included in the model.

In our previous study (13), we had not seen any difference between the spline and linear models except a slight (nonsignificant) change in the United States post-1970 (from −1.52 to −1.47; p for spline term = 0.97). When a spline model was fit to the current expanded data set, the pre-1970 North American studies showed a somewhat steeper decline than those published after 1970 (−0.93 vs. −0.55), although this difference was still not significant (p for spline term = 0.71).

In our 1997 analysis (13), quadratic terms could not be estimated and we found no evidence of curvature within any of the three regions studied. In the present analysis, it was possible to estimate the quadratic term, but its addition did not improve the fit of the model; the quadratic terms were negligible and none approached statistical significance. Thus, we again found no evidence to support either curvature, or a “leveling off” in the rate of decline in recent years.

In our 1997 analysis (13), we also fit a step function and found a significant post-1970 decrease in sperm density in all regions relative to pre-1970 data (which was entirely from the United States). Again, results were similar in the current analysis. When a step function was fit, comparing the mean sperm density for North America before and after 1970, a large step was seen (138 × 10⁶/mL vs. 131 × 10⁶/mL; p for difference < 0.001). The pre-1970 mean from North America was also significantly higher than the mean for studies from other (p < 0.001), whereas the mean for all post-1970 European studies fell between the pre- and post-1970 North American mean.

Overall, the data fit these multiple regression models approximately equally (all

![Figure 1. Mean sperm density in 101 studies published 1994–1996 and simple regression line.](image1)

![Figure 2. Interactive regression model for mean sperm density by year and geographic region, after controlling for proven fertility, abstinence time, age, specimen collection method, method of counting sperm, whether the study was included by Carlsen et al. (1), and interaction of region and study year.](image2)

Table 4. Distribution of covariates retained in multiple regression models.

| Variable | No. of studies (n = 101) | Mean sperm density (10⁶/mL) | Mean year of sample collection |
|----------|--------------------------|-----------------------------|-------------------------------|
| Region   |                          |                             |                               |
| North America | 40 | 78 | 1970 |
| Europe  | 34 | 87 | 1982 |
| Other  | 23 | 65 | 1984 |
| Included by Carlsen et al. | (1) | | |
| Yes  | 54 | 77 | 1974 |
| No  | 47 | 68 | 1985 |
| Age | | | |
| All men ≤ 40 years of age | 23 | 97 | 1970 |
| Some men ≥ 40 years of age | 53 | 71 | 1980 |
| No information | 25 | 88 | 1963 |
| Abstinence time | | | |
| Data reported: none < 3 days | 14 | 81 | 1976 |
| Data reported: some < 3 days | 14 | 78 | 1983 |
| No data reported: protocol restrictions | 49 | 80 | 1977 |
| No information | 24 | 68 | 1976 |
| Proven fertility | | | |
| Wife pregnant or post-partum | 20 | 82 | 1968 |
| At least 90% proven fertility (past) | 31 | 67 | 1978 |
| < 90% proven fertility (past) | 8 | 84 | 1979 |
| No information | 42 | 86 | 1984 |
| Method of semen collection | | | |
| Masturbation into container | 70 | 70 | 1979 |
| Other or no information | 31 | 95 | 1971 |
| Method of counting sperm | | | |
| Manual | 66 | 71 | 1982 |
| No information | 35 | 79 | 1971 |

*Does not include geographic region, which is shown in Table 2. Univariate/adjusted, weighted by the number of men in each study.**
adjusted \( R^2 \) s were between 0.56 and 0.61, but not quite as well as the models fit the data in our previous analyses (13) (Table 5). As in our 1997 analysis (13), when multiple regression models that include terms for the interaction of geographic region and year are used, there is no support for the use of a nonlinear model.

**Discussion**

As we stated previously (13), control for confounding in these analyses can be only partial because of incomplete data. Therefore, it is possible that residual confounding remains. How large is this likely to be?

One of the strongest confounders in this analysis was the type of population studied. We examined this factor in two ways: the percent of men with proven fertility and the type of study population (sperm donor, prevasectomy, etc.) Because these variables were highly correlated, we retained only one (the percent of men with proven fertility) in the final model. When this variable was added to the other variables in the multiple regression model, it increased the magnitude of the slope considerably (37.2%).

Zavos and Goodpasture (24) reported that sperm concentration is higher when semen samples are obtained using a collection device during intercourse than when the same subjects collect samples by masturbation (p < 0.01), a result that has been reported by others (25). In the current analysis, studies that did not require collection by masturbation tended to be earlier (mean publication year 1970 vs. 1978). Therefore, this variable was a strong (positive) confounder; when it was added to the model, the magnitude of the slope decreased 34.1%.

Carlsen et al. (1) required that sperm be counted by manual methods in all the studies that they included in their analysis. Nevertheless, because manual counting devices have changed somewhat over the study period, when reviewing these studies, we abstracted information on the specific counting method that was used. When the particular counting device was not specified, we assumed it was manual. Nonmanual methods are a relatively recent advance and are still considered experimental, so that studies that use nonmanual methods are likely to specify the use of such methods. In 62 of these 101 studies, the counting device was specified to be the hemocytometer, the method that has been continually recommended by the World Health Organization since 1980 (26,27). The only other counting method that was specified, the Makler chamber (28), was mentioned in only 2 studies of 101 studies. Thus, we found no evidence that the introduction of newer counting devices has resulted in lower sperm counts.

In fact, when systematic changes have been introduced by newer methods, they tended to result in higher counts (14). In any case, this variable appeared to have little effect on the observed decline in sperm density.

Some researchers have criticized the use of sperm count estimates from early in the study period, arguing that greater measurement error was likely in these historical studies. Greater imprecision in earlier studies could not have produced the negative slope we observed in Western countries. A change in the variability of sperm counts would, however, violate a basic assumption underlying the regression methods used in these analyses, the assumption of constant variance. Was this assumption justified? To answer this question we looked for a trend in the standard deviation of sperm density in these historical studies. We modeled the standard deviation (which was reported in 34 studies) as a function of year and found no evidence of a trend (slope = 0.24; p = 0.22) (14). We also used a multiple regression model to examine possible confounding of this relationship, but found no evidence of this. We concluded, therefore, that there has been no significant change in the standard deviation of sperm density over time.

Geographic region and the interactions of region and year were important covariates in these analyses. However, these geographic groupings are large and heterogeneous. For example, the category “other countries” included Thailand, India, Hong Kong, Brazil, Australia, Kuwait, Nigeria, Israel, Libya, Tanzania, Peru, Egypt, China, and Saudi Arabia. Several studies suggested that mean sperm density and trends in semen quality may vary considerably, even within small areas (29,30), so that it would have been desirable to stratify studies into narrower geographic categories if sufficient data had been available. Unfortunately, because many of these countries contributed only one study, it was not possible to use narrower geographic strata.

Abstinence time is known to be strongly related to sperm density (31–33). In this analysis, when abstinence time was added to a linear model that included all other variables, the magnitude of the slope decreased by 10.6%, suggesting moderate confounding. Although the inclusion of abstinence time in the model appears to have reduced confounding to some extent, control for this variable was undoubtedly incomplete because less than one-third of these studies included reported abstinence times. An additional 49% of studies noted that abstinence times were restricted by study protocol but, as has been demonstrated, these protocols are only advisory. Auger et al. (2) noted that only 66% of men adhered to the protocol-specified abstinence time of 3–5 days. On the other hand, to account for the observed decline in sperm density, abstinence time would have had to decline appreciably over the study period. The evidence for this is not strong: studies with longer abstinence times (none < 3 days) had higher counts (lower slopes) than those with shorter abstinence times.

Table 5. Comparison of multiple regression models from Swan et al. (13) (n = 56) and the current analysis (n = 101).

| Model          | Adjusted \( R^2 \) | Region                        | Slope within region          | Interaction                    |
|----------------|-------------------|-------------------------------|-------------------------------|--------------------------------|
|                |                   | United States                 | -1.50 (1.90 – 1.10)           | Referent                       |
| Swan et al.    | 0.80              | Europe/Australia              | -3.13 (4.96 – 1.30)           | -1.63 (0.08)                   |
|                |                   | Other countries               | 1.56 (1.00 – 4.12)            | 3.06 (0.03)                    |
| Current analysis| 0.61              | North America                 | -0.80 (1.37 – 0.24)           | Referent                       |
| Swan et al.    |                   | Europe                        | -2.35 (3.66 – 1.05)           | -1.55 (0.03)                   |
|                |                   | Other countries               | -0.21 (2.00 – 1.80)           | 0.60 (0.56)                    |
| Spline         | 0.79              | United States <1970           | -1.52 (2.37 – 0.66)           | Referent                       |
| Swan et al.    |                   | United States ≥ 1970          | -1.47 (3.00 – 0.06)           | 0.04 (0.97)                    |
|                |                   | Europe/Australia              | -3.12 (4.99 – 1.26)           | -1.61 (0.13)                   |
|                |                   | Other countries               | 1.56 (1.03 – 4.16)            | 3.08 (0.04)                    |
| Current analysis| 0.60              | North America <1970           | -0.93 (1.81 – 0.05)           | Referent                       |
| Swan et al.    |                   | North America ≥ 1970          | -0.55 (2.00 – 0.06)           | 0.37 (0.71)                    |
|                |                   | Europe                        | -2.32 (3.64 – 1.00)           | -1.39 (0.09)                   |
|                |                   | Other countries               | -0.25 (2.37 – 1.86)           | 0.68 (0.52)                    |
| Step           | 0.72              | United States <1977           | 106.7 (90.0 – 122.5)          |                                 |
| Swan et al.    |                   | United States ≥ 1970          | 67.5 (55.9 – 79.5)            |                                 |
|                |                   | Europe/Australia              | 75.0 (80.0 – 90.0)            |                                 |
|                |                   | Other countries               | 58.3 (46.0 – 70.7)            |                                 |
| Current analysis| 0.57              | North America <1970           | 137.9 (116.6 – 159.3)         |                                 |
|                |                   | North America ≥ 1970          | 113.2 (95.9 – 130.6)          |                                 |
|                |                   | Europe                        | 120.1 (103.6 – 136.6)         |                                 |
|                |                   | Other countries               | 104.0 (84.7 – 123.4)          |                                 |

*Controlled for proven fertility, abstinence time, age, specimen collection method, study goal and interaction of region and study year (Swan et al. (13); and proven fertility, abstinence time, age, specimen collection method, method of counting sperm, whether study was included by Carlsen et al. (12); and interaction of region and study year (current analysis).
days) were published only slightly earlier than those that included some abstinence times < 3 days (1976 vs. 1983).

After controlling for abstinence time and other covariates, the addition of age to the model increased the magnitude of the slope of other covariates, the addition of age to the model increased the magnitude of the slope of 2.5. However, we found little evidence that age is an important predictor of sperm density. Information was quite incomplete for this variable. Twenty-five studies contained no information on age, and these studies were only included an age range, so that we were only able to categorize age into broad categories. Nevertheless, we chose to retain this variable in the model for comparability to other analyses.

The current analysis suggests that the previously reported trends have continued, at least until 1996. We have also shown that the studies initially used by Carlsen et al. (1) did not represent a biased selection of the English language literature. Nevertheless, it is likely that neither this publication nor further statistical analyses of historical data will resolve the continuing debate over declining sperm counts. Critics will continue to challenge the reliability of historical data, and most will agree that residual confounding, which may be appreciable, cannot be completely eliminated.

The entire issue of declining sperm count has gained in importance because of the recognition of several other trends that reflect a decline in male reproductive health.

### Appendix 1: Studies not included by Carlsen et al. (1)

| Author (reference) | Year | Country | Sample size | Mean sperm density |
|--------------------|------|---------|-------------|--------------------|
| Alden et al. (39)  | 1982 | United Kingdom | 35 | 129.30 |
| Aksenovato et al. (40) | 1987 | Italy | 18 | 85.00* |
| Belding (41) | 1934 | United States | 15 | 119.00 |
| Cooper et al. (42) | 1991 | Germany | 25 | 94.20 |
| Cottell and Harrison (43) | 1990 | Ireland | 10 | 159.90 |
| Davidson (44) | 1949 | United Kingdom | 15 | 143.00 |
| De Castro and Mastrocorso (45) | 1984 | Brazil | 501 | 66.20 |
| De Castro et al. (46) | 1990 | Brazil | 1,890 | 37.00 |
| Dougherty et al. (47) | 1981 | United States | 132 | 83.00 |
| el-Shoura et al. (48) | 1995 | Saudi Arabia | 50 | 116.04 |
| Eskenazi et al. (49) | 1991 | United States | 25 | 39.00 |
| Faris et al. (50) | 1982 | United States | 112 | 75.00 |
| Fedder et al. (51) | 1993 | Denmark | 42 | 80.00 |
| Figa-Talamanca et al. (52) | 1996 | Italy | 21 | 62.00 |
| Frick et al. (53) | 1981 | Finland | 13 | 43.90 |
| Glass et al. (54) | 1979 | United States | 22 | 61.70 |
| J. Eines (55) | 1988 | Denmark | 68 | 30.20* |
| Jensen et al. (56) | 1996 | Denmark | 141 | 69.20 |
| Kolon et al. (57) | 1992 | United States | 10 | 132.80 |
| Levine et al. (58) | 1992 | United States | 142 | 100.70 |
| Milly and Wiborg (59) | 1980 | United States | 90 | 93.00* |
| Nnatu et al. (60) | 1991 | Nigeria | 21 | 64.40 |
| Noack-Fuller et al. (61) | 1993 | United States | 50 | 62.00 |
| Rickett et al. (62) | 1987 | United States | 40 | 80.00 |
| Richardson et al. (63) | 1984 | United Kingdom | 47 | 130.60 |
| Rogers et al. (64) | 1979 | United States | 21 | 114.00 |
| Rosenberg et al. (65) | 1985 | United States | 21 | 99.20 |
| Saaranen et al. (66) | 1987 | Finland | 190 | 141.07 |
| Schrader et al. (67) | 1988 | United States | 45 | 47.43 |
| Shaarawy and Mahmoud (68) | 1982 | Egypt | 45 | 77.50 |
| Sheriff (69) | 1987 | Libya | 10 | 51.40 |
| Sheriff and Legnain (70) | 1992 | Libya | 1,250 | 85.00 |
| Spira (71) | 1984 | France | 52 | 92.30 |
| Stankovic and Miacic-Devic (72) | 1976 | Yugoslavia | 67 | 55.20 |
| Sugkaroek et al. (73) | 1991 | Indonesia | 21 | 128.50 |
| Venable et al. (74) | 1980 | United States | 63 | 113.53 |
| Vignon et al. (75) | 1991 | France | 20 | 76.50 |
| Vogt et al. (76) | 1986 | Germany | 239 | 62.69 |
| Wallace et al. (77) | 1993 | United Kingdom | 52 | 66.50 |
| Wang and Yeung (78) | 1980 | Hong Kong | 15 | 89.80 |
| Ward et al. (79) | 1984 | United States | 11 | 87.40 |
| Wiedner et al. (80) | 1991 | Germany | 42 | 52.00* |
| Wyandt et al. (81) | 1996 | United States | 31 | 38.00 |
| Wicke et al. (82) | 1963 | Germany | 25 | 84.70 |
| Wirz et al. (83) | 1981 | United States | 26 | 66.20 |
| Yorke et al. (84) | 1981 | United States | 26 | 128.70 |
| Zhong et al. (85) | 1990 | China | 19 | 96.60 |

*Arithmetic mean estimated from median or geometric mean (see text).
10. Brake A, Krause M. Decreasing quality of semen [Letter]. Br Med J 2005; 330: 124–125 (2005).
11. Farow S. Failing sperm quality: fact or fiction? Br Med J 2006; 331: 39–40 (2006).
12. Bromwich P, Cohen J, Stewart I, Walker A. Decline in sperm counts: a review of changed reference range of "normal"? Br Med J 2009;364:19–22 (2009).
13. Swan SH, Elkin EP, Fenster L. Have sperm densities declined? A reappraisal of global trend data. Environ Health Perspect 2007;115:1322-1327 (2007).
14. Swan SH, Elkin EP. Declining semen quality: can the past inform the present? Bioessays 21(7):634-621 (1999).
15. Varnes J. Spermaes maegde. In: Spermaundersogeser P, Keiding N, et al. Male reproductive health and environmental factors. Aarhus, Denmark: Universitetsforlaget, 1944;42-52.
16. Robles GG. Estudio del liquido espermatico. Arch Peruano Patol Clin 1:615–661 (1947).
17. Sturzd C, Glowi Aarhus, Denmark: Universitetsforlaget, 1944;42-52.
18. Santomauro AG, Sciarra JJ, Varma AO. A clinical investigation of the role of the semen analysis and postcoital test in the evaluation of male infertility. Fertil Steril 22:234-257 (1973).
19. Bahamondes L, Abdelmassih R, Dachs J. Survey of 185 sperm abnormalities of fertile men in an infertility service. Int J Androl 1992;15:122–126 (1992).
20. Polakowski KL, Zahler WL, Paulson JD. Demonstration of proracrosin and quantitation of acrosin in ejaculated human spermatozoa. Fertil Steril 28(6):666–673 (1977).
21. Lewis EL, Rosoff JR, Wuest J. Human sperm function in the ejaculate following vasectomy. Fertil Steril 42(6):895–898 (1984).
22. SAS Institute Inc. SAS/STAT User’s Guide, Version 6. 4th ed. Cary, NC: SAS Institute Inc., 1989.
23. Rothman KJ, Greenland S. Introduction to stratified analysis. In: Modern Epidemiology. Philadelphia, PA: Lippincott-Raven, 1998;253–279.
24. Zavos PM, Goodpasture JC. Clinical improvements of male infertility: interim report of 3,182 cases. Br Med J 21328–1324 (1993).
25. de Castro MP, Mastrocroco DA. Reproductive history and semen analysis in prevasectomy fertile men with normal spermograms. J Androl 24(1):11–16 (1993).
26. De Coen AJ, Tanik MJ, Pang SY, Bottcher R, Keller M, Kuehl DW. Sperm density and toxic substances: a potential key to environmental health hazards. In: Environmental Health Chemistry: The Chemistry of Environmental Hazards. M. Kennedy J. ed. Ann Arbor, MI: Ann Arbor Science Publishers, 1981;263–278.
27. de Souza SM, Abdell M, Ali M, el Said MM, Ali KZ, Komer M, Roald A, Allam M, Elmah M. Deleterious effects of khat addiction on semen parameters and sperm ultrastructure. Hum Reprod 10(19):2295–2300 (1995).
28. Eskenazi B, Wyrobek AJ, Fenster L, Sadler M, Lee J, Hudes M, Remple DM. A study of the effect of chloroethylene exposure on semen quality in dry cleaning workers. Am J Publ Hlth 2003;105:575–581 (2001).
29. Fariss BL, Fenner DK, Plymate SR, Brannen GE, Jacob WH, Zavos PM, Goodpasture JC. Semen and Semen-Cervical Mucus Interaction: Based on Comparative Study of Semen in 1000 Cases of Infertile Marriage. J Urol 66:436–449 (1951).
30. Feidder J, Askaier SA, Hjort T. Nonspermatozoal cells in human spermatazoa. Fertil Steril 28(6):668–673 (1977).
31. Dougherty RC, Whitaker MJ, Tang SY, Bottcher R, Keller M, Kuehl DW. Sperm density and toxic substances: a potential key to environmental health hazards. In: Environmental Health Chemistry: The Chemistry of Environmental Hazards. M. Kennedy J. ed. Ann Arbor, MI: Ann Arbor Science Publishers, 1981;263–278.
32. Sheriff DS. Semen analyses in Hansen’s disease. Trans Roy Soc Trop Med Hyg 38(1):117–20 (1993).
33. Sheriff DS, Legrain M. Evaluation of semen quality in a local Libyan population. Indian J Physiol Pharmacol 36(2):83–97 (1992).
34. Nicola S. Seasonal variations of sperm characteristics. Arch Androl 12(3):23–28 (1984).
35. Stankovic H, Mikac-Devic D. Zinc and copper in human semen. Clinica Chimica Acta 70(1):123–126 (1976).
36. Sipila T, Kouts C, Lewis EJ, Christenson C, Hajar H, Kalimo O, et al. Levels of cholesterol and phospholipids in freshly ejaculated sperm and Percoll-gradient-pelleted sperm from fertile and unexplained infertile men. Fertil Steril 35(6):820–827 (1981).
37. Spira A. Seasonal variations of sperm characteristics. Arch Androl 12(3):23–28 (1984).
38. Vignon F, Le Faou A, Montagnon D, Pradigac A, Czarn C, Winiszewsky P, Pinget M. Comparative study of semen in diabetic and healthy men. Diabetes Metab 17(3):350–354 (1991).
39. Vogt H, Heider WD, Borelli S. Sperm quality of healthy smokers, ex-smokers, and never-smokers. Fertil Steril 45(1):106–110 (1986).
40. Wallace EM, Gow SM, Wu FC. Comparison between testosterone androstenedione and oestro- gen success in a male contraceptive study. I: Plasma lutening hormone, follicle stimulating hormone, testosterone, estradiol, and inhibin concentrations. J Clin Endocrinol Metab 71(1):290–293 (1993).
41. Wang C, Yeung KK. Use of low-dose oral cyprotorex acetate as a male contraceptive. Contraception 21(3):245–270 (1980).
42. Ward J, Heber JD, Smith JA, Edwards KE, Wang H, Perske MA, Whorton EB Jr, Legator MS. Sperm count, morphology and fluorescent body frequency in autopsy service workers exposed to formaldehyde. M utat Res 130(4):417–424 (1984).
43. Weidner W, Antos C, Schierle HG, Haal G, Friedrich H. Semen parameters in men with and without proven chronic bronchitis. Arch Androl 27(1):336–337 (1992).
44. Weidman TD, Schrader SM, Turner TW, Simon SD. Male analysis of military personnel associated with military duty assignments. Reprod Toxicol 10(6):521–528 (1998).
45. Wickings EJ, Freischelm CW, Langer K, Nieschlag E. Semen analysis of military personnel associated with military duty assignments. Reprod Toxicol 10(6):521–528 (1988).
46. Witschi EJ, Katsch CW, Lanier K, Nieschlag E. Heterologous ovum penetration test and seminal parameters in fertile and infertile men. J Androl 4(4):261–271 (1983).
47. Wyrobek AJ, Watchmaker G, Gordon L, Wong K, Moore DH, Winiszewsky P, Pinget M. Comparative study of semen in diabetic and healthy men. Diabetes Metab 17(3):350–354 (1991).
48. Natau SN, Giwa-Osogie DF, Essien E. Effect of repeated semen collection on semen quality. Clin Exp Obstet Gynecol 18(1):39–42 (1991).
49. Noack-Fuller G, De Beer C, Seibelt H. Cadmium, lead, selenium, and zinc in semen of occupationally unexposed men. Hum Reprod 12(9):1774–1781 (1997).
50. Ratcliffe JM, Schrader SM, Steenland K, Clapp DE, Turner T, Horning RW. Semen quality in papaya workers with long term exposure to ethylene dibromide. Br J Ind Med 40(3):226–227 (1983).
51. Richardson DW, Atkinson RG, Louden NB. The functional competence of human spermatozoa recovered after vasectomy. J Reprod Fertil 70(2):575–579 (1984).
52. Rogers BJ, Van Campen H, Ueno M, Lambert H, Bronson R, Halle R. Analysis of human spermatozoa: fertilizing ability using zona-free ova. Fertil Steril 32(6):664–670 (1979).
53. Rosenberg MJ, Wyrobek AJ, Ratcliffe J, Gordon LA, Watchmaker G, Fox SM, Moore DH, Horning RW. Sperm as an indicator of reproductive risk among petroleum refinery workers. Br J Ind Med 40(2):123–127 (1983).
54. Saarinen M, Suonio S, Kaupainen O, Saarikoski S. Cigarette smoking and semen quality in men of reproductive age. Androllogia 1986;670–676 (1987).
55. Albrechtsen I. Br J Ind Med 35(2):297–300 (1978).
56. Albrechtsen I. Br J Ind Med 35(2):297–300 (1978).
57. Albrechtsen I. Br J Ind Med 35(2):297–300 (1978).