Quantitative effects of male age on sperm motion

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BACKGROUND: Semen quality is associated with fertility status, but there is little quantitative information on risk factors that affect semen quality, especially in non-clinical populations. Advancing male age has been associated with a decline in semen quality, with the largest effect being on sperm motility. However, there is little quantitative data on the specific components of sperm motion that are affected by male age. METHODS: We performed linear regression analyses of 14 aspects of semen quality measured by computer-assisted semen analysis (CASA) in a non-clinical cohort of 90 non-smoking men, aged 22–80 years, who had no history of infertility or reproductive problems. RESULTS: We found age-associated declines in CASA-determined motility (% motile, 0.8% per year; % progressively motile, 0.9% per year; % rapidly motile, 0.4% per year, P ≤ 0.001) and three quantitative aspects of sperm motion [linearity (LIN), 0.2% per year; straight line velocity (VSL), 0.2% per year, and average path velocity (VAP), 0.3% per year, P < 0.05], with no evidence for age thresholds and no significant association with abstinence duration. Age was not significantly associated with amplitude of lateral head (ALH) displacement, beat cross frequency (BCF) and nuclear elongation or size. CONCLUSIONS: Quantitative analysis of sperm motion indicates that as men age, they produce fewer motile sperm, which are able to travel less along a linear path, thus covering less forward distance per unit time. These findings may have fertility implications for men who choose to delay fatherhood.

Key words: CASA/human/male age/motility/sperm

Introduction

One in six couples of childbearing age is unable to conceive, and male factors contribute to >25% of cases (Templeton, 1995). About 60% of male factor infertility may be due to genetic causes, but the contributions from environmental and host factors such as age and diet are poorly understood. As more couples are choosing to delay childbearing (Ventura et al., 1997), it is becoming increasingly important to understand how male age affects the risk of infertility, especially in non-clinical populations.

Prior rodent and human studies have reported that certain aspects of semen quality decline with age (Kidd et al., 2001; Sloter et al., 2004). However, most human studies have been conducted in clinical settings with sperm donors or men with fertility concerns. Thus, it is unclear whether these findings are relevant to the general population. Also, few of the clinical studies included men over the age of 50 years and seldom considered potential confounders that might explain changes with age, such as smoking history or occupational exposures (Kidd et al., 2001). We recently reported age-associated reductions in semen volume, sperm concentration and subjective sperm motility using conventional semen analyses in a group of ~100 healthy workers and retirees (Eskenazi et al., 2003). In that report, the number of motile sperm decreased by 0.7% per year of age.

The purpose of this study was to investigate the effects of age on sperm, quantitatively, using computer-assisted semen analysis (CASA) to measure 14 aspects of sperm numbers, motility and sperm head morphometry and to provide direct insight into the specific kinematic components of sperm motion that are affected by male age.

Materials and methods

Study population

Our study population consisted of 97 healthy male volunteers, aged 22–80 years, who were recruited for the Age and Genetic Effects on Sperm (AGES) study between October 1997 and July 1998 among active employees/retirees at the Lawrence Livermore National Laboratory (LLNL, Livermore, CA, USA). This workforce was relatively homogeneous and healthy, with all participants enrolled in comprehensive...
health care programmes (Eskenazi et al., 2003). Recruitment was conducted by the staff at the University of California at Berkeley (UCB, Berkeley, CA, USA) to maintain donor anonymity, and the LLNL housed the sperm analysis laboratory. The AGES study was approved by the Institutional Review Board of each participating institution, and all participants provided written consent. Potential participants were screened by telephone using the following exclusion criteria: current or prior fertility or reproductive problems; smoked cigarettes in the last 6 months; vasectomy; reported history of undescended testicle or prostate cancer; chemotherapy or radiation treatments for cancer; or a previous semen analysis with zero sperm count. If men at screening had had a fever over 101°F in the prior 3 months, their appointment date was moved to 3 months from the date of the fever. At least 15 men were enrolled for each age decade between 20 and 70 years; additional men aged >70 years were also enrolled. Eligible men were mailed a questionnaire on medical and reproductive history, sociodemographic characteristics (age, race and education), occupation, possible exposures, diet and lifestyle habits. Completed questionnaires were mailed to UCB and reviewed with the participant over the telephone. Men were requested to provide a semen sample by masturbation into the collection container after 4–7 days to deliver it inside an insulated container to a drop box at the LLNL, noting the actual duration of abstinence.

### CASA analyses

Coded specimens were delivered within 2 h of collection to the semen analysis laboratory at the LLNL. CASA was performed using the HTM-Ceros semen analyzer (Hamilton Thorne Research, USA) according to the manufacturer’s operation guidelines. Semen samples were maintained at room temperature until analysed. Fifty microlitres of each sample were diluted 1:1 using Dulbecco’s phosphate-buffered saline solution (DPBS) with 1 g/L of glucose and 0.3 g/L of bovine serum albumin (BSA) (WHO, 1992). All samples with >70 × 10⁶/mL sperm were diluted to a standardized sperm concentration of 3 × 10⁶/mL sperm. About 3–4 μL of diluted semen was pipetted into one side of a 2X-CEL 20-μm-depth chambered microscope slide (Hamilton Thorne Research) maintained at 37°C by a MiniTherm slide warmer (Hamilton Thorne Research). After 1 min, multiple microscope fields spanning the entire slide preparation were analysed on an Olympus CH30 microscope equipped with a 10× negative phase objective for 0.5 s per field using a video frame rate of 60 Hz. When possible, at least 150 motile sperm were evaluated per drop of semen. Between 2 and 4 drops of diluted semen were evaluated per donor, and the median value was used for data analyses. Each CASA field was archived onto videotape as backup using a Sony Hi-Fi Stereo VCR (model SLV-975HF) and a Videotronics TitleMaker 2000.

The 14 CASA measurements used in this study are listed in Tables I and II. Two measures of sperm number (concentration and total count) are also listed in Table I and Table II.

### Table I. Computer-assisted semen analysis measurements of sperm motility and numbers by age decade among 90 healthy non-smoking donors (the California Age and Genetic Effects on Sperm study)

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>Number of donors</th>
<th>MOT (%)</th>
<th>RAP (%)</th>
<th>PRO (%)</th>
<th>Concentration (10⁶/mL)</th>
<th>Total count (10⁹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–29</td>
<td>19</td>
<td>56.0 (32–64)</td>
<td>31.5 (17–41)</td>
<td>22.5 (12–30)</td>
<td>96.5 (55–146)</td>
<td>289.8 (118–489)</td>
</tr>
<tr>
<td>30–39</td>
<td>20</td>
<td>42.8 (28–53)</td>
<td>27.3 (22–36)</td>
<td>21.0 (14–26)</td>
<td>81.2 (68–104)</td>
<td>289.6 (207–445)</td>
</tr>
<tr>
<td>40–49</td>
<td>16</td>
<td>38.5 (14–47)</td>
<td>25.8 (10–33)</td>
<td>16.5 (6–23)</td>
<td>109.8 (70–226)</td>
<td>398.5 (219–915)</td>
</tr>
<tr>
<td>50–59</td>
<td>17</td>
<td>37.5 (7–49)</td>
<td>20.5 (4–33)</td>
<td>14.5 (2–23)</td>
<td>100.0 (70–185)</td>
<td>232.3 (126–286)</td>
</tr>
<tr>
<td>70–80</td>
<td>5</td>
<td>3.0 (2–5)</td>
<td>1.5 (2–3)</td>
<td>1.0 (0.4–2)</td>
<td>55.5 (30–70)</td>
<td>55.5 (43–987)</td>
</tr>
</tbody>
</table>

All donors 90 38.0 (12–53) 25.0 (6–34) 17.0 (5–34) 92.2 (58–172) 255.0 (151–454)

P value for age

Median values are presented (interquartile ranges 25th–75th percentile shown in parentheses). MOT, per cent motile; PRO, per cent progressive motility; RAP, per cent rapid motility.

*Slow sperm (<5 μm/s) were counted as motile. Thus, % motile sperm equals the number of sperm with any head movement divided by total sperm analysed × 100.

*Per cent rapid sperm equals the number of sperm with VAP ≥ 25 μm/s divided by the total number of sperm analysed × 100.

*Per cent progressive sperm equals the number of sperm with VAP ≥ 25 μm/s and STR ≥ 80% divided by the total number of sperm analysed × 100.

*Based on linear regression analyses, after adjusting for a history of urinary tract infections, time from collection to analysis, past smoking history and body mass index (BMI).

### Table II. Computer-assisted semen analysis measurements of sperm kinematics, size and shape by age decade among 90 healthy non-smoking men (the California Age and Genetic Effects on Sperm study)

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>Number of donors</th>
<th>Sperm motion parameters</th>
<th>Morphometry parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LIN (VSL/VCL)</td>
<td>VSL (μm/s)</td>
</tr>
<tr>
<td>20–29</td>
<td>19</td>
<td>57.5 (55–63)</td>
<td>49.1 (47–54)</td>
</tr>
<tr>
<td>30–39</td>
<td>20</td>
<td>58.0 (56–62)</td>
<td>51.0 (44–57)</td>
</tr>
<tr>
<td>40–49</td>
<td>16</td>
<td>54.3 (50–58)</td>
<td>45.9 (42–56)</td>
</tr>
<tr>
<td>50–59</td>
<td>17</td>
<td>53.0 (50–61)</td>
<td>41.3 (36–51)</td>
</tr>
<tr>
<td>60–69</td>
<td>13</td>
<td>54.8 (51–60)</td>
<td>52.0 (44–56)</td>
</tr>
<tr>
<td>70–80</td>
<td>5</td>
<td>50.0 (45–57)</td>
<td>32.7 (27–48)</td>
</tr>
<tr>
<td>All donors 90</td>
<td></td>
<td>56.0 (51–60)</td>
<td>47.9 (40–55)</td>
</tr>
</tbody>
</table>

P value for age

ALH, amplitude of lateral head; BCF, beat cross frequency; LIN, linearity; STR, straightness of trajectory; VCL, curvilinear velocity; VSL, straight line velocity.

*See Figure 1 for definitions of kinematic parameters.

*See Materials and methods for the definition of SIZ and ELO parameters. Median values (interquartile ranges 25th–75th percentile shown in parentheses).

*Based on linear regression analyses, after adjusting for a history of urinary tract infections, time from collection to analysis, past smoking history and body mass index (BMI).
Results

Characteristics of study population

The 97 male volunteers recruited for the AGES study were on average 46.4 years of age (SD = 15.8 years, range = 22–80 years) and well distributed among the age decades (Table I). Visual microscopic analyses identified seven men, all of whom were >60 years, who were either azoospermic or had no motile sperm, thereby reducing to 90 the number of men evaluated by CASA. Two of the four azoospermic men and all of the men with zero sperm motility had fathered children earlier in life, and none had been diagnosed with fertility problems in their past. The aetiology of these defects was not evident even from their questionnaires but is possibly age related.

By CASA, the median sperm concentration was 92 × 10^6/ml sperm, and total sperm count was 255 × 10^6 sperm; 38% of sperm were motile (MOT), 25% were rapidly motile (>25 μm/s, RAP) and 17% were progressively motile (i.e. rapid and linear, PRO). These CASA measures were highly correlated with the conventional semen quality data among the same subjects (Eskenazi et al., 2003); per cent motile sperm, R^2 = 0.94, Figure 2A; per cent progressively motile sperm, R^2 = 0.88, Figure 2B; and sperm concentration, R^2 = 0.85, Figure 2C. There was a 1:1 within-specimen correspondence between the conventional and CASA measurements for per cent motile and sperm concentration, but conventional analysis detected ∼30% more progressively motile sperm than did CASA.

Effects of age

CASA analyses did not detect an age effect on sperm concentration or total count per specimen but did detect an effect on MOT, RAP and PRO (Table I). Regression analyses showed age-related decreases, with no indication of a threshold (Figure 3A–C). The variation among individuals was high (Tables I and II) but not related to age. Age remained strongly associated with MOT (P < 0.0001), RAP (P < 0.0001) and PRO (P < 0.0001), after adjusting for a history of urinary tract infections, time from collection to analysis, smoking history and BMI. Regression analyses showed that MOT, RAP and PRO decreased 0.8, 0.4 and 0.9% per year of age, P < 0.001 (Figure 3A–C). Abstinence was not a confounder of the effects of age on CASA-determined motility (P >0.1). Men in their 20s averaged 31.5% RAP sperm compared with 20.5% for men in their 50s and 1.5% among men in their 70s.

Table II and Figure 3D–F summarize the effects of age on the seven CASA kinematic measurements described in Figure 1. Linear regression modelling showed significant age-related
Sperm motility parameters and male age

decreases in average path velocities (VAP, 0.3% per year, \( P = 0.04 \)), VSL (0.2% per year, \( P = 0.03 \)) and LIN (0.2% per year, \( P = 0.005 \)). There was no evidence of an age-related threshold, illustrated visually in Figure 3 and confirmed using non-linear modelling (data not shown). Although variation was high among individuals, it was not related to age (Table II). Omitting the five donors aged >69 years did not eliminate the statistical significance of these findings (VAP: \( P = 0.03 \); VSL: \( P = 0.02 \); LIN: \( P = 0.01 \)). Table III provides the values for these sperm parameters for 25- versus 55-year-old men, as predicted from the linear regression analyses (Figure 3).

We found no evidence of an association between age and lateral head amplitude (ALH), BCF, STR or VCL (\( P > 0.1 \)). There was also no evidence of an association between age and nuclear size or elongation ratio (Table II).

The associations between age and CASA-determined motility parameters were not affected by the DPBS/glucose diluent used. Sperm concentration, which dictated the amount of diluent used (see Methods), was not associated with CASA-determined motility (Figure 4); i.e. younger men did not have significantly higher sperm concentrations than older men (\( P = 0.3 \), Table I). Also, the proportion of diluent used (i.e. the dilution factor) was not associated with CASA-determined motility measurements as shown in Figure 5 for %motility (\( r = 0.03 \), \( P > 0.1 \)) nor with changes in PRO, RAP, VAP or LIN (\( P > 0.1 \)).

Correlations among CASA parameters

Table IV summarizes the correlations among 14 CASA parameters for the 90 men in this study. The three measurements of motility, MOT, PRO and RAP, were highly inter-correlated (\( P < 0.01 \)). VSL and VAP were highly correlated with each other (\( P < 0.01 \)), highly correlated with VCL (\( P < 0.01 \)), moderately correlated with MOT and PRO (\( P < 0.05 \)) and moderately correlated with STR (\( P < 0.05 \)), but neither measure is significantly correlated with LIN. However, STR and LIN are highly correlated (\( P < 0.01 \)). As summarized in Table IV, there was no correlation between the nuclear elongation ratio and any of the sperm motility (MOT, PRO and RAP) or kinematic parameters.

Discussion

CASA provides quantitative measurements of three general aspects of sperm motility as well as specific kinematic measures of sperm motion; our study is the first to use CASA to assess the effects of age on sperm kinematics. We present quantitative evidence of age-associated reductions in the proportion of motile sperm and their straight line motion. Regression analyses indicate that there are no age-related thresholds for the sperm motility (MOT, RAP and PRO) and sperm kinematic (LIN, VSL and VAP) end-points, consistent with a gradual decline in sperm motion with advancing male age.

The major effects of advancing male age were on the highly correlated CASA-determined sperm motility parameters (MOT, RAP and PRO) and on three sperm kinematic parameters (LIN, VSL and VAP). MOT, RAP and PRO have been associated with decreased pregnancy rates and longer time to pregnancy in partners of older men (Abramsson, 1988). VSL, LIN and VAP have been correlated with fertilization rates.
in vivo and may be bioindicators of the fertilizing ability of human sperm (Hirano et al., 2001). These age-related reductions in sperm motility predict fertility problems for men who choose to delay attempting fatherhood and may provide a mechanistic explanation for previous findings of decreased pregnancy rates and longer times to pregnancy in partners of older men (Abramsson, 1988; Ducot et al., 1988; Brzechffa et al., 1998; Spandorfer et al., 1998).

Inspection of the sperm kinematic parameters affected by age versus those that were not (Table II, Figure 3) leads to a quantitative model of the effects of male ageing on motile sperm. Using 25 versus 55 years of age as an example (Table III), the age-related decline in VSL predicts that the sperm of older men travel \( \sim 10\% \) shorter overall distance per unit time (50.5 versus 45.4 \( \mu \text{m/s} \)). The age-related declines for VAP and VCL suggest that sperm of older men also travel \( \sim 9\% \) slower along their average path and \( \sim 6\% \) slower along the point–point path of

**Table III.** Comparison of predicted values for sperm motion parameters among 25- and 55-year-old men

<table>
<thead>
<tr>
<th>Computer-assisted semen analysis motion parameter</th>
<th>25 years of age</th>
<th>55 years of age</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAP**</td>
<td>58.0</td>
<td>53.2</td>
</tr>
<tr>
<td>VSL**</td>
<td>50.5</td>
<td>45.4</td>
</tr>
<tr>
<td>VCL*</td>
<td>85.5</td>
<td>81.1</td>
</tr>
<tr>
<td>ALH</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>BCF</td>
<td>25.4</td>
<td>25.3</td>
</tr>
<tr>
<td>STR*</td>
<td>83.7</td>
<td>82.1</td>
</tr>
<tr>
<td>LIN***</td>
<td>58.3</td>
<td>54.7</td>
</tr>
</tbody>
</table>

ALH, amplitude of lateral head; BCF, beat cross frequency; LIN, linearity; STR, straightness of trajectory; VCL, curvilinear velocity; VSL, straight line velocity. Based on linear regression analyses, after adjusting for a history of urinary tract infections, time from collection to analysis, past smoking history and BMI. *\( P < 0.1, ** P < 0.05, *** P < 0.01 \) for linear regression analyses (see Table II).
travel (Figure 3). The lack of a significant age effect on ALH and BCF suggests that age does not alter the frequency at which sperm cross the average path (25 times per second) nor the amplitude of deviation around that average path (3.8 μm). Taken together with the age-related decrease in LIN and a trend towards a decrease in STR, our model suggests that sperm of older men follow a less linear path (i.e. more curved) than sperm of younger men, which is consistent with our visual assessments of these donors using conventional semen analyses with phase-contrast light microscopy (Eskenazi et al., 2003).

Our study did not find an age effect on ALH, and ALH was not correlated with any other motion or kinematic parameter (Table IV). ALH is often used to estimate IVF outcome (Barlow et al., 1991). ALH measures the vigour of flagellar beating in conjunction with the frequency of cell rotation (Verstegen et al., 2002), which has been associated with the ability of sperm to penetrate cervical mucus and fuse with oocytes. Taking together, our CASA findings suggest that although advancing age may not directly diminish the ability of sperm to penetrate and fuse with oocytes, older men will produce fewer sperm that reach the oocyte as a consequence of reduced per cent of motile sperm and reduced LIN of motion among the remaining motile sperm.

In our study, CASA measurements of overall sperm motility (MOT, PRO and RAP) compared well with the corresponding conventional measures. However, we had reported a small age effect on both sperm concentration and counts by conventional analysis (Eskenazi et al., 2003) but did not find this by CASA analyses (Figure 2). This might be explained in part by the observation of Verstegen et al. (2002) that conventional sperm counts are more reliable than those by CASA analyses at low sperm concentration. This may be caused by the high-background seminal debris particles of similar size and luminosity present in human semen that would be counted as immotile sperm heads (Verstegen et al., 2002).

Our study design has several notable strengths. Our study has significantly larger number of older men than any previous study (Kidd et al., 2001). Recruitment for our study was limited to men drawn from a single large occupational setting; men with ill health or with known infertility-related problems were excluded before analyses. The cohort was relatively homogeneous, consisting of employed and retired workers of middle to high socioeconomic class with employer-paid access to medical care, unlike almost all previous studies of age effects on conventional semen quality parameters (Homonnai et al., 1982; Nieschlag et al., 1982; Schwartz et al., 1983; Dondero et al., 1985; Abramsson, 1988; Check et al., 1989; Singer et al., 1990; Carlsen et al., 1992; Gallardo et al., 1996; Haidl et al., 1996; Irvine et al., 1996; Rolf et al., 1996; Berling and Wolner-Hanssen, 1997; Lemcke et al., 1997; Spandorfer et al., 1998; Kidd et al., 2001). Our study provided detailed information on a wide range of potentially confounding factors (abstinence, time between sample collection and sample processing, smoking habits, etc.), and regression analyses were adjusted in accordance with identified covariates. The statistical power to detect an association between semen parameters and age was improved by the addition of larger numbers of older men, compared with previous studies (Abramsson, 1988;Check et al., 1989; Gallardo et al., 1996; Irvine et al., 1996; Spandorfer et al., 1998).

Our findings are consistent with those of Singh et al. (2003), who reported a relation between age and reduced motility in sperm of men aged 20–57 years by conventional semen analysis, but their study was of a mixed population of patients from an infertility clinic and a non-clinical group. In contrast, Chen et al. (2004) did not find a statistically significant relationship between age and semen parameters, but their study was limited to men up to 54 years of age and they only reported per cent motile sperm.

Age-related cellular or physiologic changes in the reproductive tract, hormonal changes or increased oxidative damage...
may be primary events leading to decreased motility in older men. Age effects on the prostate may contribute to changes in seminal plasma which may affect sperm motility (Schneider and Monticone, 1978). There may also be age-related changes in the epididymis, where sperm acquire the capacity for vigorous forward motility during transit (Hamilton and Naftolin, 1981). Also, the epididymis is a hormonally sensitive tissue that plays an important role in sperm maturation. Reactive oxygen species (ROS) play a role in male infertility, where excessive amounts impair spermatozoal motility. Ageing results in histological and biochemical changes in the epididymis that are suggestive of oxidative damage (Robaire and Hales, 2003). A recent article showed that higher antioxidant intake over the normal dietary and supplement use range was associated with higher motility in the same set of men used in our study (Eskenazi et al., 2005). Also, antioxidant intake attenuates the adverse effect of age on sperm motility. Further studies are warranted to determine the cellular damage pathways that lead to detriment in some kinematic parameters and not in others.

Our findings predict that the average man may become progressively less fertile as he ages due to reduced proportions of motile sperm and decreased abilities of motile sperm to maintain forward motion along a linear path. However, the numerical relationships between the per cent changes in CASA-determined motility parameters and the magnitude of decline of male fertility remain to be established. Our data also suggest that, unlike fertility in women, there appears to be no evidence of an age threshold for these sperm parameters for men, but rather a gradual decline with advancing age throughout normal reproductive years and into senescence. Thus, our findings may have important implications for men who choose to delay fatherhood, because age may reduce their chance for success.

Acknowledgements
This work was performed under the auspices of the US Department of Energy by the LLNL contract W-7405-ENG-48, with funding from Superfund P42 ES04705 from the National Institute of Environmental Health Sciences (Eskenazi and Wyrobek, study directors).

References

Table IV. Correlation among the computer-assisted semen analysis parameters of sperm motility, kinematics, size and shape among 90 healthy non-smoking men

<table>
<thead>
<tr>
<th>MOT</th>
<th>PRO</th>
<th>RAP</th>
<th>VAP</th>
<th>VSL</th>
<th>VCL</th>
<th>ALH</th>
<th>BCF</th>
<th>STR</th>
<th>LIN</th>
<th>ELO</th>
<th>SIZ</th>
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<tbody>
<tr>
<td>1.00</td>
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<td>1.00</td>
</tr>
</tbody>
</table>

ALH, amplitude of lateral head; BCF, beat cross frequency; LIN, linearity; MOT, per cent motile; PRO, per cent progressive motility; RAP, per cent rapid motility; STR, straightness of trajectory; VCL, curvilinear velocity; VSL, straight line velocity. **P ≤ 0.01, *P ≤ 0.05.


Submitted on September 20, 2005; resubmitted on January 20, 2006, May 5, 2006; accepted on May 19, 2006