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The Relationship between Physical Attributes of Beard and Respirator Leak Rates

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Abstract. The purpose of this study was to assess the effect of various physical attributes of beard on respirator leak rates in two ethnic groups. Five study volunteers each of Middle Eastern and Anglo-Saxon ethnicity were selected for this study. They were asked not to shave for a period of two weeks and subjected to a daily leak rate measurement using a Control Negative Pressure (CNP) fit tester. At the end of the study the beard hair was collected and hair length and diameter were measured to study the association between hair characteristics and respirator leak rates.

A significantly higher length and diameter was observed in the Anglo-Saxon group. However, the leak rate was not significantly different between these ethnic groups. Independently, both hair length and diameter were not significantly correlated to leak rate but an interaction term generated to explain the aspect ratio was inversely correlated with leak rate on day ($r = 0.64$, p-value = 0.048).

The daily respirator leak rates increased exponentially over a twelve-day period with a significant change occurring between day 4 and day 5. A second order regression equation was plotted to accurately predict the respirator leak rate with the age of beard. We conclude that beard hair attributes can be used to predict respirator leak rate.

Introduction

Respirators are used for protection in hazardous environments. To be effective they must have a good facepiece to seal between the flange and the wearer's face. Factors that can interfere with this seal are beard growth, facial hair, moustaches and sideburns, thus calling into question the protective value of the respirator for the user. It has been found that wearers with different amounts of hair have an effect on the performance of a respirator and that the degree is based on the hair interference, the sealing capacities of the mask and the type of mask worn since some masks are roomier than others (Hyatt, *et al*., 1973).

In a study of the effect of facial hair on the face seal of negative-pressure respirator on bearded subjects, it was found that the presence of a beard greatly increases the leakage of the respirator face seal (Skretvedt and Loschiavo, 1984). The explanation for this is found in three components: Diameter, length and density of the beard. The conclusion was that beards should not be permitted when employees are required to wear a respirator. Another study (Nagl, 1995), found that there was a difference in rate of beard growth of pigmented and white anagen beard hair (0.47 mm/day vs. 1.12 mm/day). On the average, beard growth produces hair length of half a millimeter per day (Anonymous (a), 1999). Also hair diameter is classified from very fine which is less than 60 micrometers to more than 80 micrometers which is coarse hair (Anonymous (b), 2003). In a study of four clean shaven men, the first three days showed that hair penetration through the mask was greatest but continued to show variations from day to day. This indicated that even small moustaches, small "Van Dyke" beards and short to medium length sideburns would cause difficulty with the sealing surface of the mask. It was concluded that the most vulnerable wearer was the one with a very full 2 to 2½" long wiry beard that extended back under the chin and was long at the jaw line (Stobbe, *et al.*, 1988). In reviewing a series of studies from 1964 to 1987, all but two studies showed a 20 to 1000 times leakage rate due to hair presence compared to a clean shaven face (Stobbe, *et al.*, 1988). Another factor is that hair growth is greater in summer than winter. For this reason hair appears to be under the cyclical influence of hormones which are known to be more active in summer than winter, but can vary from individual to individual (McKee and Oestenstad, 1983).

Several factors have emerged from these studies: (1) The effect of time on the growth of a beard is not the same for each participant. (2) A beard is not static because it keeps changing from day to day. (3) Because hair interferes with respirator seal, individuals with a beard may be placing themselves in jeopardy.

Two types of respirators, Elastomeric Respirators and particulate Filter Respirators (half-mask and full facepiece), used by workers in industry, fire fighters, military men and health care professionals for protection against

chemical or biological agents or airborne diseases, are not effective with facial hair (Anonymous (c), 1994). While the Occupational Safety and Health Administration (OSHA) have granted the usage of these rubber respirators by industry workers, fire fighters, military men and health care professionals, studies conducted by OSHA show that there is some leakage caused by facial hair (beard) (OSHA, 2003). In Saudi Arabia, the majority of men have beards, from here comes the importance of this study. The purpose of this study was to examine the leakage rate on best fit between two ethnic groups to determine the impact beard growth will cause on leakage of the hazardous atmosphere into the interior of the respiratory-inlet covering.

Controlled Negative Pressure (CNP) technology is based on exhausting air from a temporarily sealed respirator facepiece to generate and then maintain a constant negative pressure inside the facepiece. The rate of air exhaust is controlled so that a constant negative pressure is maintained in the respirator during the fit test. The level of pressure is selected to replicate the mean inspiratory pressure that causes leakage into the respirator under normal use conditions. With pressure held constant, air flow out of the respirator is exactly equal to air flow into the respirator. Therefore, measurement of the exhaust stream that is required to hold the pressure in the temporarily sealed respirator constant yields a direct measure of leakage air flow into the respirator (ANSI, 2000).

Materials and Methods

A fit Tester Model 3000 Control Negative Pressure QNFT (Dynatech Nevada, Carson, NV) was used during the study. Leak rate of the air in ml/min was measured directly for each fit test with a feedback (a numerical value measuring the minimum leak rate that can be gotten from a respirator fitting with a normal donning) (Hyatt, *et al*., 1973). For each day during the 12 days period, the half-mask respirator was used only to determine beard growth effect on the seal of the respirator.

Measurements were repeated for five times every day during the 12 day period except for the weekend (day 6 and day 7) during the study. Therefore, the total is 10 different days.

Major calibrations of the CNP system for pressure and flow-rate transducers were performed at the beginning of the study each day. Calibrations involve installing test manifolds in the cartridge receptacles of the test respirator to temporarily seal its air-purifying path.

Optimum leakage of the respirator and the type of beard/hair that caused the leakage was obtained by comparing the results of the fit tests in relation to beard growth. These results were then compared between the two ethnic groups to determine which group had more leakage.

Experimental Approach

A facial fit test to determine leakage by creating a negative pressure inside the facepiece similar to normal inspiratory pressures was conducted using a half mask respirator. This study was performed to investigate the effectiveness of a respirator for the protection of a worker from a hazardous atmosphere. The study involved the same test on the same participants with a best fit for two ethnic groups to record the least amount of leak rate measurement for each. Trials were conducted until a minimum leak rate was established.

Ten men from two different ethnic groups: Five Anglo-Saxons, ages 23-60, and five Middle Easterners, ages 23-40, were fit tested.

The test was conducted for a period of 12 days, starting from the shaven face to the end of the test in which the men had not shaven. Every day the Quantitative Fit Test (QNFT) was performed, except for the first week end (Saturday and Sunday). At the end of the period, the facial hair was razor-shaved in a one inch square and 10 hairs were collected. The diameter and length of the facial hair were described under the light microscope.

The QNFT was used as the fundamental component for selecting the best fitting respirator for a given worker to achieve a desired level of protection in the workplace. QNFT is based on the use of controlled negative pressure (CNP).

Human Subject Tests

The human subject protocol involved 10 volunteer subjects: 10 males with a mature beard from two different ethnic groups 1) Middle Eastern and 2) Anglo-Saxon. Each subject participating in the study completed a 5-10 min. respirator/ fit-test familiarization training course which involved donning the mask, holding the breath, measuring the leak rate and maintaining a calm exterior position (not moving) while sitting on a chair with a straightforward look during the test . All subjects were required to razor-shave on the first day of the study only and then to refrain from shaving any facial hair growth for the rest of the 12 days period. At the end of the 12 days, the subjects were required to shave or collect 10 hairs as a minimum sample size. These collected hairs were measured in mm as to length with the Peak Scale Lupe 7X (Tohkai Sangyo Co., Ltd., Tokyo Japan). The diameter of the collected hairs was measured with the light microscope with a 10×40 power. Calibrations were done to the scale of the ocular lens of the microscope, thus giving the width of hair in millimeters.

Two different sizes, medium and large, of the MSA air purifying respirator model and elastometric (synthetic polymer) type (half-mask) (Mine Safety Appliances Co., Pittsburg, Pa., Code# 490492) were given to each subject. Two wore a medium half-mask and eight wore a large half-mask Each subject

completed 5 fit tests per day of the assigned half-mask respirator for a period of 12 days (*i.e.*, 10 subjects/one mask/subject/5 trials/fit test/mask/five day = 250 total fit tests for subjects.

A comparison was done at the end of the study between the two ethnic groups. Measurements were taken to determine which group had more leakage everyday and for each day in which there was a noticeable peak of the leak rate. The results were then compared for both ethnic groups.

Statistical Analysis

Statistical analyses were performed using STATA® (College Station, TX). Graphics were produced using Microsoft Excel® or NCSS 97 (Orem, Utah). A two-sample t-test was used to compare the mean leak rate, hair length, and diameter between Middle Eastern and Anglo-Saxon ethnic groups. All tests were two-tailed unless otherwise specified. Correlations were evaluated using Spearman's correlation coefficient.

Results and Discussion

A series of statistical tests were performed to assess the effect of beard length and diameter on respirator leak rate. A histogram of length (Fig. 1 and 2) and diameter (Fig. 3 and 4) of beard hair collected on day 12 was plotted to assess the normality of the distribution in each group.

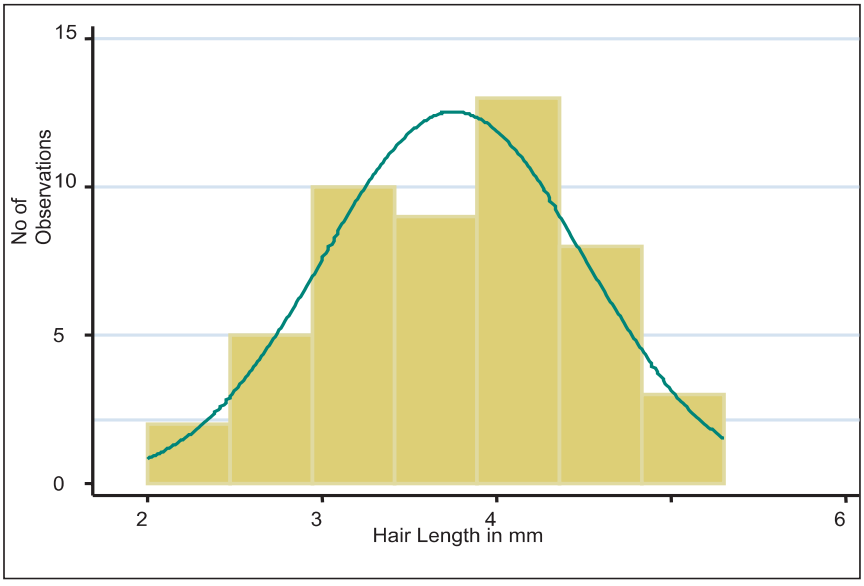

Fig. 1. Histogram of hair length in middle eastern group.

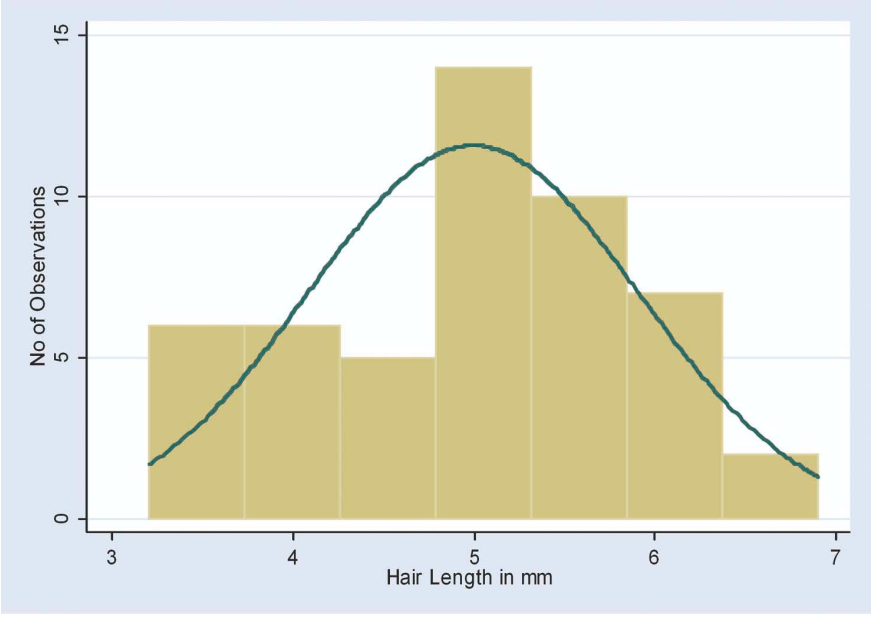

Fig. 2. Histogram of hair length in anglo-saxon group.

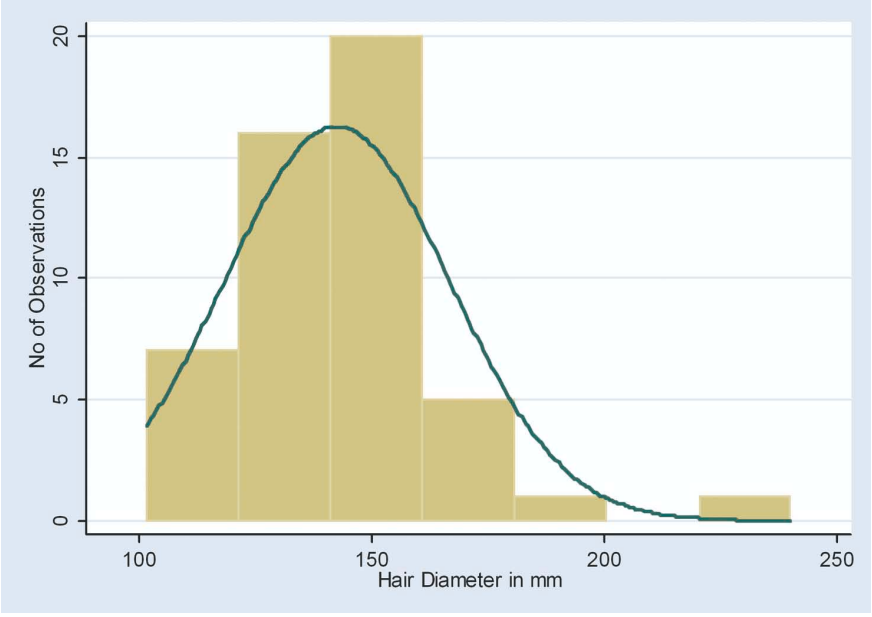

Fig. 3. Histogram of hair diameter in middle eastern group.

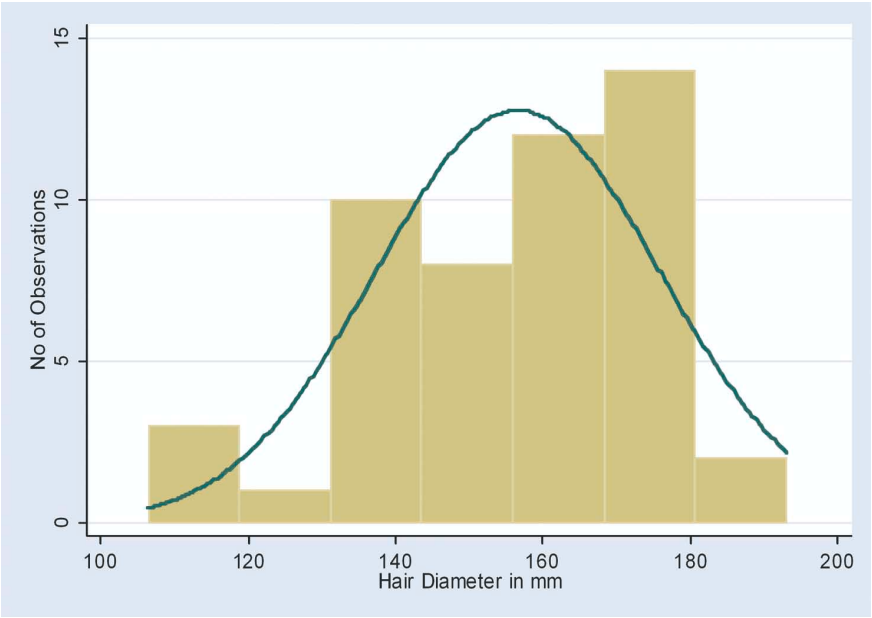

Fig. 4. Histogram of hair diameter in anglo-saxon group.

Since these distributions appear to be normal, a two-sample t-test was performed to assess the differences among these ethnic groups. Both length and diameter are significantly higher in Anglo-Saxon group (p- value <0.001 and <0.002 respectively). The data are provided in Table 1.

Table 1. Hair length and diameter on study day 12.

Day 12	Group		p-value
	Middle eastern	Anglo-Saxon	
Length m	3.7 ± 0.7	5.0 ± 0.9	< 0.001
Diameter mm	0.14 ± 0.02	0.16 ± 0.01	< 0.002

The following histograms (Fig. 5 and 6) show the distribution of day 12 respirator leak rates in Middle Eastern and Anglo-Saxon group. As distribution of this data was not normal, a Wilcoxon Rank-Sum test was performed to assess the differences between these two groups, and the difference was not significant (p-value 0.92).

Subjects from both ethnic groups were combined to examine the correlation among leak rate, beard hair length, and diameter. Neither hair length nor diameter, measured on 12's day of the study, were correlated with the respective

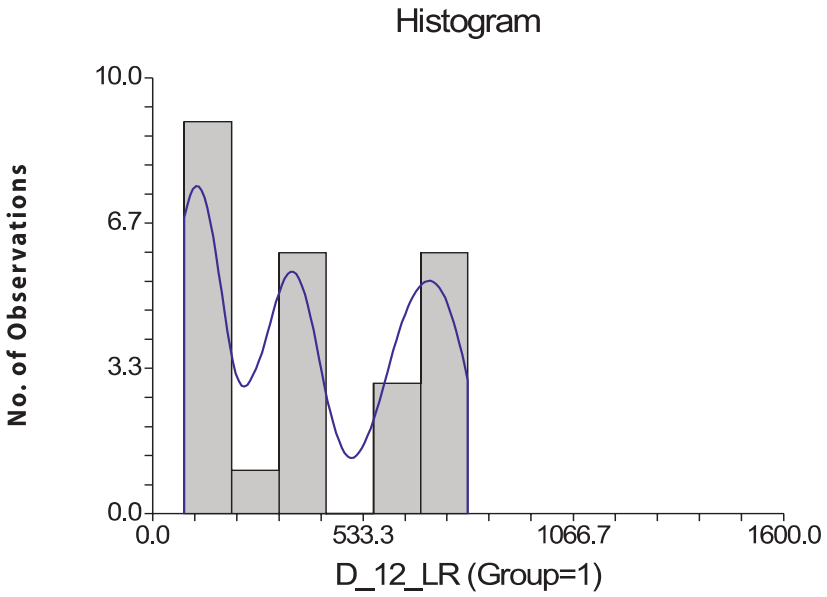

Fig. 5. Leak rate on day 12 cc/min.

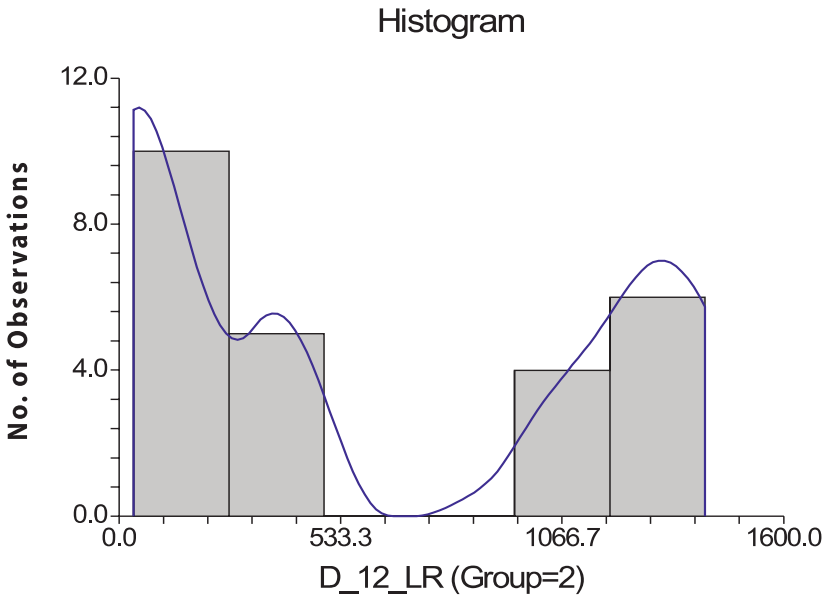

Fig. 6. Leak rate on day 12 cc/min.

study day's respirator leak rate. An interaction term of diameter over length (related to the aspect ratio of beard stubble) was positively correlated with measured leak rate (r = 0.64, p = 0.048). Figure 7 shows an exponential relationship between day 12 measured leak rate and diameter/ length of stubble.

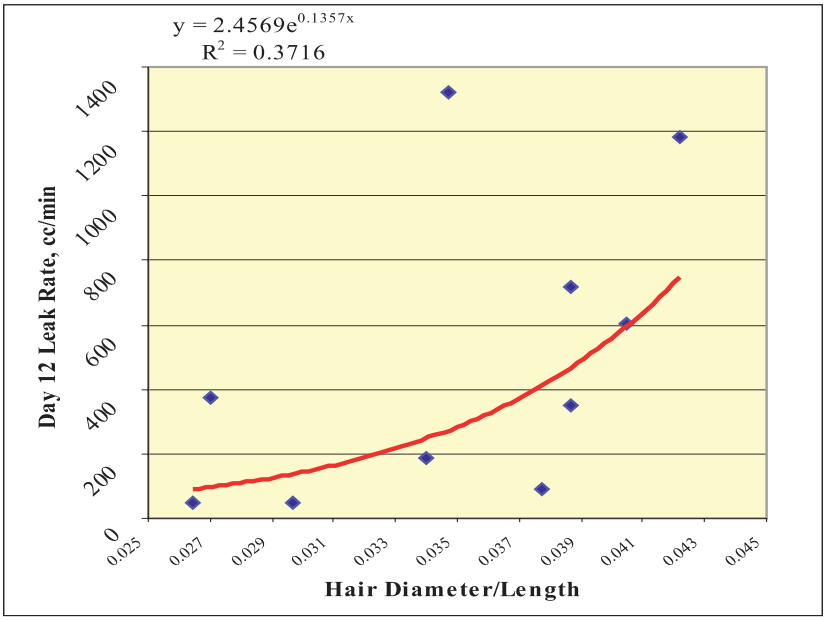

Fig. 7. Correlation between leak rate and diameter length.

Figure 8 shows daily leak rate changes over a period of 12 days excluding weekend days. As expected, the mean leak rate was lowest on days 1 and 2 (22.9 and 22.5 cc/min) and highest on day 12 (491.8 cc/min). The largest daily leak rate change occurred between day 4 and 5 (increase of 137%). As shown in Fig. 8, a second order regression appears to more than adequately describe the relationship observed between leak rate and beard growth over the twelve-day period. Added effects of beard hair characteristics such as texture and density could also contribute to the observed relationship, which is described by the following equation:

$$y = 4.77\,x^2 - 19.53x + 43.43 \quad (R^2 = 0.98)$$

Where: y = respirator leak rate

x = age of beard in days

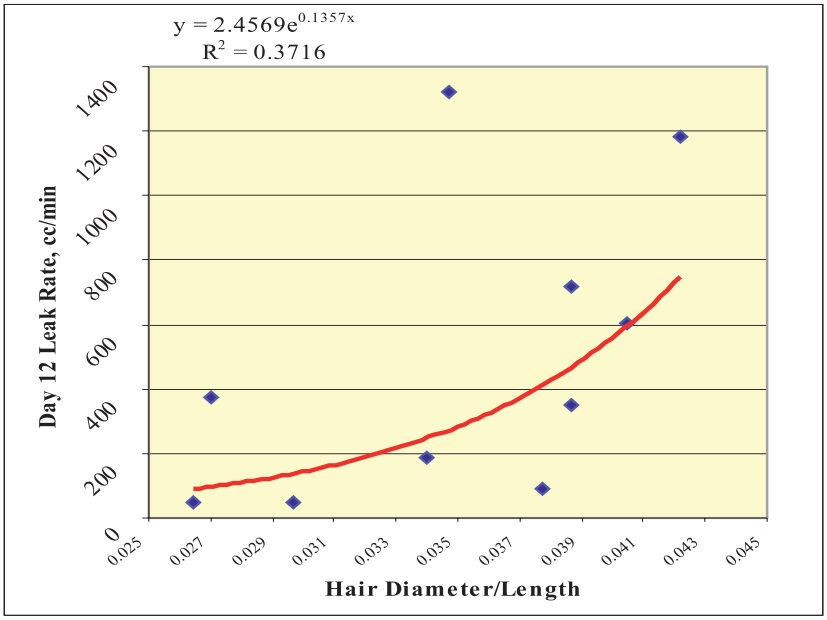

Fig. 8. Mean daily leak rate, cc/min (n = 10).

Study Limitations

A larger sample size is necessary to compensate for inter-subject variability. Further studies are also needed to more fully quantify the effect of daily beard growth and its characteristics on respirator leak rate, and to compare and quantify the effects of various beard hair characteristics on respirator leak rate in other ethnic groups as well. The effect of beard growth on leakage into other types of respirators would also be useful.

Conclusion

Although individual hair characteristics are significantly different in these two groups, the study did not reveal significant differences in respirator leak rates. A higher sample size with daily hair sampling for a longer period of time might be necessary to accurately predict relative usefulness of respirators on an unshaven face. Irrespective of either group, the age of beard growth was positively correlated to respirator leak rate. Because of their higher functional interference with beard growth, only half face respirators were used in the study with appropriate fit. Further studies are needed to quantify the effect of beard growth on full face and quarter face respirators.

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علاقة الخواص الفيزيائية للّحية بمعدلات التسرب من الكمامة

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المستخلص. تهدف هذه الدراسة إلى تقييم تأثير العوامل الفيزيائية المختلفة للّحية على معدل التسرب من الكمامات ، لدى مجموعتين عرقيتين. اشتملت الدراسة على خمسة متطوعين من العرق شرق أوسطي ومثلهم من العرق الأنجلو ساكسوني. طلب من المشتركين عدم حلاقة شعر اللحية لمدة أسبوعين ، كان خلالها يتم قياس معدل التسرب يوميا باستخدام اختبار التحكم في الضغط السلبي. وفي نهاية الدراسة تم تجميع شعر الذقن وقياس طوله وقطره ، لدراسة العلاقة بين خصائص الشعر ومعدل التسرب من جهاز التنفس.

وقد لوحظ أن هناك زيادة معنوية في طول وقطر الشعر في المجموعة الأنجلوساكسونية عن المجموعة الأخرى ، ولكن معدل التسرب لم يختلف بين المجموعتين. ولم يكن هناك ارتباطا بين كل من طول الشعر وقطره ومعدل التسرب على المستوى الانفرادي ، ولكن على المستوى التفاعلي بين الطول والقطر كان هناك ارتباطًا عكسيًا مع معدل التسرب اليومي. فكان معدل التسرب اليومي يزيد بصورة أسية ، خلال فترة الإثنى عشر يومًا مع وجود تغير معنوي بين اليوم الرابع والخامس. وقد تم تطبيق معادلة انحدار من الرتبة الثانية للتوقع الدقيق في معدل التسرب من جهاز التنفس بالنسبة لعمر اللحية. ويستنتج من هذه الدراسة أن خواص شعر اللحية يمكن استخدامها في توقع معدل التسرب من أجهزة التنفس.