Bronchial responsiveness and decline in FEV\textsubscript{1} in aluminium potroom workers

V. Søyseth\textsuperscript{*t}, J. Kongerud\textsuperscript{t}, H. Kjuus\textsuperscript{**}, J. Boe\textsuperscript{t}

ABSTRACT: We have investigated the relationship between annual decline in forced expiratory volume in one second (ΔFEV\textsubscript{1}) and bronchial responsiveness (BR) in aluminium potroom workers.

BR was measured in a cross-sectional study of 337 aluminium potroom workers half-way through a 6 yr follow-up study of lung function. A skin-prick test (SPT) was also performed. During follow-up the mean number of measurements of lung function (FEV\textsubscript{1}) in each subject was 6.8.

Mean ΔFEV\textsubscript{1} was 21.3 ml yr\textsuperscript{-1} (within subject SD=30.5 ml yr\textsuperscript{-1}). Mean ΔFEV\textsubscript{1} was 57.0, 44.5 and 16.6 ml yr\textsuperscript{-1} in subjects who had provocative concentration producing a 20% fall in FEV\textsubscript{1} (PC\textsubscript{20}) ≤8.0, 8.1–32.0 and >32.0 mg·m\textsuperscript{-1}, respectively. After adjustment for gender, atopy, smoking habit, FEV\textsubscript{1}, age and familial asthma the association between BR and ΔFEV\textsubscript{1} was weakened, and was not statistically significant. A significantly accelerated decline in FEV\textsubscript{1} with age was found. The difference in ΔFEV\textsubscript{1} between smokers and nonsmokers was 39.3 ml yr\textsuperscript{-1}, and between subjects who had a positive skin-prick test compared to subjects with a negative skin-prick test 39.6 ml yr\textsuperscript{-1}. In subjects reporting work-related asthmatic symptoms the decline in FEV\textsubscript{1} was 43.2 ml yr\textsuperscript{-1} greater than in asymptomatic subjects. In asymptomatic subjects, positive skin-prick test was also associated with increased ΔFEV\textsubscript{1}.

These data indicate that a single measurement of BR is not a predictor of ΔFEV\textsubscript{1} in aluminium potroom workers. Smoking, work-related asthmatic symptoms, and positive reaction to skin-prick test in asymptomatic workers were risk factors of increased ΔFEV\textsubscript{1}.

Eur Respir J., 1994, 7, 888–894.

Keywords: Aluminium bronchial provocation tests epidemiology forced expiratory volume in one second longitudinal studies

Received: April 14 1993 Accepted after revision December 21 1993

Methods

The study population was selected from a cross-sectional study of bronchial responsiveness in aluminium potroom workers in 1988, who participated in a follow-up study of lung function [3]. There were 380 workers employed in the potrooms, of whom 370 were available at the time of the examination by questionnaires and spirometry. Of these 370, four subjects were excluded from the methacholine challenge because they had FEV\textsubscript{1} <60% of predicted (obtained from a general asymptomatic urban population in Norway [13]), and 29
BR AND AFEV₁ IN ALUMINIUM POTROOM WORKERS

337 subjects gave their informed consent to participate in bronchial challenge testing: 38 females and 299 males, aged 18–67 yrs. Information about respiratory symptoms, smoking habits, familial asthma, and use of airway protection mask was obtained using a questionnaire [14]. Work-related asthmatic symptoms (WASTH) were defined as the combination of dyspnoea and wheezing, improving on days away from work, in subjects who had no asthma before employment. Details of the study population are described elsewhere [3].

Two dry bellows spirometers (Jones Pulmonaire, Jones Medical Instruments Co., Oak Brook, Illinois, USA) were used to measure FEV₁. Bronchial challenge to methacholine was performed in 337 workers using a shortened protocol of the COCKCROFT method [15, 3]. The response was expressed as the concentration of methacholine that could provoke a 20% decrease in FEV₁ from baseline (PC₂₀) [3]. BR was divided into three categories: bronchial hyperresponsiveness (BHR) (PC₂₀ ≤ 8.0 mg·ml⁻¹); minor responsiveness (PC₂₀ 8.1–32.0 mg·ml⁻¹); and normal responsiveness (PC₂₀ >32.0 mg·ml⁻¹) [3]. A skin-prick test (SPT) to five common aeroallergens was also performed [3], using allergen coated lancets (Phazet®, Pharmacia, Uppsala, Sweden). The test result was scored according to the largest weal to any of the five allergens: positive reaction if the largest weal was greater than the histamine reference; equivocal reaction if the largest weal was >1 mm and less or equal to the histamine reference; otherwise the test result was regarded as negative [3].

Lung function had been measured annually, during a 6 year follow-up from 1985 to 1991, by the same staff and spirometers. Some of the workers were tested more than once annually, due to temporary employment outside the potrooms, military service, or education. Some subjects started to work at the plant between 1985 and 1988, and some workers terminated their employment before 1991. Thus, the subjects had on unequal number of follow-ups. In 90% of the subjects, age at the cross-sectional survey deviated less than one year from age at the individual mean follow-up time.

Both spirometers were calibrated every half year with a 3 l syringe. At every visit, the subjects were asked to perform three expiratory manoeuvres: the best of two recordings should be reproducible within 100 ml or 5%, whichever was the largest. The lung volumes were converted to body temperature, pressure, and saturation (BTPS) values. All the recordings were obtained from the subjects in standing position, between 08.00 and 12.00 a.m.

Statistical analyses

Individual least-squares slopes of FEV₁ (bᵢ) versus time were calculated for each subject who had three or more recordings. These bᵢs were used as estimates of ΔFEV₁ and given as positive values if a decrease was estimated. In four of the 337 workers, only two recordings of FEV₁ were available. Thus, the analysis included the remaining 333 workers. A regression of bᵢs on 889

<table>
<thead>
<tr>
<th>Table 1. – Weighted mean of annual decline in FEV₁ (ΔFEV₁ ml·yr⁻¹) in 333 aluminium potroom workers at different levels of bronchial responsiveness stratified for gender, smoking habits, atopy, history of familial asthma, use of respiratory safety mask</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>PC₂₀</td>
</tr>
<tr>
<td>≤8.0 mg·ml⁻¹</td>
</tr>
<tr>
<td>8.1–32.0 mg·ml⁻¹</td>
</tr>
<tr>
<td>&gt;32.0 mg·ml⁻¹</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Skin test</td>
</tr>
<tr>
<td>Negative</td>
</tr>
<tr>
<td>Equivocal</td>
</tr>
<tr>
<td>Positive</td>
</tr>
<tr>
<td>Familial asthma</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>Safety mask</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>95% CI</td>
</tr>
</tbody>
</table>

The inverse of the variance used in the weighted regression of ΔFEV₁ was used as weight. Results are ΔFEV₁ ml·yr⁻¹, number of subjects in parenthesis. Negative values denote incline in FEV₁, positive values denote decline in FEV₁. 95% CI: 95% confidence interval of the mean; FEV₁: forced expiratory volume in one second; PC₂₀: provocative concentration producing a 20% fall in FEV₁.
the various covariates (listed in table 1) was calculated by a maximum likelihood weighted regression method (Appendix 1). The method is described as Method 1 by Diem and Liukkonen [16]. The analyses were performed using the statistical package SYSTAT [17]. The maximum likelihood estimates of the coefficients of the covariates were obtained by defining the LOSS function [17] as the log-likelihood of the $b_i$s [16]. The following covariates were included in the model: gender, atopy, age (continuous), smoking status, familial asthma, use of respiratory protection mask, and BR (Appendix 2). Lung function was expressed as standardized FEV$_1$ (SFEV$_1$, continuous), i.e. the difference between the observed and predicted value divided by residual standard deviation of the prediction lines [18]. As the relationship between ∆FEV$_1$ and SFEV$_1$ might depend on whether lung function was related to the time of inclusion in the study or to the end of follow-up, both these covariates were used in the analyses, as well as SFEV$_1$ at the cross-sectional survey. Age was expressed as the age at the cross-sectional survey. As lung function increases in the younger age groups [19], separate analyses were carried out in those younger than 25 yrs of age and in those who were 25 yrs or older.

The comparison between PC$_{20}$ and respiratory symptoms as predictors of ∆FEV$_1$ was performed by stratified analysis [20], adjusting for smoking status using weights obtained from Step 1 of the weighted regression (smoking status was regarded as the main potential confounder). The stratified analysis was chosen because there were too few subjects to perform a full regression analysis in the different symptomatic subgroups. Similarly, a comparison between respiratory symptoms and response to the SPT was performed using the same method.

**Results**

The total number of spirometric measurements was 2,206, in 333 subjects in whom more than two measurements were performed. The mean follow-up time and the mean number of spirometric measurements was 5.2 yrs (range 0.5–6.9 yrs) and 6.8 (range 3–14), respectively.

*Mean decline in FEV$_1$*

The weighted mean (using the inverse of the variance used in the maximum likelihood model as weights) of ∆FEV$_1$ was 21.2 ml·yr$^{-1}$. The mean standard deviation within subjects was 30.5 ml·yr$^{-1}$.

In table 1, weighted mean of ∆FEV$_1$ at different levels of BR stratified for gender, smoking status, atopy, familial asthma, and airway protection is shown. The weighted mean of ∆FEV$_1$ was 57.0 ml·yr$^{-1}$ in those who had BHR, 44.5 ml·yr$^{-1}$ in those who had minor responsiveness, and 16.6 mg·ml$^{-1}$ in those who had normal responsiveness. In many of the strata a similar relationship between ∆FEV$_1$ and PC$_{20}$ was not found (table 1). In subjects with positive or equivocal reaction to the SPT, ∆FEV$_1$ was 44.0 and 50.2 ml·yr$^{-1}$, respectively, compared to 12.9 ml·yr$^{-1}$ in those who had a negative reaction. There was also evidence for increased ∆FEV$_1$ among smokers (38.1 ml·yr$^{-1}$) compared to past smokers (17.6 ml·yr$^{-1}$) and lifelong nonsmokers (-19.5 ml·yr$^{-1}$). A linear relationship between ∆FEV$_1$ and age was indicated (fig. 1), whereas, ∆FEV$_1$ seemed to be independent of SFEV$_1$ at the cross-sectional survey (fig. 2). A greater ∆FEV$_1$ was also found in those who used airways protection (34.0 ml·yr$^{-1}$) compared to those who reported no use of respiratory safety mask (-102.4 ml·yr$^{-1}$).

*Factors influencing ∆FEV$_1$*

Table 2 shows the results from the weighted regression analysis with ∆FEV$_1$ as the dependent variable and age, gender, smoking status, atopy, familial asthma, SFEV$_1$, use of respiratory safety mask and WASTH as independent variables. The adjusted ∆FEV$_1$ was significantly associated to age at the cross-sectional survey.
Table 2. – Regression of annual decline ($\Delta FEV_1$)(ml·yr$^{-1}$) on some characteristics of aluminium potroom workers, using a two-stage weighted regression

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>$\beta$</th>
<th>se</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender females vs males</td>
<td>-7.1</td>
<td>14.4</td>
<td>-35.4 to 21.2</td>
</tr>
<tr>
<td>Age continuous</td>
<td>1.9</td>
<td>0.4</td>
<td>1.1 to 2.6</td>
</tr>
<tr>
<td>Smoking status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex vs nonsmoker</td>
<td>2.1</td>
<td>17.9</td>
<td>-33.0 to 37.2</td>
</tr>
<tr>
<td>Current vs nonsmoker</td>
<td>39.3</td>
<td>10.6</td>
<td>18.5 to 60.0</td>
</tr>
<tr>
<td>Skin test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equivocal vs negative</td>
<td>39.6</td>
<td>13.7</td>
<td>12.7 to 66.5</td>
</tr>
<tr>
<td>Positive vs equivocal</td>
<td>-3.6</td>
<td>17.7</td>
<td>-38.3 to 31.1</td>
</tr>
<tr>
<td>Familial asthma</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Present vs absent</td>
<td>-12.8</td>
<td>11.7</td>
<td>-35.8 to 10.1</td>
</tr>
<tr>
<td>SFEV$_1$ continuous</td>
<td>-7.4</td>
<td>5.4</td>
<td>-17.9 to 3.2</td>
</tr>
<tr>
<td>Safety mask</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never vs occasional or always</td>
<td>-79.8</td>
<td>15.5</td>
<td>-110.2 to -49.5</td>
</tr>
<tr>
<td>WASTH yes vs asymptomatic</td>
<td>43.2</td>
<td>15.9</td>
<td>12.0 to 74.5</td>
</tr>
<tr>
<td>Bronchial responsiveness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BHR vs MR</td>
<td>13.5</td>
<td>25.4</td>
<td>-36.9 to 63.2</td>
</tr>
<tr>
<td>Minor vs NR</td>
<td>0.2</td>
<td>18.4</td>
<td>-35.9 to 36.3</td>
</tr>
</tbody>
</table>

WASTH: work-related asthmatic symptoms; SFEV$_1$: standardized FEV$_1$. For further abbreviations see legend to table 1.

(1.9 ml·yr$^{-1}$). An overlap of the confidence intervals of the age effect was found between those who were 25 yrs or older and those who were younger than 25 yrs.

Current smokers had a significantly higher AFEV$_1$ (39.3 ml·yr$^{-1}$) than lifelong nonsmokers, whereas, there was no significant difference in AFEV$_1$ between ex-smokers and lifelong nonsmokers. Those who reported use of airway protection had a greater decline in FEV$_1$ than those who never used a safety mask (-79.8 ml·yr$^{-1}$).

There was no significant relationship between AFEV$_1$ and SFEV$_1$ at the cross-sectional survey or at inclusion to the study (-7.4 and 3.4 ml·yr$^{-1}$, respectively). The annual decline in FEV$_1$ was decreasing as SFEV$_1$ at the end of the follow-up increased (-11.5 ml·yr$^{-1}$; p<0.01): i.e. those who had the largest decline in FEV$_1$ had the lowest SFEV$_1$ at the end of the follow-up.

Whereas the crude rates indicated a progressive decline in FEV$_1$ with increasing BR, AFEV$_1$ was not significantly increased in subjects with BHR compared to subjects with normal responsiveness (13.5 ml·yr$^{-1}$), or subjects with minor responsiveness compared to subjects with normal responsiveness (0.2 ml·yr$^{-1}$). After deleting subjects with minor responsiveness from the model, there was no significant difference in AFEV$_1$ between subjects with BHR compared to subjects with normal responsiveness (20.2 ml·yr$^{-1}$). A continuous measure of BR was also used (slope of the dose-response curve (DRS)). No significant association, however was found between DRS and AFEV$_1$, and the use of DRS as an independent measure of BR caused no change between AFEV$_1$ and the other covariates in the model.

Different categories of respiratory symptoms were included in the model and the difference in AFEV$_1$ between those who reported respiratory symptoms and...
Table 5. – Weighted mean $\Delta FEV_1$ (ml·yr$^{-1}$) in subjects who had equivocal or positive reaction to the skin-prick test and subjects who had a negative reaction

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>SPT negative</th>
<th>SPT positive or equivocal</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No symptoms</td>
<td>-0.1 (179)</td>
<td>49.5 (60)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Dyspnœa</td>
<td>50.0 (49)</td>
<td>54.4 (21)</td>
<td>NS</td>
</tr>
<tr>
<td>Wheezing</td>
<td>55.9 (42)</td>
<td>32.7 (19)</td>
<td>NS</td>
</tr>
<tr>
<td>Cough</td>
<td>30.2 (30)</td>
<td>59.8 (13)</td>
<td>NS</td>
</tr>
<tr>
<td>WASTH</td>
<td>84.3 (19)</td>
<td>48.7 (12)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Number of subjects in parenthesis. NS: not significant; SPT: skin-prick test. For further abbreviations see legend to tables 1 and 2.

In this study, we have investigated the relationship between BR and annual decline in $FEV_1$. The unadjusted rates indicated that increased $\Delta FEV_1$ was associated with increased BR. However, after adjustment for age, gender, smoking habits, use of safety mask, familial asthma, SFEV$_1$ and WASTH the difference in $\Delta FEV_1$ between different categories of BR decreased and was not significant. We also found that $\Delta FEV_1$ in those who reported WASTH was independent of the level of BR, and that WASTH was a significant predictor of $\Delta FEV_1$. In asymptomatic subjects, the SPT was a significant predictor of $\Delta FEV_1$.

The finding that $\Delta FEV_1$ was unrelated to BR is apparently not in agreement with the "Dutch hypothesis" [6] and the findings by others [7–10]. However, in two of these studies, bronchial challenge was performed at the end of follow-up and no adjustment was made for baseline FEV$_1$. As baseline FEV$_1$ and BR are highly correlated [3, 4], the observed association between $\Delta FEV_1$ and BR could be a consequence of a decreased baseline FEV$_1$ rather than a cause of increased $\Delta FEV_1$.

Two other studies [8, 10] were restricted to patients with baseline FEV$_1$ rather than a cause of increased $\Delta FEV_1$. As baseline FEV$_1$ and BR are highly correlated, it is likely that allergy - as expressed by a positive SPT - may be associated with increased risk of developing CAL.

The relationship between $\Delta FEV_1$ and current smoking has been found by others [27–29], and seems to apply to aluminium potroom workers as well. However, the difference in $\Delta FEV_1$ between smokers and nonsmokers was higher in our study than in these studies, mainly because of a lower $\Delta FEV_1$ in nonsmokers. A linear relationship between $\Delta FEV_1$ and age was indicated. i.e. age can be treated as a continuous covariate in studies of $\Delta FEV_1$, in adults. The finding that $\Delta FEV_1$ increased with age at the cross-sectional survey is in agreement with JAAKKOLA et al. [30]. Our estimate of the relationship between age and $\Delta FEV_1$ is the mean of the estimates found by others [27, 29].

The relationship between $\Delta FEV_1$ and lung function was dependent on whether SFEV$_1$ at inclusion, at the cross-sectional survey or at the end of the follow-up was used. Those who had the lowest SFEV$_1$ at the end of the follow-up also had the largest decline in FEV$_1$, in accordance with the "horse-racing effect" [31].
The observation that those who never use airway protection have less decline in lung function is apparently surprising, and needs some comment. Firstly, after adjusting for confounding factors, such as age, smoking habit, symptoms, etc., the difference between the users and nonusers decreased. Nevertheless, a significant difference in ΔFEV₁ between these two groups remains, and we believe that the nonusers have decreased susceptibility for the development of respiratory disorders. These workers also had less symptoms [24], and were less reactive [3], than those who reported use of respiratory mask was related to the cross-sectional study, they might have used airway protection during follow-up. Alternatively, this finding could indicate technical problems could cause systematically increased values in the spirometry. Finally, it is unlikely that technical problems could cause systematically increased values in the nonusers.

In conclusion, a respiratory questionnaire seems to be a better screening tool for detection of increased ΔFEV₁ in aluminium potroom workers than a single bronchial provocation test with methacholine.

**Acknowledgements:** The authors thank all the subjects who participated in this study and Hydro Aluminium Årdal for their co-operation and permission to publish the results. They also thank the nurses who performed the majority of the spirometric measurements and methacholine provocation tests, and G. Botten, D. Malterud, E. Nordheim and the plant physicians for valuable comments on the manuscript. Special thanks to P.J. Fleury, SYSTAT, P. Laake and O.O. Aalen for their important contribution to the statistical analyses.

**Appendix 1**

Maximum likelihood estimation of regression coefficients.

We wish to estimate the coefficients in:

\[
\beta_j = \alpha + \sum_{j=1}^{13} \gamma_j \chi_{ij} + \varepsilon_i
\]

(1)

βᵢ=ΔFEV₁ of the iᵗʰ individual calculated by least square regression of FEV₁ by time and \( \chi_{ij} \) is the iᵗʰ covariate of the iᵗʰ individual. Let \( b_j \) denote the estimate of \( \beta_j \).

Now the log-likelihood of the b's is:

\[
\log L = \frac{-333}{2}\ln(2\pi) - \frac{1}{2} \sum_{i=1}^{333} \ln(\sigma^2 + \tau^2/\kappa_i) \]

\[
- \sum_{i=1}^{333} \left( (b_i - \beta_j - \sum_{j=1}^{13} \gamma_j \chi_{ij})^2 / (\sigma^2 + \tau^2/\kappa_i) \right)
\]

(2)

where \( \sigma^2 \) is the variance of \( \beta_j \) not accounted for by the covariates \( \chi_{i1}, \ldots, \chi_{i13} \), \( \tau^2 \) is the residual variance about an individual participant's regression line; and \( \tau^2/\kappa_i \) is the variance of the estimation error associated with the observed slope \( b_j \). \( \kappa_i = \sum (\gamma_j \tau^2)^2 \), i.e. the sum of squared deviation from the mean follow-up time in the iᵗʰ individual.

The NONLIN module of SYSTAT offers an algorithm that can estimate the \( \gamma_j \):

**Step 1**

Specify the model (Equation (1)):

\[
\text{BI}=C_0+C_1X_1+X_2+C_3X_3+C_4X_4+ \quad (3)
\]

\[
C_5X_5+C_6X_6+C_7X_7+C_8X_8+C_9X_9+C_{10}X_{10}+C_{11}X_{11}+C_{12}X_{12}+C_{13}X_{13}
\]

\[
\text{BI}=b_i; \quad C_1(1–13) \text{ estimates of } \alpha, \gamma_j \text{ respectively; } \text{BI}^{13}=\chi_{ij} \text{ of the iᵗʰ participant. (Regarding definition of the Cs, see Appendix 2).}
\]

**Step 2**

Specify the LOSS-function (Equation (2)):

\[
\text{LOSS} = \log(\text{VARIANCE}+\text{VARBI}) + (1/ (\text{VARIANCE} +\text{VARBI})) \times (\text{BI} - \text{ESTIMATE})^2
\]

(4)

where \( \text{VARIANCE}=\sigma^2 \) is estimated by SYSTAT in the computation of the LOSS-function, \( \text{VARBI}=\tau^2/\kappa_i \) and \( \text{BI} = b_i \) are stored on the file in each subject. ESTIMATE=ΔFEV₁ in each individual estimated from Equation (3). Then the LOSS statement is evaluated in each case using the estimate from the model statement. The LOSS is summed over all cases, and this procedure is repeated until the tolerance criteria is obtained, or maximum iteration limit is reached.

**Note:** the constant terms (Equation (2)) do not have to be included when formulating the LOSS function, as they do not make any difference when the LOSS is minimized.

**Appendix 2**

Classification of covariates in the model.

Let \( \chi_{i1}, \ldots, \chi_{i13} \) denote the covariates for the iᵗʰ participant: GENDER: FEMALE \( \chi_{i1}=1 \), MALE \( \chi_{i1}=0 \); AGE; SMOKING STATUS: CURRENT SMOKERS \( \chi_{i2}=1 \), NONSMOKERS \( \chi_{i2}=0 \), LIFELONG NONSMOkers \( \chi_{i2}=0 \); SPT: POSITIVE RESPONSE \( \chi_{i3}=1 \), EQUIVOCAL RESPONSE \( \chi_{i3}=1 \), NEGATIVE RESPONSE \( \chi_{i3}=0 \); FAMILIAL ASTHMA: YES \( \chi_{i4}=1 \), NO \( \chi_{i4}=0 \); USE OF RESPIRATORY MASK: YES \( \chi_{i5}=1 \), NO \( \chi_{i5}=0 \); RESPIRATORY SYMPTOMS: SYMPTOM-FREE \( \chi_{i6}=1 \), MINOR RESPONSIVENESS \( \chi_{i6}=0 \), BRONCHIAL RESPONSIVENESS \( \chi_{i7}=1 \), NORMAL \( \chi_{i7}=0 \).

For definition of abbreviations see text.
References


