

Temporal trends of flour dust exposure in the United Kingdom, 1985–2003

Martie van Tongeren,^{*ab} Karen S. Galea,^a John Ticker,^c David While,^{bd} Hans Kromhout^e and John W. Cherrie^a

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The aim of the study was to examine the long-term changes in inhalation exposure to flour dust in the UK. Flour dust data held in the UK National Exposure DataBase (NEDB) and from one large company from 1985 to 2003 were reviewed. Analysis of the log-transformed data was carried out using linear mixed effect models and expressed as the relative annual change in exposure. 1451 inhalable flour dust measurements were analysed. The overall mean flour dust levels ranged from 7.8 mg m⁻³ in the bakeries to 17.9 mg m⁻³ in the flour mills. Analysis of the data obtained from NEDB and industry revealed no statistically significant temporal trends in exposure. Considering these high levels have persisted over the last 20 years, there is a need for government and industry to implement further measures aimed at reducing flour dust exposures and the risk of developing occupational asthma.

Introduction

Flour is produced by milling and otherwise processing cereals and is used for human and animal consumption. Occupational exposure occurs mainly in bakeries, but also in confectionary, pasta and pizza bakeries, animal feed plants, malt factories and agriculture. Flour dust contains a number of agents and many studies have investigated the association between exposure to flour dust and related allergens, such as alpha-amylase, and prevalence or incidence of sensitization, respiratory symptoms and occupational asthma.^{1–4} A review of the available literature reported by the European Scientific Committee on Occupational Exposure Limits (SCOEL) for flour dust did not provide evidence of a threshold of flour-dust induced effects,⁵ whilst Heederik and Houba³ suggested that the lowest observed effect level for sensitization to flour dust was in the order of 0.5 and 1 mg m⁻³. In the UK there is currently a Workplace Exposure Limit (WEL) of 10 mg m⁻³.⁶ Some other countries have set a lower limit, for example, Denmark and Sweden have set an occupational exposure limit of 3 mg m⁻³, Germany have set the limit at 4 mg m⁻³, while Finland, Iceland and Norway have set exposure limits for total organic dust at 5 mg m⁻³. In the US, the ACGIH have suggested a TLV of 0.5 mg m⁻³ for flour dust.⁷

As part of a larger project aimed at identifying the long-term changes in inhalation exposure to various hazardous substances in a number of industries within the UK⁸ we investigated the temporal changes in flour dust exposure in the UK from 1985 to 2003.

Methods

Data on flour dust exposure were obtained from the UK National Exposure DataBase (NEDB) which contains occupational exposure data from a wide range of chemical and biological agents.⁹ The data were predominantly collected for HSE inspection purposes, although data from industry-wide surveys and data from industry sources were also included in NEDB. All flour dust exposure data from NEDB were extracted. In addition, data were obtained from one large industrial sized bakery in the UK. Results from personal and static inhalable dust measurements were included as were data from short- and long-term measurements.

The quality of the data was assessed using guidelines based upon occupational hygiene information, variability and precision issues and internal and external validity of the data.^{10,11} Several essential core data criteria were identified, such as sampling date; sampling device; sample duration; analytical method; measured concentration and units. Industry sector and occupation were grouped according to Table 1.

Prior to statistical analyses of the data, a number of data exclusion steps were carried out using the following criteria:

- (i) Data available for less than 5 years for an industry or occupation;
- (ii) Less than 50 measurements available across all years for an industry or occupation category;
- (iii) Less than 50 measurements available for an individual category of other potentially exposure determinants (data source, sample type, sampling duration, season).

All exposure data were log-transformed prior to statistical analyses. For two measurements the flour dust level was recorded as 0 mg m⁻³. As information on the specific detection limits of the methods used was unavailable, the value of 0 mg m⁻³ was replaced by an arbitrary value of 0.005 mg m⁻³, which was half the lowest observed value (0.01 mg m⁻³). Statistical analyses were carried out with linear mixed effect models using the Proc Mixed procedure in SAS (vs 8.02). Workers were grouped by occupation. Static measurements were also grouped using the same occupation classification, linking the most relevant occupation to

^aInstitute of Occupational Medicine, Research Avenue North, Riccarton, Edinburgh, UK EH14 4AP. E-mail: martie.van.tongeren@iom-world.org; Fax: +44 (0)870 850 5132; Tel: +44 (0)131 449 8097

^bCentre of Occupational and Environmental Health, University of Manchester, UK

^cIndependent consultant, 7 Daneway, Ainsdale, Southport, UK

^dCentre for Suicide Prevention, University of Manchester, UK

^eInstitute for Risk Assessment Sciences, University of Utrecht, Utrecht, The Netherlands

Table 1 Number of inhalable flour dust measurements and number of years with data by occupation and industry for time period 1985 to 2003^a

#	Occupation/industry	n	Years ^b
Occupation			
1	Bakery workers	283	14
2	Cleaners	68	7
3	Dough shapers/dusters	143	13
4	Drivers/forklift truck	6	3
5	Kitchen staff	7	3
6	Laboratory/quality assurance assistants	20	3
7	Maintenance workers	2	2
8	Millers	131	5
9	Mixers/weighers	679	14
10	Oven operators	75	11
11	Packers/slicers	100	10
12	Production non-baking	41	4
99	Unknown	1	1
Industry			
1	Bakeries	1156	14
2	Food products – jam, sauces, etc.	39	3
3	Food products – pizza, pastries, chicken nuggets	95	8
4	Mills and ingredients	266	5

^a n = number of measurements. ^b Total number of years for which data were available.

each location of measurement. Three categories of variables were included in the mixed models:

- 1) A continuous variable indicating the temporal trend (year).
- 2) Variables likely to be associated with exposure and which could potentially confound or modify the real temporal trend in exposure. These include the following categorical variables: occupation; industry; data source (NEDB-inspection data; NEDB-non inspection data; industry data); sample type (personal or static); sampling duration (long-term (≥ 60 minutes) or short-term measurements (< 60 minutes)); and season).
- 3) Variables that represent random effects (plant and worker). Unique identifiers for plant were available in the NEDB and industry data sets, but unique identifier for worker was only available for the industry data set. It was assumed that NEDB contained no repeated measurements on the same worker.

Year was entered first as a continuous variable and the final model was developed using a systematic forward stepwise modeling procedure based on the improvement in fit between 2 successive models. Likelihood ratio tests were used to determine if inclusion of variables significantly improved the fit of the model ($p < 0.05$). Modeling of the main effects ended when there was no further improvement in fit from systematically testing main effects. The following model was used to describe the various data sets:

$$\ln(E_{k(ij)}) = \beta_0 + \beta_1 \cdot \text{Year} + \beta_{C1} \cdot C_1 + \dots + \beta_{Cn} \cdot C_n + \chi_i + \delta_{j(i)} + \varepsilon_{k(ij)} \quad (1)$$

for $i = 1, 2, \dots, n_i$ plants; $j = 1, 2, \dots, n_{j(i)}$ workers (nested within plant); and $k = 1, 2, \dots, n_{k(ij)}$ measurements (nested within worker). The fixed effects $C_1, \dots, C_n$ represent the variables that can potentially confound or modify the temporal trend, with $\beta_{C1}, \dots, \beta_{Cn}$ as the regression coefficients for these fixed effects. χ_i represents the random effect of plant (i); and $\delta_{j(i)}$ represents the random effect of worker (j) nested within plant (i), whilst $\varepsilon_{k(ij)}$ represents the random effect of day (k) nested within worker (j)

and plant (i). It was assumed that $\chi_{(i)}$, $\delta_{j(i)}$ and $\varepsilon_{k(ij)}$ are normally distributed with zero means, and that these random effects are statistically independent. It was assumed that any two measurements on the same worker have equal correlation irrespective of the time interval between the measurements, whilst measurements on different workers are uncorrelated (compound symmetry covariance structure).¹²

The fit of the models was assessed by visually examining residuals plots (predicted *versus* residuals, residuals *versus* year, histogram of residuals) and a plot of actual *versus* predicted concentrations. The temporal trends were expressed as the annual change in geometric mean exposure using the following expression:

$$\% \text{ change per year} = 100 \times (\exp[\beta_1] - 1)$$

Results

Descriptive results

In total, 1,556 inhalable dust measurements were available from 1985 to 2003 (Table 1). Applying the exclusion criteria resulted in exclusion of 105 measurements due to insufficient data in some occupations (driver, kitchen staff, laboratory, maintenance, production-non baking and unknown) and industries ('Food products – jam, sauces, etc.'). Therefore, 1,451 inhalable flour dust measurements were available for the statistical analyses. The majority of these measurements were collected by industry after 1995 ($n = 911$, 63%). Prior to 1995, all exposure data were from the NEDB (Table 2). The dataset include results from personal ($n = 1,084$) as well as static measurements ($n = 367$) and results from long and short-term (< 1 hours) measurements.

The arithmetic mean (AM) of the whole data set was 9.7 mg m^{-3} , with a geometric mean (GM) of 3.4 mg m^{-3} and a geometric standard deviation (GSD) of 4.1. Some very high dust levels were included in the database, with a maximum value of $1,148.7 \text{ mg m}^{-3}$. Personal measurements generally resulted in higher levels than those measured by static sampling (GM =

Table 2 Inhalable flour dust exposure (mg m^{-3}) by potentially confounding variables^a

	n	AM	GM	GSD	Min	Max
Data source						
NEDB Inspection	471	11.4	4.7	3.6	0.1	571.9
NEDB Non-inspection	69	5.6	3.6	2.7	0.5	34.3
Industry data	911	9.1	2.8	4.4	0.0	1148.7
Sample type						
Personal	1084	11.3	4.3	3.6	0.1	1148.7
Static	367	5.0	1.6	4.8	0.0	115.0
Sampling duration						
Short term	163	21.5	8.9	3.8	0.3	571.9
Long term	1288	8.2	3.0	4.0	0.0	1148.7
Season						
Winter	426	9.6	3.7	4.2	0.04	213
Spring	393	8.1	3.2	3.6	0.01	571.9
Summer	360	6.4	2.7	4.2	0.01	111.4
Autumn	272	16.5	3.9	4.6	0.04	1148.7

^a n: number of measurements, AM: Arithmetic mean, GM: Geometric mean, GSD: Geometric standard deviation, Min: Minimum exposure, Max: Maximum exposure.

Table 3 Inhalable flour dust exposure (mg m^{-3}) by industry and occupation^a

	n	AM	GM	GSD _{tot}	GSD _{bp}	GSD _{bw}	GSD _{ww}	Min	Max
Industry									
Bakeries	1148	7.8	3.2	3.9	2.0	2.3	2.3	0.0	571.9
Food products – pizza, etc.	67	13.0	5.5	4.2	2.2	3.6	—	0.0	175.0
Mills and Ingredients	236	17.9	4.0	5.1	2.2	2.7	3.0	0.0	1148.7
Occupation									
Bakery workers	283	7.9	3.5	3.6	2.2	2.5	1.7	0.0	213.0
Cleaners	67	42.4	6.9	5.8	3.7	2.2	2.4	0.1	1148.7
Dough shapers/dusters	143	8.5	4.5	3.4	2.4	2.5	—	0.2	70.1
Millers	131	8.2	3.3	4.3	1.8	2.3	2.9	0.0	112.6
Mixers/weighers	662	9.2	3.4	4.3	2.3	2.2	2.6	0.0	571.9
Oven operators	75	4.0	2.2	3.3	1.9	2.3	1.8	0.0	26.8
Packers/slicers	90	3.4	1.6	3.6	2.3	2.8	—	0.1	29.1

^a n: number of measurements, AM: Arithmetic mean, GM: Geometric mean, GSD_{tot}: Total geometric standard deviation, GSD_{bp}: Between plant geometric standard deviation, GSD_{bw}: Between worker/location geometric standard deviation, GSD_{ww}: Within worker/location geometric standard deviation, Min: Minimum exposure, Max: Maximum exposure.

4.3 mg m^{-3} vs 1.6 mg m^{-3} , respectively), whilst results from short-term measurements were generally higher than those from long-term measurements (GM = 8.9 mg m^{-3} vs 3.0 mg m^{-3} , respectively). Exposure levels were generally higher for the NEDB data (GM = 3.6 mg m^{-3} for non-inspection data and 4.7 mg m^{-3} for inspection data, respectively), than for the industry data (GM = 2.8 mg m^{-3}). No data from inspection visits were available from 1993 to 2000. Data from non-inspection visits are only sporadically available, whilst data from industry are only available from 1995 onwards. Inhalable flour dust exposure appears to be higher during the autumn (GM = 3.9 mg m^{-3}) with lowest levels observed during the summer (GM = 2.7 mg m^{-3}).

Table 3 details the descriptive statistics for industry and occupation. High exposure levels were observed in all sectors, but were particularly high in ‘Mills and ingredients’ (GM = 4.0 mg m^{-3}) and in ‘Food products – pizza, etc’ (GM = 5.5 mg m^{-3}). The highest exposure levels for occupations were observed for ‘Cleaning staff’ with a GM of 6.9 mg m^{-3} . The lowest but still substantial exposure levels were observed for the ‘oven operators’ (GM = 2.2 mg m^{-3}) and the ‘Packers/slicers’ (GM = 1.6 mg m^{-3}). After excluding short-term and static measurements very similar results were obtained, with GM for ‘Mills and ingredients’ being 5.8 mg m^{-3} and the GM for ‘Food products – pizza, etc’ being 5.7 mg m^{-3} . When summarizing the result by occupation using only long-term personal measurements, the results were again very similar to the whole dataset with the GM exposure level ranging from 1.9 mg m^{-3} for ‘Packers/slicers’ to 7.0 mg m^{-3} for ‘Cleaning staff’.

Table 3 also shows the between-plant, between-worker/location and within-worker/location or day-to-day variability. No repeated measurements on individual workers were available for the ‘Food products – pizza, etc.’ sector and for the occupations ‘Dough shapers/dusters’ and ‘Packers/slicers’, hence no within-worker GSD could be estimated. The between-plant GSD was relatively high for the ‘Cleaners’, indicating that exposure levels for this group varied widely between different sites. The between-worker GSDs were similar across the jobs, ranging from 2.2 for ‘Cleaners’ to 2.8 for ‘Packers/slicers’. Relatively high within-worker GSDs were observed for ‘Millers’, ‘Mixers/weighers’ and ‘Cleaners’, indicating that exposure levels for the same worker could vary significantly from one day to the next.

Mixed effect models

Table 4 provides information on the model fit for the various stages in the model development, together with parameter estimates for annual trend and the variance components in the exposure data. In the order that they were entered, the final model includes the main effects of year, sample type (personal vs static samples), sampling duration (long-term vs short-term measurements), occupation, season and industry. Inclusion of year into the model did not significantly improve the fit of the model, nor was the effect of year statistically significantly associated with flour dust exposure at any point in the model development. The between-plant variance was decreased by just 7% in the final model compared to model that only included random effects, whilst the between-worker variance decreased by 39%. The within-worker variance was not reduced in the final model compared to the random-effects model. The mixed effects analyses were repeated after excluding all the static and short-term measurements, which did not alter the annual trend in flour dust exposure; a non-significant annual trend of -0.1% was found.

Table 5 provides the parameter estimates from the final mixed model. The results from the mixed effects model confirms that the geometric mean for the static measurements was lower than the geometric mean for personal samples and that geometric mean from long-term measurements was lower than short-term measurements. Exposure levels were higher during the winter season than during other seasons. For industry, it appears that the ‘Mills and Ingredients’ have the highest exposure levels whilst ‘Bakeries’ have the lowest. The ‘Packers/slicers’ have lower exposure levels compared to the other occupations.

Stratified analyses for ‘Bakeries’ and ‘Mills and ingredients’ were also carried out. After correcting for sample type, sampling duration, occupation and season, a non-significant annual trend of -1.0% was observed for inhalable flour dust exposure for ‘Bakeries’. In contrast, for ‘Mills and ingredients’ a non-significant annual increase of nearly 15% was observed for inhalable flour dust exposure in this industry, suggesting that exposure levels may have increased in recent years. Finally, stratified analyses were carried out for data source (NEDB inspection survey, NEDB non-inspection survey and industry); no annual

Table 4 Information on stages of mixed effects model development^a

Model ^b	-2RLL	AIC	Diff	df	p-value	β_{year}	SE	Annual Trend (%)	Between-Plant	Between-worker	Within-worker
0	4912.5	4918.5							0.5395	0.7300	0.8106
1	4915.4	4921.4	-2.8	1	NE ^c	0.024	0.012	2.5	0.5501	0.7293	0.8060
2	4803.9	4809.9	111.5	1	<0.001	0.027	0.011	2.8	0.4931	0.5556	0.8613
3	4734.3	4740.3	69.6	1	<0.001	0.008	0.011	0.8	0.4739	0.5526	0.7965
4	4709.9	4715.9	24.4	6	<0.001	0.005	0.012	0.5	0.5148	0.5085	0.8021
5	4695.1	4701.1	14.8	3	0.002	0.005	0.012	0.5	0.5356	0.4437	0.8427
6	4688.3	4694.3	6.8	2	0.034	0.001	0.012	0.1	0.5039	0.4443	0.8410

^a -2RLL: -2 Residual Log Likelihood estimate; AIC: akaike information criterion (smaller is better); Diff: difference in -2RLL associated with the inclusion of the additional variable (ie difference with the model in the previous row); df: degrees of freedom associated with inclusion of the additional variable; p-value: p-value of log-likelihood ratio test, to determine improvement in fit; β_{year} : parameter estimate for year; SE: standard error for β_{year} ; Between-plant: between plant variance in exposure; Between-worker: between worker (within plant) variance in exposure; Within-worker: within-worker or day-to-day variance. ^b 0: no fixed effects included in the model; 1: Year; 2: Year and Sample type; 3: Year, Sample type and Sampling duration; 4: Year, Sample type, Sampling duration and Occupation; 5: Year, Sample type, Sampling duration, Occupation and Season; 6: Year, Sample type, Sampling duration, Occupation, Season and Industry. ^c NE = p-value not estimable.

Table 5 Parameter estimates, standard errors and p-values for the final mixed effects regression model for log-transformed inhalable flour dust exposure^b

Description of effect	β	SE
Intercept	2.234	0.339
Year ^a	0.001	0.012
Sample type		
Static	-0.873	0.079
Personal		Base
Sampling duration		
Long-term	-0.929	0.112
Short-term		Base
Occupation		
Bakery workers	0.675	0.165
Cleaners	0.621	0.223
Dough shapers/dusters	0.749	0.178
Millers	0.305	0.245
Mixers/weighers	0.880	0.149
Oven operators	0.492	0.205
Packers/slicers		Base
Season		
Autumn	-0.243	0.135
Spring	-0.325	0.116
Summer	-0.496	0.113
Winter		Base
Industry		
Bakeries	-0.610	0.220
Food products - pizza, etc	-0.138	0.319
Mills and ingredients		Base

^a The values for the variable year were changed from 1985 to 2003 to 0 to 18. ^b β : Parameter estimate for fixed effects, SE: Standard error of parameter estimate.

change in flour dust exposure was observed in any of these three data sources.

Discussion

Results from the analyses presented in this paper suggest that the flour dust exposure levels in the UK are relatively high, with some individual measurements results in excess of 100 mg m⁻³. Furthermore, no downward temporal trend in flour dust exposure in the UK was observed over the period 1985–2003. This is in contrast to many other occupational exposures in other industry sectors where annual trends in the range of approximately -5 and -15% have been observed.¹³ When stratified analyses were carried out by industrial sector, a non-statistically significant increasing trend (15% per year) was observed between

1999 and 2003 in 'Mills and Ingredients'. Unfortunately, no data were available before 1999; therefore, it was not possible to determine the temporal trend before that year, although it seems unlikely that this trend of increasing flour dust exposure over time had existed for many years prior to 1999. In the Netherlands comparison of exposure levels from studies performed between 1993 and 2005 also indicate no clear trend in exposure levels for flour dust, wheat allergens and α -amylase.^{14,15} However, de Pater *et al.*¹⁴ reported that for flour mills, data on flour dust exposure available from 1988 and 2001 seemed to indicate an overall downward trend in exposure.

We assume that inhalation exposure levels in industry tend to decline exponentially, rather than, for example, in a stepwise manner. Although it is possible that exposure levels within one plant may change abruptly at a number of time points, when analysing data across one or several industrial sectors, it is unlikely that these changes all occur at the same time. Hence, we feel that the use of a continuous variable to indicate the temporal change in exposure is justified.

Flour dust exposure levels vary between occupation and industry and therefore the analyses of trends were corrected for these variables as the frequency of measurements in different occupations and industry sectors may have changed over time. In addition, any systematic changes over time in the sample type, sample duration or season may have resulted in an apparent change in exposure, even if in reality the exposure levels remained the same. Therefore, all analyses of temporal trends were adjusted for these variables. However, this approach could potentially disguise any temporal trends that exist in subsets of the data. To review this, several stratified analyses were also carried out, by occupation, industry, data source, sample type and sample duration. None of these stratified analyses revealed any statistically significant temporal trends in subsets of the exposure data, although for industry ('Mills and ingredients') a non-significant annual increase of nearly 15% was observed.

Guidance on dust control in bakeries has been issued in the UK. For example, the Health and Safety in Bakeries Liaison Committee (HSBLC), which consists of representatives from all the relevant trade associations and unions, together with the HSE produced the publication 'Guidance on dust control and health surveillance in bakeries'.¹⁶ The industry, in cooperation

with the HSE also produced an interactive training package in 1998 entitled "Breathe Easy" which includes a copy of the guidance, training notes and a video illustrating the control measures specified in the guidance.¹⁷ However, there is currently no strong evidence that these initiatives had a major impact on exposure to flour dust. This was confirmed by a recent UK wide flour dust survey, involving 55 randomly selected bakeries which suggested that there was limited knowledge of good working practices.¹⁸ Note that these data were not included in our database. Activities such as dry sweeping and flour dusting by hand were still repeatedly undertaken by the majority of bakeries, local ventilation was present in only 28% of companies and less than half of the companies were judged to have adequate control measures.

Exposure to flour dust has been associated with increased risk for developing sensitization and occupational asthma, with no evidence of a trustworthy threshold of flour-dust induced effects,⁵ possibly because the allergenic components of flour dust linked to asthma do not exist in constant proportion to the flour dust itself.¹⁹ In the UK, it is estimated that in the last 10 years at least 600 people have developed asthma as a result of flour (or grain) exposure.²⁰ The HSE also reports that between the years 2000 and 2002 the number of new asthma cases caused by flour and grain remained at about the same level, while new reported cases of occupational asthma from most causes fell during the same period.²⁰ A limited analysis of the actual and estimated cases of occupational asthma attributed to flour dust reported to the Surveillance of Work-Related & Occupational Respiratory Disease (SWORD) by chest physicians between 1997 and 2006 also suggest that the numbers of actual and estimated cases are not reducing in number (Table 6).

Table 6 Actual and estimated cases of occupational asthma attributed to flour dust reported to SWORD by chest physicians by years 1997–2006^{a,b}

Year	Actual cases	Estimated cases
1997	17	83
1998	14	14
1999	13	24
2000	7	29
2001	11	44
2002	23	67
2003	12	12
2004	23	34
2005	19	52
2006	23	34
Total	162	393

^a Source personal communication from The Health and Occupation Reporting network (THOR) (<http://www.medicine.manchester.ac.uk/coeh/thor>). ^b Note: The cases were reported by a selection of the UKs chest physicians with an interest in occupationally related diseases. Some physicians (core group) reported cases to the reporting scheme throughout the year, while others (sample group) only reported during one (randomly selected) month of the year. The actual number of cases is the number of cases reported to the scheme. The estimated number of cases is the total number of cases that would have been reported if all physicians participating in the scheme were reporting throughout the year: Estimated cases = (cases reported by core group) + (cases reported by sample group during a single randomly allocated month per year × 12).

It is clear that there is a need for government and industry to implement further measures to improve the communication and promotion of good practice in controlling flour dust exposure so that possible future downward trends, both in flour dust exposure and the incidence of occupational asthma attributable to this, are observed. Given that no data were available for analysis after 2003, the effect of the introduction in the UK of the 10 mg m⁻³ flour dust exposure limit in 2001 is difficult to determine. However, we believe that this limit must be substantially lower if progress is to be made in reducing the incidence of occupational asthma from flour dust exposure.

In the UK the collection and storage of new measurement data appears to be decreasing. For example, as Tickner²¹ discussed in his review of NEDB, the addition of new data within this database is diminishing, in part due to changes in operational procedures and also due to the costs associated with data collection. It should be recognized that there is a continuing need to collect and systematically store new exposure measurement data to help assess the effectiveness or otherwise of the Workplace Exposure Limits (WELs) as well as any future initiatives to ensure that inhalation exposure to flour dust decreases.

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