Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub. 2006, 150(1):135–141.

INFLUENCE OF DEMOGRAPHIC, SURGICAL AND IMPLANT VARIABLES ON WEAR RATE AND OSTEOLYSIS IN ABG I HIP ARTHROPLASTY

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Received: April 28, 2006; Accepted: May 18, 2006

Key words: Total hip arthroplasty/ABG I prosthesis/Wear rate/Polyethylene/Periprosthetic osteolysis/Demographic variables/Surgical variables/Risk analysis

Periprosthetic osteolysis is associated with accelerated wear rates. The goal of this study was to investigate the influence of demographic and technical variables on wear rates and size of osteolytic lesions. Eighty retrieved ABG I prostheses were analyzed according to prospectively established criteria. There were 22 men and 58 women with an average age of 52 years (34–65) at the time of revision. The average time from index surgery to revision was 67 months (26 to 106). Polyethylene wear measurements were performed using a Universal-type measuring microscope. The average linear wear and volumetric wear rate was 0.363 mm per year (0–0.939, SD 0.241) and 161 mm^3 per year (0–467, SD 118.2), respectively. The wear rates were significantly higher (a) in patients with primary osteoarthritis in comparison with postdysplastic hips, (b) in hips where zirconia prosthetic heads articulated against the polyethylene liner, and (c) in cups placed laterally to Kohler's line. Risk that linear wear rate could be more than 0.2 mm per year was three times higher in patients who were operated in 1997 and later (OR 3.0, 95 % CI 1.126–7.993, p = 0.03). A strong association was revealed between magnitude of wear and size of femoral osteolysis.

INTRODUCTION

Periprosthetic osteolysis is considered a key problem of total hip arthroplasty[1]. It can be defined as excessive bone resorption caused by predominantly polyethylene particles that trigger an adverse host response against the bone bed[2]. Briefly, large numbers of particles derived from articulating surfaces induce increased maturation and survival of osteoclasts, metalloproteinase liberation, and formation of joint fluid together resulting in periprosthetic bone destruction[3]. Therefore, wear fuels particle disease, and a direct relationship has already been postulated between bone loss and wear rates.

Dumbleton et al.[4] have made a thorough literature review on the subject of polyethylene wear, suggesting the existence of an "osteolysis threshold". A wear rate that exceeded 0.1 mm per year, corresponding to volumetric wear rates of 80 mm^3 and 62 mm^3 per year for 32-mm and 28-mm heads, respectively, was considered a critical border. Another review stressed significant discrepancies in wear rates among individuals with identical implants[5]. Obviously, there must be other factors of either patient or surgical origin playing an important role in wear rates, in particular, age, weight, primary diagnosis, activity level, cup position, and other variables[6–8]. Orishimo et al.[9] investigated patients with bilateral hip arthroplasty to determine patient influence on wear rates. These authors found that patient factors accounted for 61 % of the variance in wear rate. On the other hand, Hopper et al.[10] from the same institution reported that all of the variables identified in their study as statistically significant including three patient-related factors (age, BMI, primary diagnosis) accounted for only 26 % of the variance in the wear data.

The objective of this study was (1) to investigate the impact of patient-, surgical technique-, and implant-related factors on the variability of wear rates, and (2) to evaluate the association between polyethylene wear and size of bone loss in patients with ABG I prosthesis.

MATERIAL AND METHODS

This study compared the wear data for 80 retrieved ABG I polyethylenes with demographic, surgical technique, implant and osteolytic variables. The revision surgeries were performed between August 2000 and December 2003. There were 22 men (27.5 %) and 58 women (72.5 %) included, with an average age of 52 years (34 to 65, SD 7.16) at a time of revision. The reasons for revision were as follows excessive wear and periprosthetic osteolysis, painful synovitis, or aseptic loosening. All revisions were performed under standard conditions with the written informed consent of the patients. The average time from index to the revision surgery was 67 months (26 to 106, SD 18.9), and the average Harris hip score before revision surgery was 65 points (10 to 98, SD 18.5).

A description of the ABG I prosthesis ("Anatomique Benoist Girard", Howmedica, Staines, England) has been published elsewhere[11]. The technique of manufacturing the polyethylene liner was ram-extrusion from Hostalen GUR 4150 followed by sterilization with 25 kGy gamma irradiation in an open-air environment. The length of storage was not documented during the index surgery. Both standard and hooded polyethylene liners were implanted, the former being used in 64 hips. The polyethylene thickness was ranging from 4.9 to 12.9 mm. In nearly all the hips a metallic 28-mm femoral head was inserted except for six cases where a zirconia head was used.

The patients were examined by two of us (JG, IC) prior to surgery. The data collected comprised patient age, gender, primary diagnosis, height, weight, Harris Hip score[12], and Charnley classification of activity[13]. Radiographic investigation was performed in the lying position (non-weight bearing radiographs). Evaluation was made of the cup placement relative to Kohler's line, and graded as lateral, in contact, or medial. Additionally, the cup position was determined by means of the true acetabular region concept[14]. The abduction angle of the cup equalled the angle formed by a horizontal line along the ischial tuberosities or obturator foramina and a line along the open face of the cup.

Osteolysis was assessed radiographically, but the final determination was made intraoperatively. With regard to specific features of osteolysis around ABG I prosthesis a novel bone lesion classification was developed and used. There were *small acetabular bone defects* (similar to grade I or II of the modified Gross's scheme[15]) when the extension of bone lesions did not compromise the ability of the bone bed to fix a cementless acetabular component, and the loss of acetabular wall was less than twenty percent of the circumferences. The *medium bone defects*

Table 1. List of patient-, implant-, and surgical technique-related characteristics.

Variable	Categories	Report
Age at index surgery (years)		46.5 (27–57, SD 6.87) *
Gender	Men/Women	22/58
Weight (kg)		75 (48–114, SD 14.65)
Height (cm)		165 (149–186, SD 8.07)
BMI		27.5 (18-43, SD 4.5)
Primary diagnosis	Osteoarthritis Osteonecrosis Hip dysplasia Traumatic hip	18% (14/80) 19% (15/80) 50% (40/80) 14% (11/80)
Charnley activity class	A B C	36% (29/80) 55% (44/80) 9% (7/80)
Liner geometry	Standard Hooded	81% (65/80) 19% (15/80)
Head material	Metallic Ceramic	93% (74/80) 8% (6/80)
Date of index surgery	1994 to 1996 1997 to 2000	41% (33/80) 59% (47/80)
Cup size (mm)		50 (46–60, SD 3.36)
PE thickness (mm)		6.99 (4.9–11.9, SD 1.68)
Cup position in relation to Kohler's line (KL)	Lateral to KL In contact with KL Medial to KL	10% (8/80) 19% (15/80) 71% (57/80)
Cup position	TA Above TA	79% (63/80) 21% (17/80)
Abduction angle of the cup (°)		44.5° (30–72, SD 8.02)
Acetabular bone defects	Small Medium Severe	66% (53/80) 20% (16/80) 14% (11/80)
Femoral bone defects	Small Severe	86% (69/80) 14% (11/80)

BMI = body mass index, PE = polyethylene, TA = true acetabulum.
* Values are presented as the mean (minimum-maximum value, SD = Standard Deviation)

Table 2. Comparison of demographic, surgical technique, and implant variables with linear and volumetric wear data. P values were obtained with Student t-test, ANOVA analysis, Mann-Whitney U-test;

Variable	**Linear wear rate**	***p* value**	**Volumetric wear rate**	***p* value**	**Volumetric wear**	***p* value**
Age	*r* = 0.038	0.740	*r* = 0.055	0.632	*r* = 0.032	0.778
Gender Men Women	 0.432 (SD 0.244)* 0.342 (SD 0.234)	0.136	 199.2 (SD 128.6) 149.1 (SD 110.9)	0.09	 989.7 (SD 733.6) 823.2 (SD 628.0)	0.315
Weight	*r* = 0.205	0.072	*r* = 0.254	0.025	*r* = 0.258	0.021
Height	*r* = 0.219	0.054	*r* = 0.22	0.053	*r* = 0.138	0.222
BMI	*r* = 0.098	0.392	*r* = 0.154	0.178	*r* = 0.198	0.080
Charnley activity class A B C	 0.381 (SD 0.229) 0.358 (SD 0.233) 0.380 (SD 0.339)	0.917	 163.3 (SD 100.7) 157.9 (SD 116.0) 196.0 (SD 189.5)	0.734	 813.1 (SD 544.6) 876.1 (SD 677.4) 1056 (SD 897.4)	0.684
PE liner Standard Hooded	 0.371 (SD 0.243) 0.355 (SD 0.227)	0.820	 165.7 (SD 118.8) 151.9 (SD 114.9)	0.692	 909.8 (SD 663.3) 692.1 (SD 626.0)	0.251
Cup size	*r* = 0.072	0.531	*r* = 0.094	0.413	*r* = 0.077	0.495
Liner thickness	*r* = 0.072	0.531	*r* = 0.094	0.413	*r* = 0.077	0.495
Abduction angle	*r* = 0.032	0.780	*r* = – 0.002	0.985	*r* = – 0.033	0.772
Cup position TA Above TA	 0.386 (SD 0.246) 0.303 (SD 0.203)	0.207	 169.7 (SD 120.0) 140.1 (SD 108.3)	0.361	 894.8 (SD 671.1) 773.3 (SD 617.7)	0.503

r = Pearson correlation coefficient. BMI= body mass index, PE= polyethylene, TA= true acetabulum.
Values are presented as the mean (SD = Standard Deviation)

were still able to support cementless cups but the extension of acetabular ring defects varied between twenty-five and forty percent of the circumference (similar to grade III of modified Gross's scheme[15]). The *severe acetabular defects* seriously compromised the bone bed requiring major reconstruction with the assistance of an acetabular ring device, bone grafting, and cemented cups (similar to grade IV or V of modified Gross's scheme[15]). At the femoral site there were detected two categories of bone lesions; *small defects* (overlapping from grade I to III of modified Gross's scheme[15]) were located strictly in the metaphyseal region. In case the stem revision was needed, a conventional cementless implant was sufficient. On the other hand, *severe defects* with seriously compromised metaphyso-diaphyseal region required long stem revision implants (similar to grade IV or V of modified Gross's scheme[15]).

After prosthesis extraction, all the polyethylene liners were immersed in Sekusept aktiv (Ecolab GmbH, Düsseldorf, Germany) for 24 hours, and sterilized in formaldehyde for 2 hours. Having been dried, they were photographed, and sealed in plastic film prior to measurement. The wear measurement was performed by one of us (VH) using a Universal-type measuring microscope (VEB, Carl Zeiss Jena, Germany) and his original methodology[16].

We hypothesized that there were significant relationships between distinct variables of a different origin, and polyethylene wear rates measured by an optical method. Furthermore, we believed that more serious bone defects were associated with an increased polyethylene wear rate. A variety of parametric and nonparametric tests were applied for statistical analyses including correlation analysis, ANOVA, Student's t-test, Mann-Whitney U-test, as applicable (JZ). Table 1 gives a complete overview of the variables incorporated in the statistical analysis performed by means of the commercial SPSS, v.10.1 statistical package (SPSS Inc., Chicago, USA). The accepted significance level was 0.05. In addition, odds ratio calculations were performed having divided the cases under study into two subgroups according to wear rate thresholds (i.e. 0.1 mm per year and 0.2 mm per year, respectively).

RESULTS

The average linear wear of the whole set of retrieved cups equalled 1.958 mm (0 to 8.735, SD 1.37), and the average volumetric wear was 869 mm^3 (0 to 2824, SD 658.2). Two outliers were excluded according to the remote value specific analysis (stem-and-leaf plots, normal Q-Q plots). The average linear wear rate for the reduced group was then 0.363 mm per year (0 to 0.939, SD 0.241), and the corresponding average volumetric wear rate was 161 mm^3 per year (0 to 467, SD 118.2).

Patient-related factors

Significantly higher wear rates were found in patients whose **primary diagnosis** was osteoarthritis compared to postdysplastic hip (ANOVA, for linear wear rate $p = 0.011$, for volumetric wear rate $p = 0.036$). A weak positive correlation was found between both linear and volumetric polyethylene wear and the **patient weight** ($r = 0.226$, $p = 0.045$, and $r = 0.258$, $p = 0.021$, respectively). A similar relationship was assessed for the volumetric wear rate ($r = 0.254$, $p = 0.025$), but not for the linear one ($r = 0.205$, $p = 0.072$). The other variables were not considered important for polyethylene wear including the BMI (Tab. 2).

Prosthesis-related factors

There were significantly higher annual linear wear rates in hips where the **zirconia prosthetic heads** articulated against polyethylene liners compared to metallic balls (t-test, $p = 0.011$), but the same observation was not valid for annual volumetric wear rates (t-test, $p = 0.174$). As we were unable to investigate the role for the true polyethylene storage age we tried to examine relationships between the **dates of index surgery** and wear rates. Surprisingly, significantly higher wear rates were found in the hips operated after January 1997 in contrast to the cases where index surgery had been performed before that date (Fig. 1a, 1b). This variable seemed to be really important because its significance was also proved by odds ratio analysis. The risk of wear rate exceeding 0.2 mm per year was three times higher in the patients who underwent index surgery after January 1997 (OR 3.00, 95 % CI 1.13–7.99, Fisher exact probability test, $p=0.03$). A comparison of annual linear and volumetric wear rates for polyethylene liner type, cup size or polyethylene thickness brought about no significance (Tab. 2).

Surgical technique-related factors

The ANOVA demonstrated a strong relationship between annual wear rate and **position of the cup with regard to Kohler's line** (ANOVA, $p = 0.002$ for linear wear rate, $p = 0.0005$ for volumetric wear rate). Both linear and volumetric annual wear rates were significantly higher in the cups placed laterally, as opposed to those placed medially to Kohler's line (Post Hoc Tests, $p = 0.001$ and $p = 0.0001$, respectively). The annual wear rate differences between the cases in contact and medial to Kohler's line were not significant (Post Hoc Tests, $p = 0.092$ and $p = 0.25$, respectively). No relationships were found comparing the wear rate data to the cup position (with respect to the true acetabulum region) or abduction angle (Tab. 2).

Osteolysis-related factors

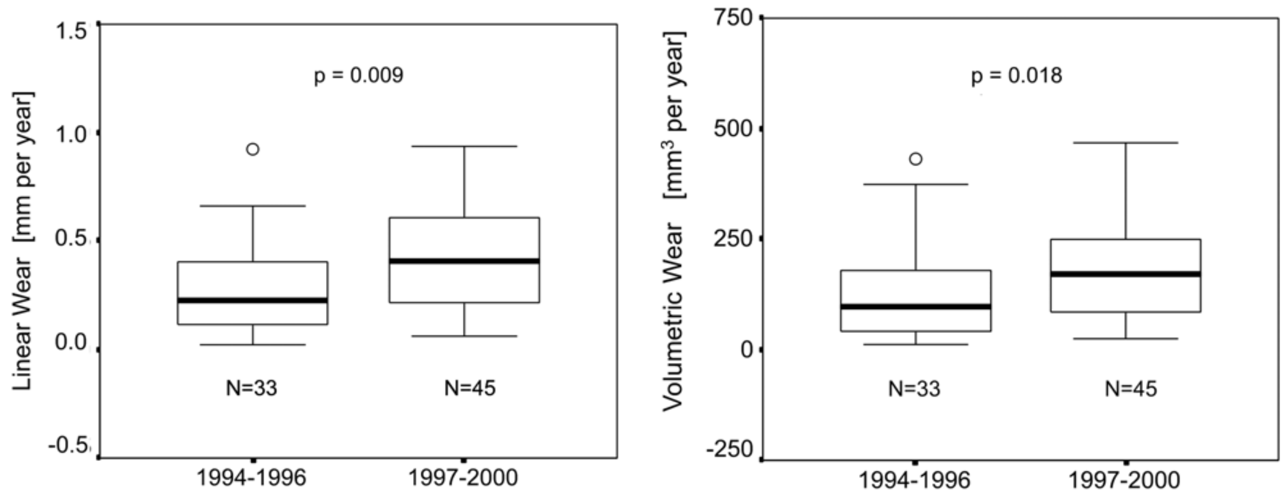
At the time of surgery, a wide range of osteolytic defects was observed and subsequently grouped into three acetabular and two femoral categories. When the wear rate data were compared with the extension of the osteolytic defects, the results were inconclusive. At the acetabular site there was only a relationship between volumetric wear rates and acetabular defect types (ANOVA, $p = 0.037$). The cups associated with **small acetabular defects** had significantly lower volumetric wear rates (Post Hoc Tests, $p = 0.013$) than those with medium bone loss (Fig. 2a). Surprisingly, the method of multiple comparisons failed to show a relationship between medium and severe acetabular defects (Post Hoc Tests, $p = 0.372$) or even between small and severe ones (Post Hoc Tests, $p = 0.257$) in terms of the volumetric wear rate. On the other hand, if total linear and volumetric wears were compared with the acetabular defects then significant differences were identified for all of them (ANOVA, $p = 0.031$ and $p = 0.021$, respectively). Significantly higher annual linear (t-test, $p = 0.01$) and volumetric (t-test, $p = 0.008$) wear rates were found in cases with **severe femoral bone defects** (Fig. 2b).

DISCUSSION

In recent decades, polyethylene wear has been considered a key parameter for periprosthetic osteolysis development, and its multifactorial origin is now generally accepted[4]. Many authors have clearly elucidated the effects of wear-related variables[6–8, 17]. The present study compared the *in vitro* measured wear rates in the group of 80 hips with ABG I prostheses revised due to periprosthetic osteolysis, excessive particle synovitis or aseptic loosening.

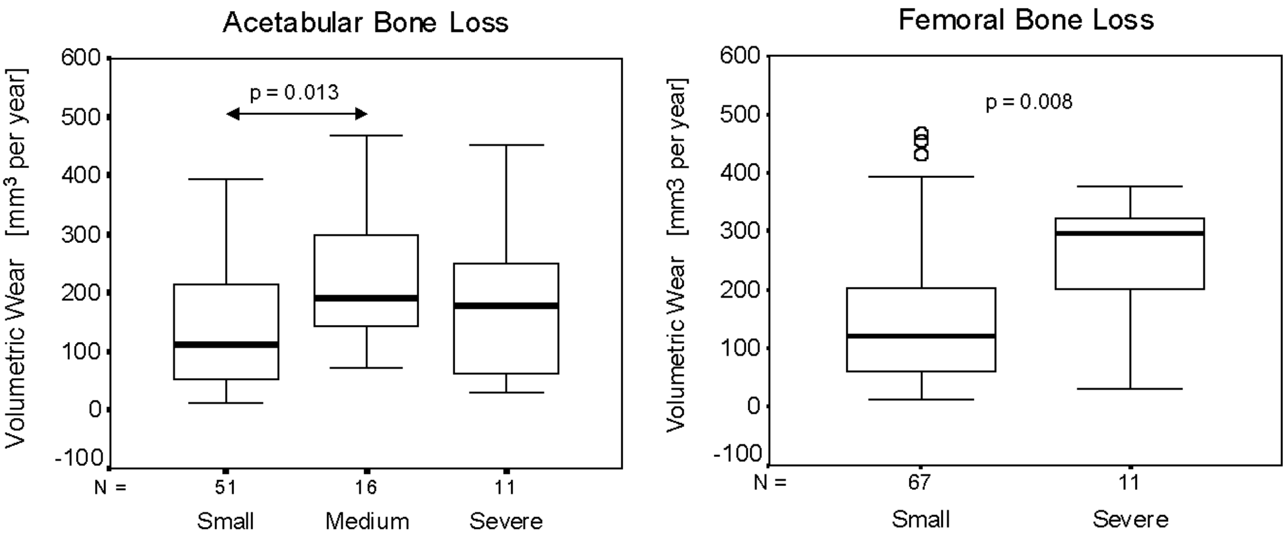
We found significantly higher polyethylene wear rates in the patients with idiopathic osteoarthritis compared to postdysplastic hips as a primary diagnosis. This may be intuitive, as the patients with hip dysplasia who have chronically adapted from childhood to a lower level of activity, may not increase it much after the surgery. In addition, the factor of gender might have also influenced our analysis because more than 72 % of the cups included had been retrieved from women, whereas several studies claimed that women had lower wear rates in comparison with men[7, 17, 18]. On the other hand, the association between hip dysplasia and wear rate reduction was not proved by multiple linear regression rather pointing to inflammatory arthritis[10]. Furthermore, it is believed that wear is a function of use[19], but when the Charnley classification[13] was used as a measure of activity in our study, no significant association with wear was revealed. This could be interrelated with the poor sensitivity of this tool as previously suggested by others[6, 8]. In fact, a certain role might be played by the small number of Charnley C patients included in our study (only seven). The correlation between patient BMI and wear rates was very weak, which questions the routine requirement for obese patients to undergo a drastic lowering diet before hip or knee arthroplasties. Moreover, Hopper et al.[10] found that an increase in BMI unit was associated with a decrease in wear rate which might be related to a lower activity level in fatter people.

According to our analysis zirconia femoral heads represent no advantage for wear rate reduction which is in concordance with the study of Hernigou and Bahrami[20] who revealed significantly higher linear and volumetric wear rates for zirconia 28-mm heads. Moreover, they observed this wear accelerated after five years of follow-up which is comparable to the present study. The above authors concluded that higher wear rate was likely related



a b

Fig. 1a, b: The box plots comparing the date of index surgery and the linear (a) and volumetric (b) wear rate; Mann Whitney U-test. Horizontal line in the box is median value; whiskers mark the farthest values that are not outliers.



a b

Fig. 2a, b: The box plots showing inconsistency between type of acetabular bone defect and volumetric wear rate (a); Post Hoc Tests. The relationship between volumetric wear rate and femoral bone loss type (b) is in line with hypothesis of the study; Student t-test. Horizontal line in the box is median value; whiskers mark the farthest values that are not outliers.

to deterioration of the zirconia ceramic surface which changed in its sphericity and roughness over a distinct period of time. Surprisingly, we determined no relationship between polyethylene liner thicknesses and wear rates. This is in contrast with other authors, who concluded that the wear rate is higher with thinner than thicker polyethylene cups[21,22]. However, it is in a good agreement with the study of Hopper et al.[10] who recorded a trend towards increasing polyethylene wear rates in cases with a thicker polyethylene liner. As explanation, the above authors speculated on joint reactive forces as a stronger variable in contrast to polyethylene thickness. As a result, the former variable predominates over the latter. Even though this theory looks very attractive it would still require further research in the future.

Besong et al.[23] emphasized the role of polyethylene age on wear rates because of changes to the material properties as a consequence of oxidation in polyethylene that had been gamma sterilized in an air environment. This process has been shown to result in accelerating wear. Sychterz et al.[24] recently found a correlation between shelf-life and the true wear rate *in vivo*. The current study was unable to comment on that as there were no true shelf life data available. Nevertheless, we found significantly higher wear rates for polyethylene liners implanted after January 1997 compared to those used before this date. This may alert us to the role of extended polyethylene storage as the manufacturer made no substantial changes in the raw materials, technological process, and sterilization during that period of time (information provided by Howmedica, Stryker, USA). In fact, the company finished with the ABG I project around the 1996 replacing it by new generation of ABG prostheses (ABG II).

In our study, significantly lower wear rates were observed in hips with cups placed across the Kohler's line. Actually, this was not surprising because the same finding was reported by others[8], and Charnley believed that the centre of rotation should be as medial as possible to reduce the resultant force magnitude and risk of loosening[25] as supported later by a mathematical model of the hip joint[26]. In addition, deeper cup settlement should reflect the dysplastic acetabular terrain suggesting the lower activity level, as fifty percent of all the cups investigated in our study had been retrieved from these hips.

Many clinicians believe that there is a direct relationship between wear and prevalence and magnitude of periprosthetic osteolysis[18,27]. This is supported by our findings in spite of slight inconsistencies at the acetabular site which may be partially due to the different pathogenesis of retroacetabular and femoral osteolysis[1,28]. Furthermore, the classification scheme of acetabular lesions used in our study might be less sensitive than at the femoral site.

We conclude that the wear magnitudes obtained in this study exceeded the expected wear data after similar follow-up for contemporary polyethylenes which was in a good agreement with other papers dealing with ABG I prosthesis[29-32]. Therefore, it may be alleged that the major factors leading to premature failure and high polyethylene wear rates were design and material weaknesses. In addition, some patient- and surgical technique-related factors, including primary diagnosis and cup position in relation to Kohler's line, may have played a distinct role in wear development. Finally, we confirmed a relationship between the polyethylene wear and bone loss extent in concert with the pathogenetic fundamentals of particle disease.

ACKNOWLEDGEMENTS

We wish to thank Drs. M. J. Spangehl & A. Oulton, and Ms. Jarmila Potomkova for critical review of this manuscript.

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