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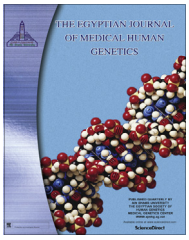

REVIEW

Prevalence of glucose-6-phosphate dehydrogenase deficiency in India: An updated meta-analysis

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KEYWORDS

G6PD deficiency;
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Abstract *Background:* Glucose-6-phosphate dehydrogenase (G6PD) is a house keeping enzyme which catalyzes the first step in the hexose monophosphate pathway of glucose metabolism. G6PD deficiency is the commonest hemolytic X-linked genetic disease, which affects approximately 400 million people worldwide. The prevalence rate of G6PD deficiency varies worldwide with a higher prevalence in malarial endemic population. In India several studies were published and reported with varying incidences of this disease in different populations.

Objective: The aim of the present study was to assess the overall frequency of G6PD deficiency in the Indian population using meta-analysis.

Methods: PubMed, Science Direct, Google Scholar and Springer Link databases were searched for studies that investigated G6PD deficiency in Indian population. If any author studied different sub-populations we treated the study as an independent study.

Results: A total of 72 studies with a total sample size of 38,565 and 2,623 G6PD deficient subjects were included in the present meta-analysis. Meta-analysis was performed in both fixed and random effect models. Meta-analysis with random model showed an overall prevalence proportion as 0.085 (95% CI = 0.070–0.103; $p = 0.000$; tau = 0.826; $I^2 = 0.486$; Cochran $Q = 0.999$).

Conclusion: In conclusion the present meta-analysis confirms the overall magnitude of the frequency of G6PD deficiency (8.5%) in the Indian population.

Contents

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1. Introduction

Glucose 6-phosphate dehydrogenase (G6PD) deficiency was discovered half a century ago and is still the most common inherited enzymopathy. Clinically, deficiency of this enzyme affects as many as 400 million individuals worldwide [1]. This inherited deficiency causes neonatal hyperbilirubinemia and chronic hemolytic anemia. Although most affected individuals are asymptomatic, exposure to oxidative stresses such as certain drugs or infection, can elicit acute hemolysis. G6PD deficiency was first identified in American blacks (African and Asian descent) in the course of studies of sensitivity to the hemolytic effect of primaquine [2]. Soon after G6PD deficiency was also reported from Mediterranean populations and it became apparent that the enzyme deficiency in the Mediterranean population was much more severe than the prototype deficiency that had been found in American blacks [3].

In 1986, the G6PD gene was cloned independently by Persico et al. [4] and Takizawa et al. [5]. G6PD gene is located on the long arm of the X chromosome (Xq28), and consists of 13 exons [6]. G6PD locus is thought to be one of the most polymorphic loci among humans with almost 300 allelic variants reported [7]. The G6PD enzyme monomer consists of 515 residues with over 59 kDa molecular weight. It was reported that the enzymatically active form of G6PD is either a dimer or tetramer of a single polypeptide subunit according to cellular pH [8].

2. Methods

2.1. Searched strategy and identification of studies

For the present meta-analysis PubMed, Science Direct, Springer link and Google scholar databases were searched for suitable articles using keywords "G6PD deficiency" and "Glucose 6 phosphate dehydrogenase deficiency". Since the retrieved article list was too long only the studies carried out in India were taken into consideration. The included articles were also hand searched for additional studies which can be included in this study.

2.2. Inclusion and exclusion criteria

The inclusion criteria for the studies were as follows: studies: (1) should be original and published, (2) that used only Indian samples. Studies were excluded if they were: (1) molecular analyses, (2) case reports, and (3) reviews and editorials.

2.3. Data extraction

From all the eligible studies the following information was extracted: first authors' family name, year of publication, population/ethnic group, the number of samples analyzed, the number of G6PD deficient subjects and journal name. If in any study samples were taken from multiple caste/race then information was abstracted separately for each caste.

2.4. Statistical analysis

Prevalence proportion (PP) was computed from the number of deficient and sample sizes (N) with the corresponding 95% confidence interval (CI) from each study. A pooled PP was then estimated on the basis of the individual PPs. The PP was estimated either by using fixed effects [9] or random effects [10] model depending upon heterogeneity. The heterogeneity between studies was tested using the Q-statistics and quantified using the I^2 statistic [11]. If $I^2 > 50\%$ then random effect model was used [12]. Publication bias was investigated by using the funnel plots. All p values are two tailed with a significance level at 0.05. All statistical analyses were undertaken by computer program Meta-analyst.

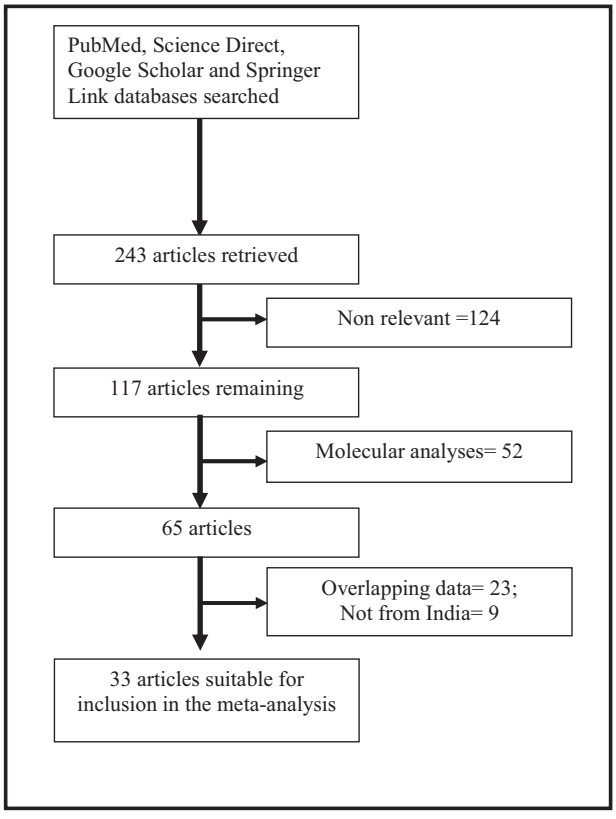

Figure 1 Flow diagram of selection of studies.

Table 1 Details of studies included in the meta-analysis.

Study	State	Cast/Race	Sample size	No of G6PD deficient	% G6PD	References
Baxi, 1961	Maharashtra	Mixed	110	15	13.64	Curr. Sci; 30: 16–17
Baxi, 1963	Maharashtra	Parsee	216	34	15.74	Indian J. Med. Sci; 17: 493–500
Chatterjea, 1966	India	Mixed	173	8	4.62	Bull. World Health Organ; 35: 837–856
Deshmukh, 1968	Maharashtra	Mahar	100	10	10	Indian J. Med. Res; 56; 821–825
Kate, 1978	Maharashtra, West Bengal	Mixed	993	75	7.55	Hum. Genet; 44: 339–343
Ghosh, 1981	West Bengal	Mixed	490	21	4.28	Hum. Hered; 31: 119–121
Saha, 1987	West Bengal	Lepchas	215	0	0	Hum Hered;37:113–21
Chhotray, 1990	Orissa	Juang	53	7	13.20	Indian J Med Res;;92: 443–446
Chhotray, 1990	Orissa	Munda	52	6	11.54	Indian J Med Res. 92: 443–446.
Chhotray, 1990	Orissa	Bhuyan	102	15	14.71	Indian J Med Res; 92: 443–446
Verma, 1990	Punjab	Mixed	1000	39	3.9	Indian J Pediatr; 57: 385–8
Jain, 1922	Rajasthan	Mixed	9433	170	1.80	J Assoc Physicians India; 40: 662–3
Kaede, 1995	Orissa	Bhuyan	204	30	14.71	Am J Hum Genet; 57:1335–1341
Kaede, 1995	Orissa	Bhatudi	106	12	11.32	Am J Hum Genet; 57:1335–1341
Kaede, 1995	Orissa	Munda	104	14	13.46	Am J Hum Genet; 57:1335–1341
Kaede, 1995	Orissa	Santhal	53	6	11.32	Am J Hum Genet; 57:1335–1341
Kaede, 1995	Orissa	Koda	56	5	8.93	Am J Hum Genet; 57:1335–1341
Kaede, 1995	Orissa	Saunti	52	4	7.69	Am J Hum Genet; 57:1335–1341
Kaede, 1995	Orissa	Juang	57	7	12.28	Am J Hum Genet; 57:1335–1341
Kaede, 1995	Orissa	Ganda	49	3	6.12	Am J Hum Genet; 57:1335–1341
Kaede, 1995	Orissa	Pana	216	8	3.70	Am J Hum Genet; 57:1335–1341
Kaede, 1995	Madhya Pradesh	Baiga	263	11	4.18	Am J Hum Genet; 57:1335–1341
Kuruvilla, 1998	India	Mixed	212	25	11.79	Indian Ped; 35:52–55
Joshi, 2001	Western India	Vataliya Prajapati	385	87	22.59	Haematologia 31: 57–60 (Budap)
Murhekar, 2001	Andaman and Nicobar Islands	Negrito tribe	29	1	3.45	Hum. Biol. 73: 739–744
Sukumar, 2004	India	Mixed	3166	332	10.49	Blood Cells Mol. Diseases 33: 141–145
Santhi, 2004	Haryana	Jat	136	13	9.56	Anthropologist; 6(4): 291–292
Santhi b, 2004	Haryana	Brahmin	152	14	9.21	Anthropologist; 6(4): 291–292
Chhotray, 2004	Orissa	Juang	879	115	13.08	Annual Report of RMRC (ICMR), Bhubaneswar; 46–47
Chhotray, 2004	Orissa	Bodo	839	3	0.36	Annual Report of RMRC (ICMR), Bhubaneswar; 46–47
Chhotray, 2004	Orissa	Didayi	1014	17	1.68	Annual Report of RMRC (ICMR), Bhubaneswar; 46–47
Chhotray, 2004	Orissa	Kondh	645	51	7.91	Annual Report of RMRC (ICMR), Bhubaneswar; 46–47
Balgir, 2004	Orissa	Bathudi	95	13	13.68	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Bhatra	166	14	8.43	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Bhumiz	116	20	17.24	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Bhuyan	92	12	13.04	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Gond	219	25	11.41	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Kharia	54	6	11.11	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Kisan	130	8	6.15	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Kolha	102	19	18.63	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Kondh	254	28	11.02	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Lodha	78	7	8.97	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Munda	96	25	26.04	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Oraon	104	11	10.58	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Paraja	176	49	27.84	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Santhal	100	15	15	Anthropologist; 6: 69–75
Balgir, 2004	Orissa	Saora	177	28	15.82	Anthropologist; 6: 69–75
Gupte, 2005	Gujarat	Vataliya Prajapati	1644	358	21.78	Indian J. Med. Sci. 59 (2005) 51–56
Saraswathy, 2005	New Delhi	Brahmin	147	4	2.72	Anthropologist; 7(1): 69–70
Pao M, 2005	India	Mixed	2479	50	2.02	Indian J Pediatr;72:835–7
Dash, 2005	Mizoram	Mizos	490	86	17.55	Indian J Pathol Microbiol;48:17–8
Balgir, 2006	Central Eastern India	Mixed	1959	186	9.49	Homo 57 (2006) 163–176

(*continued on next page*)

Table 1 (*continued*)

Study	State	Cast/Race	Sample size	No of G6PD deficient	% G6PD	References
Bhasin, 2006	Jammu & Kashmir	Mixed	124	7	5.64	Int J Hum Genet; 6(1): 49–72
Bhasin, 2006	Nagaland	Naga	85	23	27.06	Int J Hum Genet; 6(1): 49–72
Bhasin, 2006	Karnataka	Mixed	87	0	0	Int J Hum Genet; 6(1): 49–72
Bhasin, 2006	Kerala	Mixed	1809	22	1.22	Int J Hum Genet; 6(1): 49–72
Bhasin, 2006	Assam	Mixed	558	49	8.78	Int J Hum Genet; 6(1): 49–72
Nishank, 2008	Orissa	Tribal	3480	223	6.41	Ann. Hum. Biol; 35: 355–361
Saraswathy a, 2008	Andhra Pradesh	Koyadoras	132	6	4.54	Anthropologist; 10(2): 163–165
Saraswathy b, 2008	Andhra Pradesh	Nayakpoda	40	2	5	Anthropologist; 10(2): 163–165
Samtani, 2008	Dadra and Nagar Haveli	Warli tribe	79	8	10.13	Anthropologist; 10(4): 301–303
Devi, 2009	Dadra and Nagar Haveli	Rajputs	47	1	2.13	Anthropologist, 11(1): 45–47
Achoubi, 2010	Manipur	Muslim	136	29	21.32	Anthropological Science; 118(3): 201–204.
Achoubi, 2010	Manipur	Brahmin	127	12	9.45	Anthropological Science; 118(3): 201–204
Achoubi, 2010	Manipur	Kabui	51	4	7.84	Anthropological Science; 118(3): 201–204
Sharma, 2010	Uttar Pradesh	Dangurai Tharu	56	13	23.21	Anthropologist; 12(1): 59–61
Sharma, 2010	India	Mixed	810	50	6.17	Indian J Pathol Microbiol; 54(4) 850–851
Kabita a, 2011	Himachal Pradesh	Rajput	65	1	1.54	Anthropologist; 13(1): 39–41
Kabita b, 2011	Himachal Pradesh	Brahmin	47	1	2.13	Anthropologist; 13(1): 39–41
Rai and Kumar, 2012	Uttar Pradesh	Scheduled Caste	200	20	10	J Anthrop. doi:10.1155/2012/984180
Kumar and Rai,2012	Uttar Pradesh	Yadav	200	7	3.5	Res. Environ. Life Sci; 5(4): 213–214
Rai and Kumar,2014	Uttar Pradesh	Muslim	200	26	13	Indian J Hum Genet; 20(1): 96–97

3. Results

The preliminary search resulted in 243 publications from PubMed, Google scholar, Science Direct, and Springer Link. Out of which 124 were irrelevant for the present meta-analysis, which includes reviews, editorials, book chapters, case reports, etc. After initial exclusion of 124 articles, total 117 articles remained. Out of which, in 52 articles molecular analyses were carried out, 23 articles reported overlapping data and 9 were not from India. Thus, a total of 33 articles were included in present meta-analysis. The search workflow was shown in Fig. 1.

Study characteristics were summarized in Table 1. Thirty-three articles that reported G6PD deficiency from different parts of India were found suitable for the inclusion in the present meta-analysis [13–47]. All studies were published between the periods of 1961 and 2014. A few authors studied several different caste populations, so each population was included as an individual study. A total of 72 populations were studied in thirty-three articles. All these thirty-three studies were performed in different states of the India, Maharashtra [16,17,23,29], West Bengal [25,29,36], Orissa [14,20,21,30,35], Punjab [44], Rajasthan [27], Madhya Pradesh [30], Western India [27], Central Eastern India [15], Uttar Pradesh [32,37,38,44], Andaman and Nicobar [35], Haryana [41], Gujarat [26], New Delhi [42], Mizoram [22], Jammu and Kashmir [18], Nagaland [18], Karnataka [18], Kerala [18], Assam [18], Andhra Pradesh [43], Dadra and Nagar Haveli [24,40], Manipur [13], and Himachal Pradesh [29].

In thirty-three studies included in the present meta-analysis, the smallest sample size was 29 [35], and highest sample size was 9,433 [27]. Totally 8,565 samples were analyzed, out of which 2,626 individuals were G6PD deficient.

Meta-analysis was performed using both fixed and random effect models. Meta-analysis with Fixed effects model showed 0.096 (95% CI = 0.093–0.100) (Fig. 2). Meta-analysis with random effect model showed an overall prevalence proportion as 0.087 (95% CI = 0.070–0.103; $p = 0.000$; tau = 0.826; $I^2 = 0.486$; Cochran $Q = 0.999$) (Fig. 3). Publication bias was absent (Fig. 4).

4. Discussion

According to World Health Organization [48] the prevalence of G6PD deficiency in India ranges 0–10% which is population specific and is reported to be higher among tribals in comparison to caste population [49]. In general, the frequency of G6PD deficient allele is comparatively higher in North and West India, which indicates considerable stability of the allele in these areas, whereas in South India it is uniformly low except in Andhra Pradesh and Tamil Nadu. Bhasin [18] reported the distribution of G6PD deficient (Gd^-) allele according to natural regions, climatic regions, Himalayan regions, and different ethnic groups. In the Himalayan region, the frequency is quite high (0.087) as compared to non–Himalayan region (0.043) and frequency of G6PD deficient allele in scheduled tribes is high (0.055) as compared to other ethnic groups.

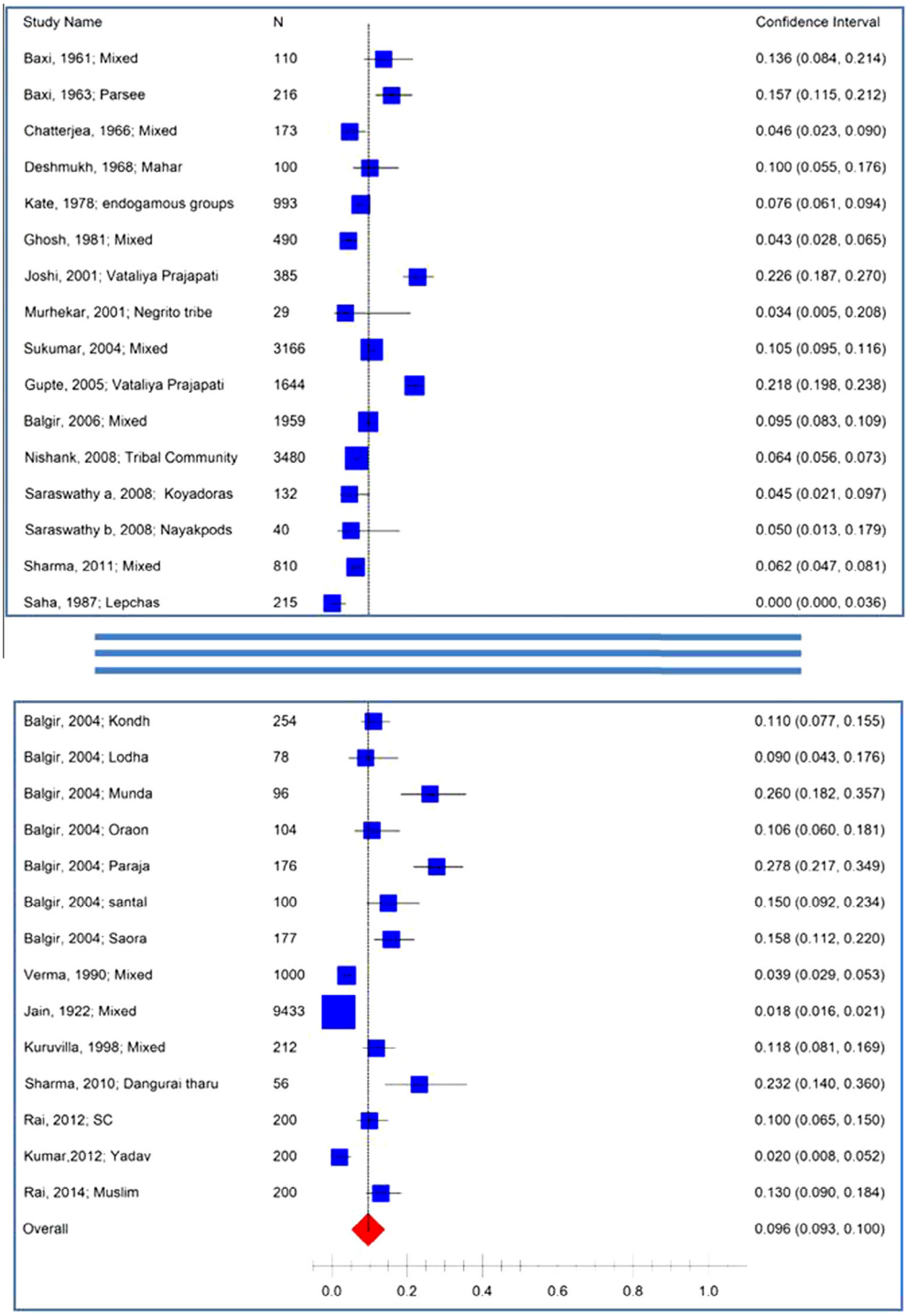

Figure 2 Forest plot of prevalence proportion of fixed effect model.

Several reports regarding the frequency of G6PD deficient (Gd^{-}) allele was published from all the states and also in several caste groups like-Parsee [17], Muslim [13], Brahmin [13,29,42,43,50], Jat [42], Rajputs [24,29,31,50], and Scheduled caste [38,46]. Bhasin [9] reviewed that G6PD deficiency in India varies from 1% to 27% in different communities and regions of India. The review shows varying frequencies in different regions and ethnic groups depending upon the hyperendemicity of malaria. In eastern India, the frequency is the highest in Angami Nagas (27.1%), followed by Adi (19.4%), Apatani (16.7%), Nishi (16%), Rabha (15.8%), Mikir (15.6%), Santhal (14.1%), etc. [51]. In western India, higher frequency is found in the Vataliya Prajapati (caste) community (27.9%), Gonds (24.4%), Warli (19.5%), Parsis (15.7%), Madia (14.4%), Kutchi Bhanushalis (13%), etc. In the North, high frequency has been shown in Meghwal-Chamars (15.1%) and Punjabi Khatris (14%) for this defective enzyme. In South India, high incidence of G6PD deficiency is found in the tribals

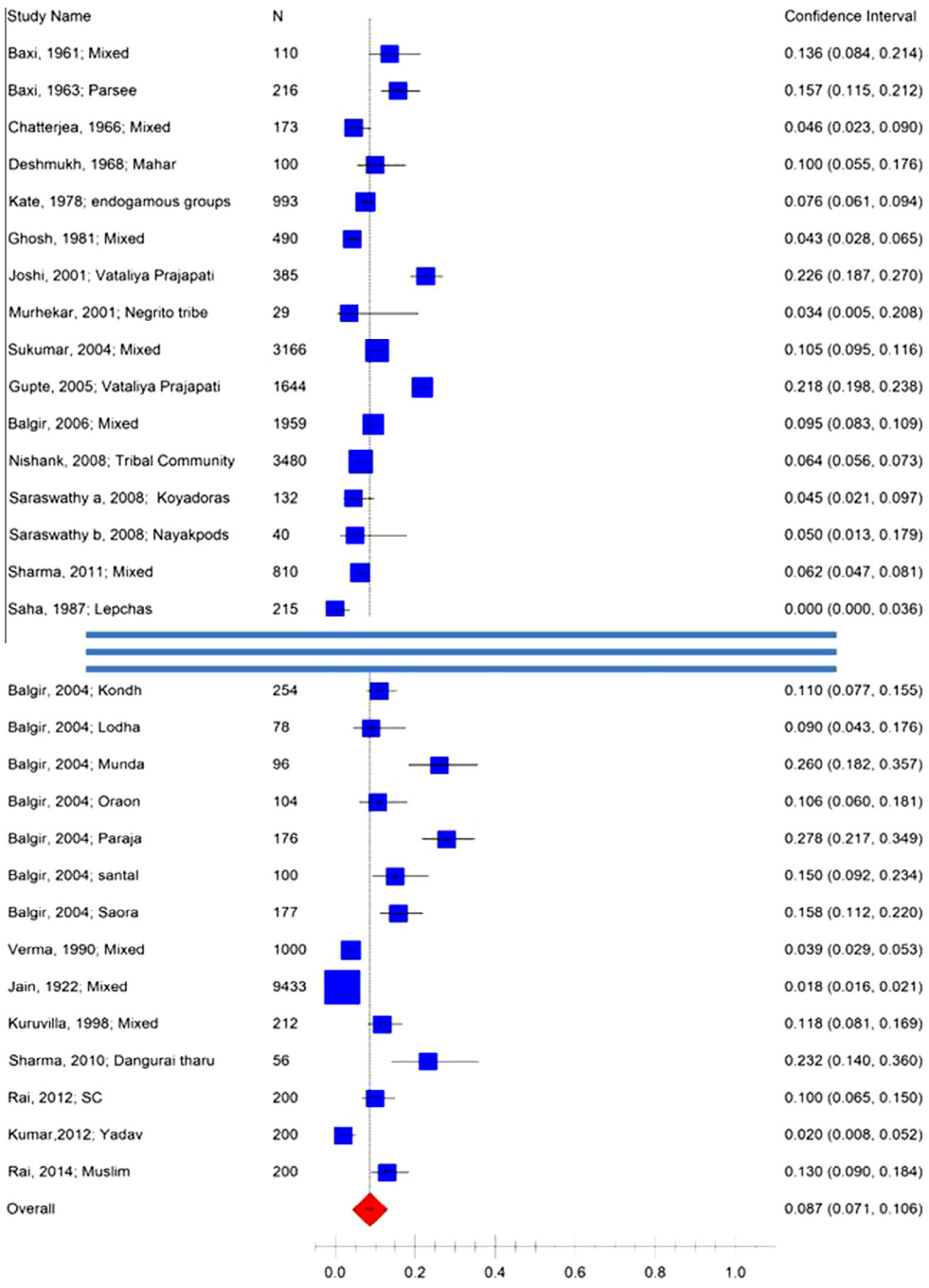

Figure 3 Forest plot of prevalence proportion of random effect model.

(13%) of Andhra Pradesh and Kurumba tribe (11.9%) of Kerala [51]. The frequency of G6PD deficiency in Dhelki Kharia subtribe (30.4%) is the highest so far reported from India.

As an important statistical method developed recently, meta-analysis quantitatively combines several small analysis of the same topic with low statistical power and small number of participants and with a homogeneous design. Because of the large sample sizes, meta-analysis has more statistical power than a single study to obtain reliable results. Several meta-analysis studies were already published, which investigated effects of gene variants in disease causing or prevalence proportion of pathogenic variants in different populations to assess small effect of MTHFR C677T polymorphism as risk factor for different diseases [52,53].

Early detection and prevention is the key strategy for the successful management and control of G6PD deficiency. The G6PD deficient individuals are asymptomatic (until they are exposed to oxidative stress) so they transmit pathogenic mutated gene to the next generation. In addition, G6PD deficiency carriers are partially protected against malarial infection hence this mutation is naturally selected in malarial endemic regions of India. The results of the present meta-analysis determined the exact magnitude of the G6PD defi-

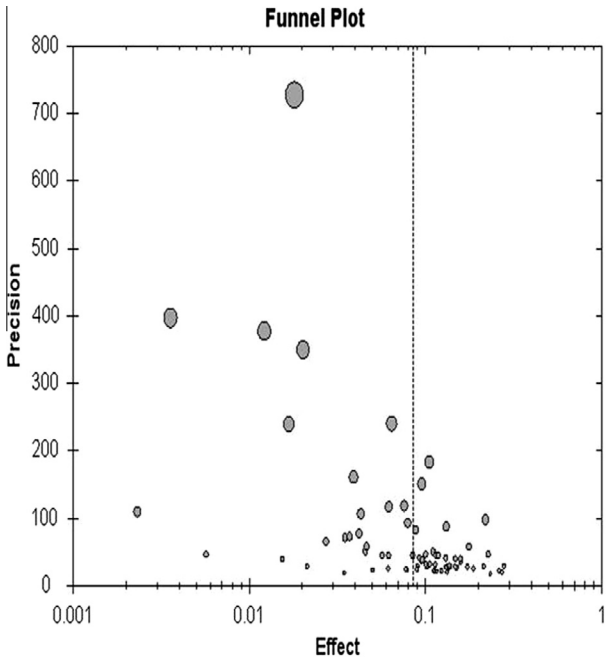

Figure 4 Forest plot:standard error versus PP.

ciency in Indian population i.e. 8.5%, which can aid in planning programs to improve neonatal health and also help to plan the strategy to successful management and control of this genetic disorder.

Conflict of interest

None.

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References

[1] Luzzatto L, Battistuzzi G. Glucose 6-phosphate dehydrogenase. Adv Hum Genet 1985;14:217–329.
[2] Beutler E, Vulliamy TJ. Hematologically important mutations: glucose-6-phosphate dehydrogenase. Blood Cells Mol Dis 2002;28:93–103.
[3] Marks PA, Banks J, Gross RT. Genetic heterogeneity of glucose-6-phosphate dehydrogenase deficiency. Nature 1962;194:454.
[4] Persico MG, Viglietto G, Martini G, Dono R, D'Urso M, Toniolo D, Vulliamy T, Luzzatto L. Analysis of the primary structure of human G 6 PD deduced from the cDNA sequence. In: Yoshida A, Beutler E, editors. Glucose-6-phosphate dehydrogenase. Orlando, FL: Academic; 1986. p. 503–16.
[5] Takizawa T, Huang IY, lkuta T, Yoshida A. Human glucose-6-phosphate dehydrogenase: primary structure and cDNA cloning. Proc Natl Acad Sci USA 1986;83:4157–61.
[6] Chen EY, Cheng A, Lee A, Kuang W-J, Hillier L, Green P, et al. Sequence of human glucose-6-phosphate dehydrogenase cloned in plasmids and a yeast artificial chromosome (YAC). Genomics 1991;10:792–800.
[7] Beutler E. The hemolytic effect of primaquine and related compounds. A review. Blood 1959;14:103.
[8] Luzzatto L. Glucose 6-phosphate dehydrogenase deficiency: from genotype to phenotype. Haematologica 2006;91(10):1305.
[9] Mantel N, Haenszel W. Statistical aspects of the analysis of data from retrospective studies of disease. J Natl Cancer Inst 1959;22:719–48.
[10] DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trial 1986;7:177–88.
[11] Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med 2002;21:1539–58.
[12] Whitehead A. Meta-analysis of controlled clinical trials. Chichester, West Sussex, England: John Wiley & Sons Ltd; 2002.
[13] Achoubi N, Asghar M, Meitei SY, Sachdeva MP, Sarawathy KN, Murry B. Haemoglobinopathies and glucose-6-phosphate dehydrogenase deficiency in a malaria endemic region of Manipur, northeast India. **Anthropol Sci** 2010;118(3):201–4.
[14] Balgir RS. Ethnic and regional variations in the red cell glucose-6-phosphate dehydrogenase deficiency in India. Indian J Hematol 1989;7:101–9.
[15] Balgir RS, Dash B, Murmu B. Blood groups, hemoglobinopathy and G-6-PD deficiency: investigations among fifteen major scheduled tribes of Orissa, India. Anthropologist 2004;6:69–75.
[16] Baxi AJ, Balakrishnan V, Sanghvi LD. Deficiency of G6PD observations on sample from Bombay. Curr Sci 1961;30:16.
[17] Baxi AJ, Balkrishnan V, Undevia JV, Sanghvi LD. Glucose 6-phosphate dehydrogenase deficiency in the Parsi community, Bombay, India. Indian J Med Sci 1963;17:493–500.
[18] Bhasin MK. Genetics of castes and tribes of India: glucose-6-phosphate dehydrogenase deficiency and abnormal hemoglobins (Hb S and Hb E). Int J Hum Genet 2006;6(1):49–72.
[19] Chatterjee JB. Haemoglobinopathies, glucose-6-phosphate dehydrogenase deficiency and allied problems in the Indian subcontinent. Bull World Health Organ 1966;35:837–56.
[20] Chhotray GP, Ranjit MR. Prevalence of G-6-PD deficiency in a malaria endemic tribal area of Orissa (India). Indian J Med Res 1990;92:443–6.
[21] Chhotray GP. Intervention programme on nutritional anaemia and haemoglobinopathies in some primitive tribal population of India. Annual Report of RMRC (ICMR), Bhubaneswar 2004;46–47.
[22] Dash S, Chhanhimi L, Chhakchhuak L, Zomawaia E. Screening for haemoglobinopathies and G6PD deficiency among the Mizos of Mizoram: a preliminary study. Indian J Pathol Microbiol 2005;48:17–8.
[23] Deshmukh VV, Sharma KD. Deficiency of erythrocyte glucose-6-phosphate dehydrogenase and sickle cell trait: a survey of Mahar students at Aurangabad, Maharashtra. Indian J Med Res 1968;56:821–5.
[24] Devi NA, Sachdeva MP. Sickle cell haemoglobin and glucose-6-phosphate dehydrogenase deficiency among the Rajputs of Dadra and Nagar Haveli. Anthropologist 2009;11(1):45–7.
[25] Ghosh U, Banerjee T, Banerjee PK, Saha N. Distribution of haemoglobin and glucose-6-phosphate dehydrogenase phenotypes among different caste groups of Bengal. Hum Hered 1981;31:119–21.
[26] Gupte SC, Shaw AN, Shah KC. Hematological findings and severity of G6PD deficiency in Vataliya Prajapati subjects. J Assoc Physicians India 2005;53:1027–30.
[27] Jain RC. G-6PD deficiency in malaria endemic areas of Udaipur District in Rajasthan. J Assoc Physicians India 1992;40:662–3.
[28] Joshi SR, Patel RZ, Patel HR, Sukumar S, Colah RB. High prevalence of G6PD deficiency in Vataliya Prajapati community in western India. Haematologia 2001;2001(31):57–60.
[29] Kabita S, Khurana P, Saraswathy KN, Sachdeva MP. Glucose-6-phosphate dehydrogenase deficiency among the Rajputs and Brahmins of Solan District, Himachal Pradesh. Anthropologist 2011;13(1):39–41.

[30] Kaeda JS, Chhotray GP, Ranjit MR, Bautista JM, Reddy PH, Stevens D, et al. A new glucose-6-phosphate dehydrogenase variant, G6PD Orissa (44 Ala–>Gly), is the major polymorphic variant in tribal populations in India. Am J Hum Genet 1995;57:1335–41.
[31] Kapoor AK. Glucose-6-phosphate dehydrogenase deficiency among high and low altitude Himalayan populations. Indian J Phys Anthropol Hum Gen 1989;15(1–2):61–4.
[32] Kate SL, Mukherjee BN, Malhotra KC, et al. Red cell glucose-6-phosphate dehydrogenase deficiency and haemoglobin variants among ten endogamous groups of Maharshtra and West Bengal. Hum Genet 1978;44:339–43.
[33] Kumar P, Rai V. Climate change and human health: malaria and glucose-6-phosphate dehydrogenase deficiency. Res Environ Life Sci 2012;5(4):211–2.
[34] Kuruvilla KA, Atanu STS, Jana K. Glucose-6-phosphate dehydrogenase deficiency in neonatal hyperbilirubinemia in a South Indian Referral Hospital. Indian Ped 1998;35:52–5.
[35] Murhekar KM, Murhekar MV, Mukherjee MB, Gorakshakar AC, Surve R, Wadia M, et al. Red cell genetic abnormalities, beta-globin gene haplotypes, and APOB polymorphism in the Great Andamanese, a primitive Negrito tribe of Andaman and Nicobar Islands. India. Hum Biol 2001;73:739–44.
[36] Nishank SS, Chhotray GP, Kar SK, Ranjit MR. Molecular variants of G6PD deficiency among certain tribal communities of Orissa, India. Ann Hum Biol 2008;35:355–61.
[37] Pao M, Kulkarni A, Gupta V, Kaul S, Balan S. Neonatal screening for glucose-6-phosphate dehydrogenase deficiency. Indian J Pediatr 2005;72:835–7.
[38] Rai V, Kumar P. Epidemiological study of glucose-6-phosphate dehydrogenase deficiency in scheduled caste population of India. J Anthrop 2012:1–5.
[39] Rai V, Kumar P. Glucose 6-phosphate dehydrogenase deficiency in Muslim community settled in jaunpur district. Indian J Hum Genet 2014;20(1):96–7.
[40] Saha N, Bhattacharyya SP, Mukhopadhyay B, Bhattacharyya SK, Gupta R, Basu A. A genetic study among the Lepchas of the Darjeeling area of eastern India. Hum Hered 1987;37:113–21.
[41] Samtani R, Mondal MP, Saraswathy KN. Glucose-6-phosphate dehydrogenase deficiency and sickle cell hemoglobin among the Warli tribe of Dadra and Nagar Haveli. Anthropologist 2008;10(4):301–3.
[42] Santhi A, Sachdeva MP. Glucose-6-phosphate dehydrogenase deficiency among the Jats and Brahmins of Sampla (Haryana). Anthropologist 2004;6(4):291–2.
[43] Saraswathy KN, Aggarwal S. Study of glucose-6-phosphate dehydrogenase deficiency and sickle cell anemia among the Tamil Brahmins of Delhi. Anthropologist 2005;7(1):69–70.
[44] Saraswathy KN, Sachdeva MP. G6PD deficiency, sickle cell trait, haptoglobin and transferrin polymorphisms among Koyadoras and Nayakpods of Andhra Pradesh. Anthropologist 2008;10(2):163–5.
[45] Sharma TP, Rajkumari. Glucose-6-phosphate dehydrogenase deficiency in Danguria Tharu Settled in Baharaich District of Uttar Pradesh. Anthropologist 2010;12(1):59–61.
[46] Sukumar S, Mukherjee MB, Colah RB, Mohanty D. Molecular basis of G6PD deficiency in India. Blood Cell Mol Dis 2004;33:141–5.
[47] Verma M, Singla D, Crowell SB. G6PD deficiency in neonates: a prospective study. Indian J Pediatr 1990;57:385–8.
[48] WHO working group. Glucose-6-phosphate dehydrogenase deficiency. Bull WHO 1989;67:601.
[49] Tripathy V, Reddy BM. Present status of understanding on the G6PD deficiency and natural selection. J Postgrad Med 2007;53(3):193–200.
[50] Sidhu PK, Kaur K, Kumar I, Lata S. Glucose-6-phopshate dehydrogenase deficiency in blood donors: screening by micro-methaemoglobin reduction test. Indian J Pathol Microbiol 2001;44(1):23–5.
[51] Balgir RS. Do tribal communities show an inverse relationship between sickle cell disorders and glucose-6-phosphate dehydrogenase deficiency in malaria endemic areas of Central-Eastern India? Homo 2006;57:163–76.
[52] Rai V, Yadav U, Kumar P, Yadav SK, Mishra OP. Maternal methylenetetrahydrofolate reductase C677T polymorphism and down syndrome risk: a meta-analysis from 34 studies. PLoS ONE 2014;9(9):e108552.
[53] Yadav U, Kumar P, Yadav SK, Mishra OP, Rai V. Polymorphisms in folate metabolism genes as maternal risk factor for neural tube defects: an updated meta-analysis. Metab Brain Dis 2015;30(1):7–24.