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Distribution of Extended Red Blood Cell Phenotypes Among Blood Donors: Experience from a Low- and Middle-Income Country

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Abstract

Background: Although information on minor blood group antigen frequencies is limited in many low- and middle-income countries, extended red blood cell (RBC) phenotyping is crucial for reducing alloimmunization in patients undergoing chronic transfusions. This study aimed to characterize the distribution of extended red blood cell antigens across multiple clinically significant blood group systems among blood donors in a low- and middle-income country to inform transfusion strategies.

Methods: Between April and September 2024, we carried out a cross-sectional pilot study involving 200 healthy blood donors recruited from five blood banks in a low- and middle-income country. In accordance with the AABB guidelines, the antigen frequencies for the Kell (K, k, Kpa, Kpb), Duffy (Fya, Fyb), Kidd (Jka, Jkb), MNS (M, N, S, s), Lewis (Lea, Leb), Lutheran (Lua, Lub), and P1 systems were determined via manual tube agglutination. Lutheran and Lewis systems were examined in randomly chosen subgroups (n = 120 and n = 110, respectively) due to resource scarcity. Phenotype match probabilities were calculated as $\Sigma(p_i^2)$ and compared with published population data using chi-square tests with Bonferroni correction.

Results: The following unique antigen distributions were found: S (88.5%, 83.4–92.4), Jka (72.5%, 65.8–78.3), P1 (70.5%, 63.9–76.4), K (7.0%, 95% CI: 4.2–11.3), and k (97.0%, 93.8–98.9). Significant gene flow from Africa was demonstrated by the 17.5% (12.8–23.4) that had the Fy(a−b−) null phenotype. There were differences in phenotype matching within the population, ranging from 28.2% (Kidd) to 66.7% (Lutheran). The highest cross-population compatibility was found with African donors for Duffy (29.6%) and P1 (67.3%) and Israeli donors for Kidd (43.7%). Importantly, Duffy's compatibility with Asian people was only 10.9%, meaning that using Asian donors would result in a 90% sensitization risk.

Conclusions: These pilot results show that Palestinians have unique RBC antigen patterns that call for transfusion techniques tailored to their demographics. The results encourage the introduction of extended phenotyping in tiers, starting with the Kell, Duffy, and Kidd systems, and the creation of a national phenotyped donor registry (achievable within 2-3 years given 35,000 annual donations). However, before policy is mandated, further extensive molecularly validated investigations involving Gaza and Jerusalem are needed.

Keywords: blood group antigens, phenotype frequency, Palestinian population, transfusion medicine, alloimmunization

Introduction

Alloimmunisation to non-ABO antigens contributes to delayed hemolytic transfusion reactions, although reported rates vary widely depending on the patient population and transfusion burden.[1,2]. The antigens of the MNS, Duffy, Kidd, and Kell systems are considered among the most immunogenic [3]. The risk of alloimmunisation is largely influenced by population-specific antigen frequencies; for example, K-negative blood is common in Asians (<0.1% K antigen) but uncommon in Europeans (9% K antigen). [4] Marked differences in antigen frequencies between populations illustrate the importance of local antigen mapping for transfusion planning. In today's blood banking, serological phenotyping is still the standard practice for routine transfusion, although molecular genotyping is more accurate and precise [5].

In Palestine, on the basis of the Annual Health Report for 2024 issued by the Palestinian Ministry of Health, there are approximately 600 patients with sickle cell disease and 2500 thalassemia patients who are dependent on blood transfusions [6]. ABO/RhD matching is the method of choice in current practice in Palestine, and the only patients who undergo extended phenotyping are patients with confirmed alloantibodies. In 2023, Al-Makassed Hospital conducted an audit and reported that 18% of patients who receive multiple transfusions develop clinically significant alloantibodies within two years [7]. In a setting with limited resources and movement restrictions, the lack of a phenotyped donor inventory demands reliance on foreign rare donor programs, which come with high costs and delays [8].

Data on the systematic extended RBC phenotype for Palestinians are severely lacking. This study focused on eight clinically significant systems (Kell, Kidd, Duffy, MNS, Lewis, Lutheran, P1, and Rh-related antigens) due to their known role in transfusion reactions, although isolated studies have reported Kell frequencies in Bethlehem (n=400) [9] and genotyping data from thalassemia patients (n=87) [7]. According to population genetics studies [10],

the genetic heritage of the Palestinian population reflects Canaanite, Arab, European, and African admixture, making extrapolation from nearby populations unreliable for transfusion planning.

The objective of this pilot study was set to determine the distribution of extended RBC phenotypes among blood donors in the West Bank. We determined antigen frequencies for the Kell (K, k, Kpa, Kpb), Duffy (Fya, Fyb), Kidd (Jka, Jkb), Lewis (Lea, Leb), Lutheran (Lua, Lub), P1, and MNS (M, N, S, s) systems and calculated phenotype match probabilities and compared them to reference populations.

Methods

Study Design and Setting

We conducted a cross-sectional pilot study at five West Bank blood banks (An-Najah National University and Rafidia Hospitals) in the North, the National Blood Bank in the Center, and the Alia and Al-Ahli Hospitals in the South from April 1 to September 30, 2024. The An-Najah National University Hospital Blood Bank served as the central testing laboratory.

Participants and Sampling

We acknowledge the possibility of selection bias because we used convenience sampling but used this sampling method because of the limited availability of resources. We enrolled 200 healthy volunteer donors who met the donation eligibility standards (aged 18–65 years, weight ≥50 kg, and hemoglobin ≥12 g/dL). We excluded donors who had blood transfusions within six months, who had autoimmune or hematologic disorders, and who were of non-Palestinian ancestry (defined as self-reported Palestinian origin with both parents born in Palestine to ensure genetic homogeneity confirmed through donor registration records). This criterion was applied to ensure genetic homogeneity and reduce ancestry-related variability in phenotype frequencies. The geographic distribution of West Bank donors was 68 (34.0%)

from the Northern West Bank, 71 (35.5%) from the Central West Bank, and 61 (30.5%) from the Southern West Bank.

Selection Bias Assessment

Convenience sampling may lead to differences between the enrolled donors and the general Palestinian population. To evaluate potential bias, we compared cohort demographics to national donor statistics (Additional file 1: Supplementary Table S1). This reflects the well-described 'healthy donor effect,' whereby blood donors tend to be younger, healthier, and of higher socioeconomic status than the general population [11]. Moreover, the self-selection of volunteer donors may favour specific geographic or ethnic subgroups that are not representative of the population's overall genetic composition. We acknowledge these limitations, and we will be able to generalize our findings to eligible, healthy blood donors rather than all Palestinian people. Potential sources of selection bias and their expected effects are summarized in Supplementary Table S2 (Additional file 1).

Sample size

The sample size was determined using prevalence-estimation principles assuming maximum variability (50%), a 95% confidence level, and precision of ±3.8%, which required approximately 200 donors.

Phenotyping procedure

Phenotyping was performed for the following red blood cell antigens: K, k, Kpa, Kpb, Fya, Fyb, Jka, Jkb, M, N, S, s, Lea, Leb, Lua, Lub, and P1 using the manual tube agglutination method according to AABB guidelines. Commercial antisera from DIAGAST, France. A 5% suspension of RBCs in low-ionic-strength solution was incubated with antisera at 37°C for 10 minutes, washed three times, treated with polyspecific anti-human globulin, and centrifuged at 120 g for 1 minute before being read macroscopically. All tests were performed within 48 hours of collection. Because of limited

reagent availability, phenotyping for Lua and Lub antigens was conducted in the first 120 consecutively enrolled donors, while Lea and Leb antigens were tested in a subsequent subset of 110 donors. To confirm that these subsets did not introduce selection bias, we compared subset demographics (age, sex, and region) to those of the full cohort via chi-square tests (all $p > 0.05$), confirming representativeness.

The interobserver agreement between the two independent technologists was excellent (Cohen's $\kappa = 0.92$, 95% CI: 0.88–0.96). Each batch included manufacturer-positive and manufacturer-negative controls (DiaPanel, Bio-Rad). Discordant results (>1 grade difference) were resolved by repeated testing with a third senior technologist. Equipment was calibrated monthly per the Clinical and Laboratory Standards Institute (CLSI) guidelines.

Statistical analysis

Antigen frequencies are expressed as percentages with 95% Wilson confidence intervals. The phenotype match probability was calculated as $\Sigma(p_i^2)$, where p_i represents the phenotype frequency. For comparative analysis with published population data [9,10,12–18], chi-square tests with Bonferroni correction were used for multiple comparisons (adjusted $p < 0.05$). We chose reference populations on the basis of geographic proximity (Israeli, Saudi) and historic gene-flow patterns (African, Asian, European) described in the population genetics literature [10]. The confidence intervals for match probabilities were estimated via bootstrap resampling with 10,000 iterations. Analyses were performed in IBM SPSS Statistics version 23.

Ethical considerations

The study received ethical approval from the Institutional Review Board of An-Najah National University (Mas.Oct.2023/39). In addition, all necessary approvals were obtained from the Palestinian Ministry of Health. Written informed consent was obtained from all individual blood donors prior to participation in the study.

Results

Cohort characteristics

A total of 200 donors were enrolled from five blood banks across the West Bank. The cohort included 124 males (62.0%) and 76 females (38.0%) with a mean age of 31.4 ± 9.7 years, representing all major geographic regions. (Table 1).

Antigen and phenotype frequencies

The complete phenotype distributions are provided in Supplementary Tables S3–S8 (Additional file 1). The antigen frequency across all the tested systems revealed a clear dominance of high-prevalence antigens, especially k, Kpb, S, and Lub, but low-frequency antigens such as K, Kpa, Lua, and Fy(a+b−) were rare. The K+k+ phenotype is typically rare in populations with low K antigen frequency. The absence here is consistent with the low K frequency (7.0%) observed. Although there are some differences in the Duffy and MNS systems, where the frequencies of Fy(a−b−) and S were significantly higher than those reported in nearby groups, this pattern is consistent with Middle Eastern populations.

There were notable significant differences from the reference populations (full comparisons in Supplementary Table S8: Additional file 1): the S antigen frequency (88.5%) was significantly greater than that of Europeans (55.0%, $p < 0.001$), Fy(a−b−) (17.5%) was greater than that of Asian populations (<1.0%, $p < 0.001$), and P1 (70.5%) was significantly lower than that of African populations (94.0%; $\chi^2 = 32.1$, $p < 0.001$). Null phenotypes were uncommon but clinically relevant: Jk(a−b−) occurred in 1.0% (CI: 0.3–3.6) and Lu(a−b−) in 13.3% (subset). Rare antigens exhibited wide confidence intervals reflecting detection uncertainty in this sample size (e.g., Kpa 1.0%, CI: 0.3–3.6%). The key findings are summarized in Tables 2 and 3.

The high-frequency combination phenotypes were clearly dominant across all the tested blood group systems. For the Kell system, the K−k+ phenotype was very common (90%), but the K+k− phenotype was found in only 7% of the samples. On the other hand, the Duffy system showed considerable variability, with Fy(a−b+) being the most frequent (42%), followed by Fy(a+b+) (36%) and Fy(a−b−) (17.5%). The most common phenotype in the Kidd system was Jk(a+b+) (45.5%), with Jk(a+b−) and Jk(a−b+) occurring at similar frequencies (27% and 26.5%, respectively). The M+N+S+s+ phenotype (41.5%) was the most common in the MNS system. The predominant phenotype in the Lewis system was Le(a−b+) (42.5%). Lu(a−b+) (81%) was the most common in the Lutheran system. Finally, the P1+ phenotype accounted for 70.5% of the tested blood donors. Overall, most of the tested systems clearly presented a dominant phenotype pattern with varying degrees of secondary phenotypes.

Cross-Population Comparisons

The range of intrapopulation phenotypic matching was 21.7% (MNS) to 66.7% (Lutheran). The majority of antigens, especially the S antigen (χ^2 = 87.3 vs. Europeans), Fy (a−b−) phenotype (χ^2 = 45.7 vs. Asians), and P1 (χ^2 = 32.1 vs. Asians), were significantly different from those of the reference groups (adjusted $p < 0.05$).

When we compared the phenotype compatibility between the Palestinian population and global reference groups (Table 4), we found variable matching probabilities. The highest compatibility was found for the Lutheran system (66.7%), whereas other systems, such as Kell (54.1) and P1 (42.4), presented moderate matching compatibility.

Compared with other populations, Asian populations had the highest match probabilities for Lutheran (81.8%) and Kell (58.2%), African populations for P1 (67.3%) and Duffy (29.6%), European populations for MNS (55.0%), Israeli populations for Kidd (43.7%), and Chinese people for Lewis (41.4%). Clinical

risk is directly correlated with these percentages. For example, the 10.9% Duffy compatibility with Asian populations suggests that approximately 90% of Palestinian patients would be at risk for anti-Fya or anti-Fyb antibodies if they received random Asian donor units. On the other hand, approximately two-thirds of Palestinian patients would be safely transfused with matched African donors for this antigen, whereas one-third would be at risk for anti-P1 sensitization.

The lowest match probabilities varied by system: Europeans showed the lowest compatibility for Kell (52.1%), Asians for Duffy (10.9%) and P1 (35.2%), Africans for Kidd (22.5%) and Lutheran (65.1%), and Europeans again for Lewis (28.7%). Overall, the findings show that compatibility patterns vary significantly by antigen system, indicating both system-specific antigen variety and regional genetic structure.

Discussion

This pilot study established the first thorough RBC phenotype reference for West Bank Palestinians and revealed antigenic signatures that support our theory that population-specific transfusion strategies are necessary and that extrapolation of blood group data from nearby populations is unreliable. The distinct genetic legacy of the Palestinian people, which reflects Canaanite, Arab, European, and African mixing, translates into unique antigen profiles that have direct clinical implications for the risk of alloimmunization.

Like other populations in the Middle East, the Kell system has a low K antigen frequency (7.0%) but is much lower than that of Europeans (9.0%) [3]. Although this lowers the possibility of anti-K sensitization, relying on Asian rare-donor programs would not be appropriate because the Kp(a) frequency (1.0%) is significantly higher than that in Asian populations (<0.1%) [4]. Random Palestinian donor matching performs relatively well for

Kell, according to the 54.1% intrapopulation compatibility; nonetheless, a targeted K-negative inventory is still necessary for K-sensitized patients [12].

Fy(a−b−) frequency (17.5%), although substantially lower than that reported in Saudi Arabian and African populations, was higher than that observed in most Middle Eastern cohorts, indicating a measurable contribution of African ancestry to the Palestinian gene pool and highlighting the limited reliability of extrapolating Duffy antigen data from neighbouring populations for transfusion planning [13,14]. Importantly, approximately 438 of the 2,500 thalassemia patients in Palestine had this null phenotype. This subgroup is a substantial at high risk for anti-Fya and anti-Fyb antibodies if they are not matched prospectively [15]. Palestinians are distinguished from Asian groups whose Fy(a+b−) predominates (>80%) by the predominant Fy(a−b+) phenotype (42.0%), which leads to poor cross-population compatibility (10.9%) [13]**.** This means that approximately 90% of Palestinian patients receiving random Asian donor units would be at risk for Duffy sensitization because of this distinct incompatibility, which is especially problematic considering past procurement trends where some centers sourced units from Asian donor programs due to local shortages.

The MNS system exhibited the most unique profile, with an S antigen frequency (88.5%) that was significantly greater than that of the reference populations (European 55%, Asian 25%, African 32%) [4,13,17]. This leads to low cross-population compatibility (21.7-55.0%), highlighting the urgent need for a national donor registry that is ethnically matched for patients who regularly receive transfusions. Inventory management has a clear aim because of the 41.5% M+N+S+s+ phenotypic frequency.

The Kidd system has the following immediate operational difficulties: While Jk(a+b+) is more prevalent (45.5%), the Jk(a−b−) null phenotype (1.0%) is more prevalent than in Asian or European populations [16,18]. These findings reinforce the need for population-specific antigen databases to support

safer transfusion strategies [19]. We predict that 350 Jk(a−b−) donors enter the system each year provided that 35,000 annual donations; if these donors are regularly identified, this would be enough to create a rare-donor inventory [8].

Practical, tiered implementation is necessary due to resource limitations:

- Tier 1 (immediate): Phenotype all donors for Kell, Duffy, and Kidd because they are very immunogenic and incompatibility could result in higher risk of alloantibody formation [3,20]. According to our data, this would prevent an estimated 60-70% of preventable alloimmunization events in chronically transfused patients [1]. The Palestinian Ministry of Health, in collaboration with hospital blood banks, should oversee this phased implementation.
- Tier 2 (1 year): Because of the population's uniqueness and poor cross-compatibility with all reference populations, add MNS. This is critical for sickle cell disease patients who are high MNS responders [21].
- Tier 3 (as resources allow): Include Lewis, Lutheran, and P1 systems. Despite their importance, many antigens exhibit greater compatibility with current donor pools or are less immunogenic [22].

A registry of 5,000-10^3,000 phenotyped donors is needed to guarantee ≥5 donors for any phenotypic <5% frequency; this could be achieved in two to three years given Palestine's annual donation rate of approximately 35,000 units. Serologic phenotyping would cost approximately $15-25 per donor, which would be a one-time investment of $75,000-250,000. This cost is significantly lower than the current annual cost of rare-donor units worldwide [8,23].

Limitations

These results must be considered with some limitations because this is a pilot study. Despite being demographically matched to national donors, our convenience sample probably underestimates actual antigen frequency

variability in three important ways: First, donor deferrals exclude individuals with conditions (anaemia, chronic disease) that correlate with specific genetic backgrounds, possibly compressing recessive phenotype frequencies by an estimated 10–15%. Second, due to the tendency of urban blood banks to oversample city volunteers and donors, significant genetic variations found in rural and underprivileged areas may be overlooked. Although 38% of the donors were women, which is consistent with national donor trends, this does not accurately represent the percentage of women in the Palestinian population as a whole. Women are underrepresented in our donor sample, which may be clinically relevant given that females of childbearing age are more likely to require transfusion in certain settings. Third, rare genotypes such as Fy(a−b−) and Kp(a+) are likely underestimated because the need for two Palestinian-born parents eliminates groups of different origins with different RBC antigen patterns.

Furthermore, molecular validation is very important because serologic techniques cannot identify hybrid alleles that are frequent in admixed populations or GATA mutation-driven Fy(a−b−). For common antigens, our sample size offers only ±3.8% precision, whereas for unusual antigens, the intervals are significantly larger (e.g., Kpa CI: 0.3–3.6%). Most importantly, the current conflict restricts generalizability to the entire Palestinian population, as donors from Gaza and Jerusalem are totally unrepresented because of entry restrictions.

Conclusion

According to these pilot findings, West Bank Palestinians have unique RBC antigen patterns that call for blood transfusion strategies tailored to their community. The results acknowledge that this is preliminary evidence-based that is not yet ready for policy mandates, but they support the immediate creation of a national phenotyped donor registry starting with Tier 1 antigens. The next action consists of the following:

1. Molecular genotyping of 1,000 random donors should be categorized by district, including Jerusalem and Gaza, when possible.
2. Assess alloimmunization rates prospectively and apply Kell/Duffy/Kidd matching for 100 patients receiving regular transfusions.
3. Compares the costs of registry maintenance with those of current international donor procurement.
4. These data are provided to the Palestinian Ministry of Health to obtain funding from the budget for blood services.

These phenotype frequencies guide mandatory extended matching for hemoglobinopathy patients only after molecular validation and expanded geographic representation. The current data, however, provide sufficient evidence to justify immediate pilot implementation and prospective evaluation.

List of Abbreviations

AABB: American Association of Blood Banks

ABO: ABO blood group system

CI: Confidence interval

CLSI: Clinical and Laboratory Standards Institute

IRB: Institutional Review Board

MOH: Ministry of Health (Palestinian)

RBC: Red blood cell

RhD: Rhesus D antigen

SCD: Sickle cell disease

SPSS: Statistical Package for the Social Sciences

Declarations

Ethics approval and consent to participate: Ethics approval and consent to participate: The study protocol was reviewed and approved by the Institutional Review Board (IRB) of An-Najah National University (IRB Reference No.: Mas.Oct.2023/39) and was conducted in accordance with the ethical principles of the Declaration of Helsinki. All necessary administrative permissions were obtained from the participating hospitals and the Palestinian Ministry of Health. Written informed consent was obtained from all individual blood donors prior to participation in the study. All participants were adults aged 18 years or older; therefore, no legal guardians were involved. All collected data were used exclusively for scientific research purposes, stored securely, and accessible only to the research team. To ensure confidentiality, identifiable information was replaced with numerical codes throughout the study and analysis.

Consent for publication: not applicable.

Clinical trial number: not applicable.

Data Availability Statement De-identified aggregate data are available upon reasonable request to the corresponding author (email: aabutaha@najah.edu). Individual participant data are not available due to privacy regulations and IRB restrictions.

Competing Interest: The authors declare that they have no competing interests in this research.

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Author contributions: WAS, MAS, SHZ, and AA contributed to the conception of the study. They also planned the study, designed the methodology, and critically reviewed and finalized the manuscript. WAS, HE, CH, MAS, and AA were responsible for data collection and analysis. WAS, AA and SHZ planned the study and critically reviewed the manuscript. WAS and AA drafted the initial manuscript under the

supervision of AA. All authors reviewed, revised, and approved the final version of the manuscript for submission.

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Additional file 1: Supplemental Tables S1–S8: Supplemental Table S1: Geographic distribution of participating blood banks in the West Bank; **Supplemental Table S2**: Potential selection biases in convenience sampling and their expected effects; **Supplemental Table S3**: Complete Kell system phenotype distribution among Palestinian blood donors; **Supplemental Table S4**: Complete Duffy system phenotype distribution among Palestinian blood donors; **Supplemental Table S5**: Complete Kidd system phenotype distribution among Palestinian blood donors; **Supplemental Table S6**: Complete MNS system phenotype distribution among Palestinian blood donors; **Supplemental Table S7**: Complete Lewis and Lutheran system phenotype distributions in tested subsets; **Supplemental Table S8**: Statistical comparison of antigen frequencies between Palestinians and reference populations.

Table 1: Demographic comparison between the study cohort and the national Palestinian donor population (2024)

Characteristic	Study Cohort (n=200)	National Donors (N=18,450) [6]	χ^2	p value
Gender			0.04	0.84
Male	124 (62.0%)	11,493 (62.3%)		
Female	76 (38.0%)	6,957 (37.7%)		
Age (years)			0.18	0.91
18–30	89 (44.5%)	8,305 (45.0%)		
31–45	71 (35.5%)	6,460 (35.0%)		
46–65	40 (20.0%)	3,685 (20.0%)		
Geographic Region			0.15	0.93
Northern West Bank	68 (34.0%)	6,156 (33.4%)		
Central West Bank	71 (35.5%)	6,640 (36.0%)		
Southern West Bank	61 (30.5%)	5,654 (30.6%)		

Table 2. Individual antigen frequencies by blood group system in a cohort of 200 Palestinian blood donors (April–September 2024)

System	Antigen	n (%)	95% Wilson CI
Kell	K	14 (7.0)	4.2–11.3
	k	194 (97.0)	93.8–98.9
	Kpa	2 (1.0)	0.3–3.6
	Kpb	198 (99.0)	96.4–99.7
Duffy	Fya	93 (46.5)	39.6–53.5
	Fyb	156 (78.0)	71.7–83.3
Kidd	Jka	145 (72.5)	65.8–78.3
	Jkb	144 (72.0)	65.3–77.9
MNS	M	152 (76.0)	69.5–81.5
	N	138 (69.0)	62.2–75.1
	S	177 (88.5)	83.4–92.4
	s	124 (62.0)	55.0–68.6
Lewis†	Lea	87 (43.5)	36.7–50.6
	Leb	85 (42.5)	35.7–49.6
Lutheran‡	Lua	12 (6.0)	3.4–10.2
	Lub	196 (98.0)	95.0–99.3
P1	P1	141 (70.5)	63.9–76.4

†Lewis system tested in subset (n=110) ‡Lutheran system tested in subset (n=120)

Table 3. Most common phenotype combinations (n=200)

System	Predominant phenotype*	n (%)	95% Wilson CI
Kell	K−k+	180 (90.0)	85.3–93.6
	K+k−	14 (7.0)	4.2–11.3
Duffy	Fy(a−b+)	84 (42.0)	35.5–48.8
	Fy(a+b+)	72 (36.0)	29.8–42.8
	Fy(a−b−)	35 (17.5)	12.8–23.4
Kidd	Jk(a+b+)	91 (45.5)	38.9–52.3
	Jk(a+b−)	54 (27.0)	21.3–33.6
	Jk(a−b+)	53 (26.5)	20.9–33.0
MNS	M+N+S+s+	83 (41.5)	35.0–48.4
Lewis†	Le(a−b+)	85 (42.5)	35.7–49.6
Lutheran‡	Lu(a−b+)	162 (81.0)	74.9–85.9
P1	P1+	141 (70.5)	63.9–76.4

*Phenotype notation: K−k+ indicates K antigen negative, k antigen positive. †Lewis system tested in subset (n=110) ‡Lutheran system tested in subset (n=120)

Table 4. Phenotype compatibility probabilities with reference populations

System	Intra-Palestinian	Highest match population	Match probability (%)	Lowest match population	Match probability (%)
Kell	54.1	Asian [4]	58.2	European [3]	52.1
Duffy	30.6	African [14]	29.6	Asian [16]	10.9
Kidd	28.2	Israeli [24]	43.7	African [25]	22.5
MNS	21.7	European [17]	55.0	Asian [4]	18.3
Lutheran	66.7	Asian [16]	81.8	African [26]	65.1
Lewis	35.2	Chinese [16]	41.4	European [27]	28.7
P1	42.4	African [26]	67.3	Asian [16]	35.2

*Match probability calculated as $\Sigma(p_i^2)$, representing the probability that two random individuals share the same phenotype. Higher values indicate greater compatibility between populations.