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Toward National Implementation of Pulse Oximetry Screening for Critical Congenital Heart Disease in Türkiye: A Multicenter Survey of Neonatal Centers

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Abstract

Background

Pulse oximetry screening for critical congenital heart disease (CCHD) is an established adjunct to routine newborn assessment and has increasingly been incorporated into organized screening programs. In Türkiye, center-level adoption has expanded over the last decade, and nationwide implementation is planned within the Ministry of Health screening framework. We aimed to assess current screening practices, documentation systems, and institutional perspectives relevant to national scale-up across neonatal centers in Türkiye.

Methods

We conducted a cross-sectional, web-based survey of neonatal centers in Türkiye under the coordination of the Scientific Commission of the Turkish Neonatology Society. After center-level review for duplicate submissions and data cleaning, 82 unique centers were included in the final analysis. Survey domains included institutional characteristics, current CCHD pulse oximetry screening practice, documentation systems, personnel involved in screening, perceived cost-effectiveness, support for inclusion in a national screening program, and implementation barriers. Analyses were primarily descriptive; exploratory comparative analyses were also performed according to hospital type and neonatal unit level.

Results

Participating centers represented 33 provinces in Türkiye. Current CCHD pulse oximetry screening was reported by 79 of 82 centers (96.3%). Manual documentation remained the dominant recording method (70.7%), whereas only 15.9% of centers reported digital recording systems. Most respondents considered screening cost-effective (80.2%), supported inclusion in a national screening program (81.7% definite support), and favored a centralized recording system (79.3%). The most frequently reported barriers were device/infrastructure limitations (39.0%), insufficient trained personnel (25.6%), and lack of standardization (12.2%). In exploratory analyses, physician involvement in screening was more common in academic centers, while disposable probe use was less frequent in higher-level neonatal units.

Conclusions

CCHD pulse oximetry screening is already widely adopted across responding neonatal centers in Türkiye, suggesting strong professional acceptance ahead of national rollout. However, broad clinical uptake should not be equated with full implementation maturity. Persistent gaps in digital data systems, workforce capacity, and protocol standardization indicate that coordinated system-level support will be essential for equitable, high-quality national implementation.

Introduction

Critical congenital heart disease (CCHD) remains an important cause of neonatal morbidity and mortality, particularly when diagnosis is delayed until after ductal closure or clinical decompensation. Although prenatal ultrasonography and postnatal physical examination improve case detection, a proportion of affected newborns may still be discharged without a diagnosis, placing them at risk for acute hypoxemia, circulatory collapse, end-organ injury, and death [1, 2]. Pulse oximetry screening has therefore become an important adjunct to routine newborn assessment because it is noninvasive, widely available, and capable of detecting hypoxemia that may not be clinically apparent on examination alone [1–3].

International momentum for routine newborn CCHD screening by pulse oximetry accelerated after the 2011 recommendation by the U.S. Secretary of Health and Human Services to add CCHD to the Recommended Uniform

Screening Panel (RUSP), followed by implementation-focused guidance addressing screening workflow, staff training, equipment, and management of positive screens [4, 5]. The American Academy of Pediatrics subsequently endorsed standardized implementation, and later updates refined screening algorithms and program recommendations based on accumulating evidence and real-world implementation experience [6–8].

Experience from multiple health systems has demonstrated that successful CCHD screening implementation depends on more than a screening algorithm alone. Program performance is influenced by coordination among birthing facilities, referral hospitals, echocardiography access, reporting structures, data systems, and public health follow-up pathways, particularly during transition from local practice to organized regional or national models [1, 2, 9, 10]. In parallel with global developments, pulse oximetry screening for CCHD has been increasingly adopted in Türkiye since the early 2010s through center-level initiatives and growing professional awareness [11–16].

The national guidance framework prepared by members of the Scientific Commission of the Turkish Neonatology Society, commissioned by the Ministry of Health, reflects an ongoing transition from heterogeneous local practices toward standardized nationwide implementation, including defined screening workflow, documentation, and referral processes [16]. In collaboration with the Department of Child and Adolescent Health of the Ministry of Health, the Scientific Commission of the Turkish Neonatology Society has also identified ongoing needs in protocol standardization, registration systems, and follow-up pathways, indicating a gap between local adoption and a fully integrated national screening program [17]. Against this background and considering the nationwide implementation timeline announced by the Ministry of Health (to take effect on July 1, 2026), understanding frontline readiness and institutional perspectives is essential for safe and effective scale-up.

We therefore conducted a multicenter, web-based survey of neonatologists working across different hospital types and neonatal care levels in Türkiye. The primary aim of this study was to assess the current status of CCHD pulse oximetry screening and implementation-related practices relevant to nationwide implementation.

Methods

Study Design

This was a cross-sectional, web-based survey developed by the Scientific Commission of the Turkish Neonatology Society in collaboration with the Ministry of Health of the Republic of Türkiye to evaluate current practices and implementation-related perspectives regarding pulse oximetry screening for critical congenital heart disease (CCHD) across neonatal centers in Türkiye. The unit of analysis was the center rather than the individual respondent. Neonatologists working in neonatal units from different hospital categories, including university hospitals, foundation university hospitals, Ministry of Health training and research hospitals, public state hospitals, and private hospitals, were invited to participate. Participation was voluntary and anonymized.

Survey Procedures

The questionnaire was administered electronically during August 1–31, 2025. Before final analysis, responses were reviewed at the center level to identify duplicate submissions. When multiple responses originated from the same institution, records were reconciled during data cleaning to retain a single center-level entry and avoid overrepresentation. The final analytic sample comprised 82 unique centers.

Variables And Outcomes

The survey consisted of 13 items designed to capture institutional characteristics, current screening practice, implementation infrastructure, and perceived barriers to national scale-up. The questionnaire included items on institution name, hospital type, neonatal unit level, annual birth volume, whether pulse oximetry screening for critical congenital heart disease was performed before discharge, and whether a formal recording system was available for documentation of screening results. Additional items assessed the availability of relevant clinical specialties within the institution, perceptions regarding the cost-effectiveness of screening, support for inclusion of CCHD screening in the National Newborn Screening Program, and support for the development of a mobile application for centralized monitoring and rapid referral. The survey also examined the types of devices and probes used, the personnel responsible for screening, and the perceived reasons why routine nationwide implementation has not yet been achieved. Multiple-choice items allowed single or multiple responses, depending on the structure of the question.

Statistical Analysis

Analyses were performed at the center level. Categorical variables were summarized as frequencies and percentages. Primary analyses were descriptive and focused on institutional characteristics, current screening uptake, documentation systems, personnel involved in screening, device and probe preferences, perceived cost-effectiveness, support for national program integration, support for centralized digital monitoring, and reported barriers to wider implementation. Exploratory subgroup comparisons were conducted according to hospital type and neonatal unit level using the chi-square test or Fisher's exact test, as appropriate. For selected binary comparisons, odds ratios with 95% confidence intervals were calculated. Because subgroup analyses were exploratory and hypothesis-generating, the findings should be interpreted with caution.

Bias and Limitations in Survey Design

Given the survey-based design, the study is subject to selection bias and non-response bias. Because participating centers were predominantly tertiary and higher-level neonatal units, the survey may overrepresent implementation readiness in referral settings relative to lower-volume or lower-level centers.

Ethics

This study was based on a voluntary, anonymized, center-level survey and did not collect directly identifying personal or patient-level data. Completion of the survey was accepted as informed consent to participate. Formal ethics committee approval was not obtained because the study involved an anonymous, non-interventional institutional survey without patient-level data.

Results

A total of 82 unique neonatal centers from 33 provinces in Türkiye were included in the final analysis after center-level review and removal of duplicate institutional responses. Participating centers represented a range of hospital types. The largest proportion were university hospitals (n = 29, 35.4%), followed by Ministry of Health training and research hospitals (n = 27, 32.9%). Additional participating centers included public state hospitals (n = 11, 13.4%), foundation university hospitals (n = 9, 11.0%), and private hospitals (n = 6, 7.3%). Overall, the sample was predominantly composed of academic and tertiary-affiliated institutions (university and training-research hospitals), accounting for 68.3% of participating centers (Table 1).

Most participating centers were Level 3 neonatal units (n = 54, 65.9%), followed by Level 4A (n = 17, 20.7%) and Level 4B units (n = 8, 9.8%); only 3 centers (3.7%) were Level 2 units. In total, 96.3% of centers were Level 3 or higher, indicating that the survey predominantly reflects practices and perspectives from higher-acuity neonatal care settings (Table 1).

Annual birth volume categories were available for all 82 centers. The majority reported 1,000–5,000 births/year (n = 52, 63.4%). The remaining centers were distributed across < 1,000 births/year (n = 12, 14.6%), 5,000–10,000 births/year (n = 12, 14.6%), and 10,000–60,000 births/year (n = 6, 7.3%) (Table 1).

Table 1
Characteristics of participating centers (n = 82).

Variable	Category	n (%)
Institution type	University hospital	29 (35.4)
	Ministry of Health training and research hospital	27 (32.9)
	Public state hospital	11 (13.4)
	Foundation university hospital	9 (11.0)
	Private hospital	6 (7.3)
Neonatal unit level	Level 3	54 (65.9)
	Level 4A	17 (20.7)
	Level 4B	8 (9.8)
	Level 2	3 (3.7)
Annual birth volume	1,000–5,000 births/year	52 (63.4)
	< 1,000 births/year	12 (14.6)
	5,000–10,000 births/year	12 (14.6)
	10,000–60,000 births/year	6 (7.3)

Note. Values are presented as n (%).

Survey responses were obtained from 82 centers across 33 provinces in Türkiye, indicating broad geographic participation. As shown in Fig. 1, participation was heterogeneously distributed, with greater concentration in major metropolitan provinces. The highest number of participating centers was from Istanbul (n = 17), followed by Ankara (n = 11) and Izmir (n = 7). Additional contributions were observed from Gaziantep (n = 5) and Bursa (n = 4), while most other provinces contributed one or two centers.

Current CCHD pulse oximetry screening was reported by 79 centers (96.3%), while 2 centers (2.4%) reported planned implementation and 1 center (1.2%) reported no current or planned screening (Table 2). Screening results were most commonly documented using a manual recording system (n = 58, 70.7%), whereas 13 centers (15.9%) reported a digital recording system and 11 centers (13.4%) reported no recording system.

Most respondents considered CCHD pulse oximetry screening to be cost-effective (65/81 valid responses, 80.2%). Support for inclusion of CCHD screening in a national program was high, with 67 centers (81.7%) indicating that it should definitely be included and 8 centers (9.8%) supporting inclusion after a pilot phase. Similarly, 65 centers (79.3%) reported that a centralized system would be useful, while 11 (13.4%) considered manual systems sufficient and 6 (7.3%) were undecided (Table 2).

Screening was most commonly performed by nurses (n = 49, 59.8%). Screening by physicians alone was reported by 11 centers (13.4%), and combined physician-nurse involvement by 18 centers (22.0%); 1 center (1.2%) reported screening by a health technician (Table 2). Among centers reporting probe preference (valid n = 79), disposable probes were preferred in 59 centers (74.7%), whereas 20 centers (25.3%) preferred reusable probes.

The most frequently reported main barrier to implementation was device/infrastructure limitations (n = 32, 39.0%), followed by insufficient trained personnel (n = 21, 25.6%) and lack of standardization (n = 10, 12.2%) (Table 2).

Table 2

Current CCHD pulse oximetry screening practices, perceptions, and implementation barriers among participating centers.

Domain	Variable	Category	n (%)
Current practice	Current CCHD pulse oximetry screening practice	Yes	79 (96.3)
		No, planned	2 (2.4)
		No, not planned	1 (1.2)
	Recording system	Manual recording	58 (70.7)
		Digital recording system	13 (15.9)
		No recording system	11 (13.4)
Perceptions and implementation support	Perceived cost-effectiveness*	Yes	65 (80.2)
		No	8 (9.9)
		Undecided	8 (9.9)
	National program inclusion	Yes, definitely	67 (81.7)
		Yes, but pilot first	8 (9.8)
		Undecided	4 (4.9)
		No, local practices should continue	3 (3.7)
	Centralized system usefulness	Yes	65 (79.3)
		No (manual system is sufficient)	11 (13.4)
		Undecided	6 (7.3)
Operational practice	Personnel performing screening	Nurse	49 (59.8)
		Physician	11 (13.4)
		Physician and nurse (combined)	18 (22.0)
		Health technician	1 (1.2)
Perceived barriers	Main barrier to implementation	Device/infrastructure limitations	32 (39.0)
		Insufficient trained personnel	21 (25.6)
		Lack of standardization	10 (12.2)
		Early discharge	7 (8.5)
		Reliability concerns	4 (4.9)
		Referral/management difficulties	4 (4.9)
		Other	4 (4.9)
Equipment preference	Probe type†	Disposable	59 (74.7)
		Reusable	20 (25.3)

Note. Values are presented as n (%). Percentages are based on valid responses for each item. *For perceived cost-effectiveness, percentages were recalculated after excluding one blank/unlabeled response (valid n = 81). Probe type percentages are based on valid responses (n = 79).

Exploratory comparative analyses identified differences in selected implementation-related practices across center types and neonatal care levels (Table 3). Physician involvement in CCHD pulse oximetry screening (physician alone or physician plus nurse) was significantly more common in academic centers than in non-academic centers (50.0% vs 22.7%; chi-square p = 0.010; OR 3.40, 95% CI 1.32–8.79). Disposable probe use was less common in Level 4A/4B units than in Level 2/3 units (60.0% vs 82.5%; chi-square p = 0.029; OR 0.32, 95% CI 0.11–0.91). Other exploratory comparisons did not show statistically significant differences in digital recording use, centralized system support, or perceived cost-effectiveness (Table 3).

Table 3
Exploratory Comparative Analyses of Implementation-Related Practices Across Participating Centers

Comparison (Predictor -> Outcome)	Groups / Outcome Definition	Test	Effect size (95% CI)	p-value
Academic center status -> Physician involvement in screening	Academic centers (university/foundation university) vs non-academic centers; physician involvement = physician alone or physician+nurse	Chi-square	OR 3.40 (1.32–8.79)	0.010
Neonatal unit level -> Physician involvement in screening	Level 4A/4B vs Level 2/3	Chi-square	OR 2.17 (0.82–5.72)	0.113
Neonatal unit level -> Disposable probe use	Level 4A/4B vs Level 2/3; outcome = any disposable probe use	Chi-square	OR 0.32 (0.11–0.91)	0.029
Neonatal unit level -> Digital recording system use	Level 4A/4B vs Level 2/3; outcome = digital recording (vs non-digital/no system)	Fisher's exact	OR 1.02 (0.28–3.67)	1.000
Neonatal unit level -> Support for centralized mobile system	Level 4A/4B vs Level 2/3; outcome = Yes (vs no/undecided)	Chi-square	OR 1.07 (0.33–3.43)	0.914
Neonatal unit level -> Perceived cost-effectiveness	Level 4A/4B vs Level 2/3; outcome = Yes (vs no/undecided)	Chi-square	OR 1.55 (0.45–5.34)	0.484
Institution group -> Digital recording system use	Academic / Public-MoH / Private; outcome = digital recording (yes/no)	Chi-square	Cramer's V = 0.17	0.306
Institution group -> Support for centralized mobile system	Academic / Public-MoH / Private; outcome = Yes (vs no/undecided)	Chi-square	Cramer's V = 0.07	0.825
Institution group -> Perceived cost-effectiveness	Academic / Public-MoH / Private; outcome = Yes (vs no/undecided)	Chi-square	Cramer's V = 0.24	0.098
Neonatal unit level -> Composite implementation readiness score*	Level 4A/4B vs Level 2/3	Mann-Whitney U	Rank-biserial correlation = 0.26	0.046

Notes.

- Analyses are exploratory and based on center-level responses.
- Academic centers were defined as university hospitals plus foundation university hospitals.
- Public-MoH centers included public state hospitals plus Ministry of Health training and research hospitals.
- Odds ratios (ORs) are reported for binary outcomes.
- Fisher's exact test was used when expected cell counts were low.
- *Composite implementation readiness score (0–6) was constructed from prespecified binary indicators reflecting current screening and implementation support domains (current screening practice, availability of any recording

system, pediatric cardiology availability, definite support for national program inclusion, support for a centralized mobile monitoring system, and perceived cost-effectiveness).

Discussion

This multicenter survey provides a national snapshot of implementation-related practices and institutional perspectives regarding CCHD pulse oximetry screening in Türkiye during a critical pre-implementation period. The principal finding is that screening uptake among responding centers is already very high, whereas implementation infrastructure remains uneven. In particular, the predominance of manual documentation, the limited availability of digital recording systems, and the frequency of reported infrastructure- and workforce-related barriers suggest that widespread clinical adoption has preceded full program maturation. From a policy perspective, these findings indicate that the next phase of national implementation should focus less on clinician acceptance and more on standardization, traceability, quality monitoring, and equitable operational support across centers.

According to the 2024 Birth Statistics of the Turkish Statistical Institute (TURKSTAT), approximately 938,000 live births occurred in Türkiye [18]. Assuming an overall congenital heart disease (CHD) prevalence of 1%, this corresponds to an estimated 9,376 newborns with CHD annually. Given that critical congenital heart disease (CCHD) accounts for approximately 0.3–0.5% of live births, an estimated 2,813–4,688 newborns each year may require early catheter-based intervention and/or cardiac surgery. In addition, a recent multicenter report indicating that 12.7% of hospitalized CCHD cases involved foreign-national infants suggests that referral-center workload may be approximately 13% higher, corresponding to an estimated 3,170–5,283 cases annually. Against this background, our findings demonstrate both high uptake of CCHD pulse oximetry screening and strong support for national integration. At the same time, persistent gaps in recording systems, infrastructure, trained personnel, and standardization highlight heterogeneity in implementation capacity and emphasize the need for coordinated policy and operational support during national scale-up.

A major strength of this study is its geographic scope, with responses from 82 centers in 33 provinces, capturing frontline perspectives during a clearly defined policy transition period. Although participation was concentrated in metropolitan provinces and higher-level neonatal units, this distribution is highly relevant for implementation planning because tertiary and referral centers are likely to serve as early anchors for protocol dissemination, staff training, echocardiographic confirmation pathways, and quality monitoring during the initial implementation phases [1, 2, 5].

The high prevalence of current CCHD pulse oximetry screening (96.3%) suggests that the planned national rollout in Türkiye is not introducing a completely new clinical practice, but rather formalizing and integrating an already widely adopted one. This trajectory is consistent with implementation patterns observed in other settings, where local uptake and professional consensus often precede formal inclusion in national screening programs [4, 5, 9]. Consequently, implementation efforts in Türkiye may need to focus less on clinician acceptance and more on consistency, quality assurance, and equitable systems support.

Our findings also indicate that clinical adoption should not be equated with implementation maturity. Most centers relied on manual documentation, and only a minority reported the use of digital recording systems. Population-level screening programs require reliable registration, traceability, referral documentation, quality monitoring, and feedback mechanisms [1, 2, 5]. Accordingly, limited digital recording should be interpreted as a system-level implementation gap rather than a local clinical shortcoming. The high level of support for a centralized system further supports this interpretation.

Broad professional support for national program inclusion and generally favorable perceptions of cost-effectiveness indicate alignment between clinical practice and policy direction. International experience with CCHD screening implementation has shown that sustained program success depends not only on technical feasibility but also on stakeholder consensus regarding program value, professional responsibilities, and care pathways [5, 7, 8]. Our data suggest that such consensus is already largely present among responding neonatal centers in Türkiye.

Operationally, screening was most commonly performed by nurses, consistent with routine neonatal care workflows and reports from multiple settings [1, 2]. Physician involvement was significantly more common in academic centers, likely reflecting differences in staffing models and training environments rather than differences in the perceived value of screening. National implementation should therefore define quality standards, training requirements, and escalation pathways that can be achieved across different workforce configurations.

Most centers preferred disposable probes, although disposable probe use was less frequent in Level 4A/4B units than in Level 2/3 units. This pattern may reflect institutional differences in procurement structures, device ecosystems, infection-prevention workflows, patient acuity, or cost-containment strategies. Regardless of the underlying mechanism, this finding underscores the need for national guidance addressing practical equipment standards, procurement planning, and device compatibility, in addition to screening timing and interpretation [4, 8, 16].

The reported barrier profile is particularly informative for rollout strategy. Device and infrastructure limitations and insufficient trained personnel were the most frequently reported barriers, followed by lack of standardization. This pattern suggests that the dominant obstacles are not conceptual resistance, but rather capacity- and process-related constraints. A dual-track implementation strategy is therefore needed: resource and workforce support, including equipment, probes, and training capacity, combined with process and systems support, including protocols, documentation standards, referral pathways, and quality monitoring [1, 5, 9, 10].

Exploratory comparative analyses further suggested that implementation-related practices were not fully uniform across centers. Differences in physician involvement and probe preferences according to institutional context and level of care support the need for tiered operational support during national rollout. An important contextual consideration is that nationwide CCHD screening in Türkiye is being introduced within an already institutionalized preventive child health screening framework. The evolution of neonatal and childhood screening programs in Türkiye, beginning with phenylketonuria screening in 1987 and nationwide expansion in 1993, followed by formalization with congenital hypothyroidism in 2006 and subsequent inclusion of biotinidase deficiency in 2008, cystic fibrosis in 2015, congenital adrenal hyperplasia in 2017, and SMA in 2022, represents a strong example of sustained national screening policy [20, 21]. The Ministry of Health's expansion of childhood vision and hearing screening further demonstrates established national capacity for scaling and maintaining population-level screening programs [19]. Within this broader trajectory, the planned nationwide implementation of newborn CCHD screening on July 1, 2026 may be understood as the next step in an evolving national early-life screening platform [12, 19].

This broader institutional context represents a major opportunity. Türkiye can build on prior experience in national screening governance, standardized workflows, data recording and follow-up structures, public communication, and implementation oversight [19–22]. However, CCHD pulse oximetry screening introduces operational challenges that differ from those of metabolic or genetic screening programs, including time-sensitive bedside measurement, immediate interpretation, rapid decision-making, and referral coordination within a limited postnatal window [1, 2, 6]. Successful rollout will therefore require not only integration into the existing screening infrastructure but also CCHD-specific operational planning, training, and quality assurance.

This study provides geographically broad frontline neonatal perspectives from a unique pre-implementation period in Türkiye, covering multiple hospital and neonatal unit types, with center-level duplicate screening to reduce overrepresentation. However, as a voluntary, self-reported survey, it remains vulnerable to selection and non-response bias, and implementation capacity may have been overestimated because higher-level and academic centers were overrepresented. Despite these limitations, the findings offer actionable guidance for national rollout: prioritization of standardized protocols, training, equipment and infrastructure support, and digital centralized recording and follow-up systems, with tiered support according to center type. Overall, uptake and professional support appear to be high, but coordinated system-level support remains essential for equitable and high-quality implementation.

In conclusion, responding neonatal centers in Türkiye report widespread use of pulse oximetry screening for CCHD and strong support for national program integration. However, important implementation gaps remain, particularly in digital registration systems, staffing capacity, and standardization of practice. These findings support the feasibility of national rollout, but also underscore that successful implementation will depend on coordinated policy, infrastructure investment, training, and monitoring systems rather than screening uptake alone.

Declarations

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Conflict of interest

The authors declare no competing interests.

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Figures

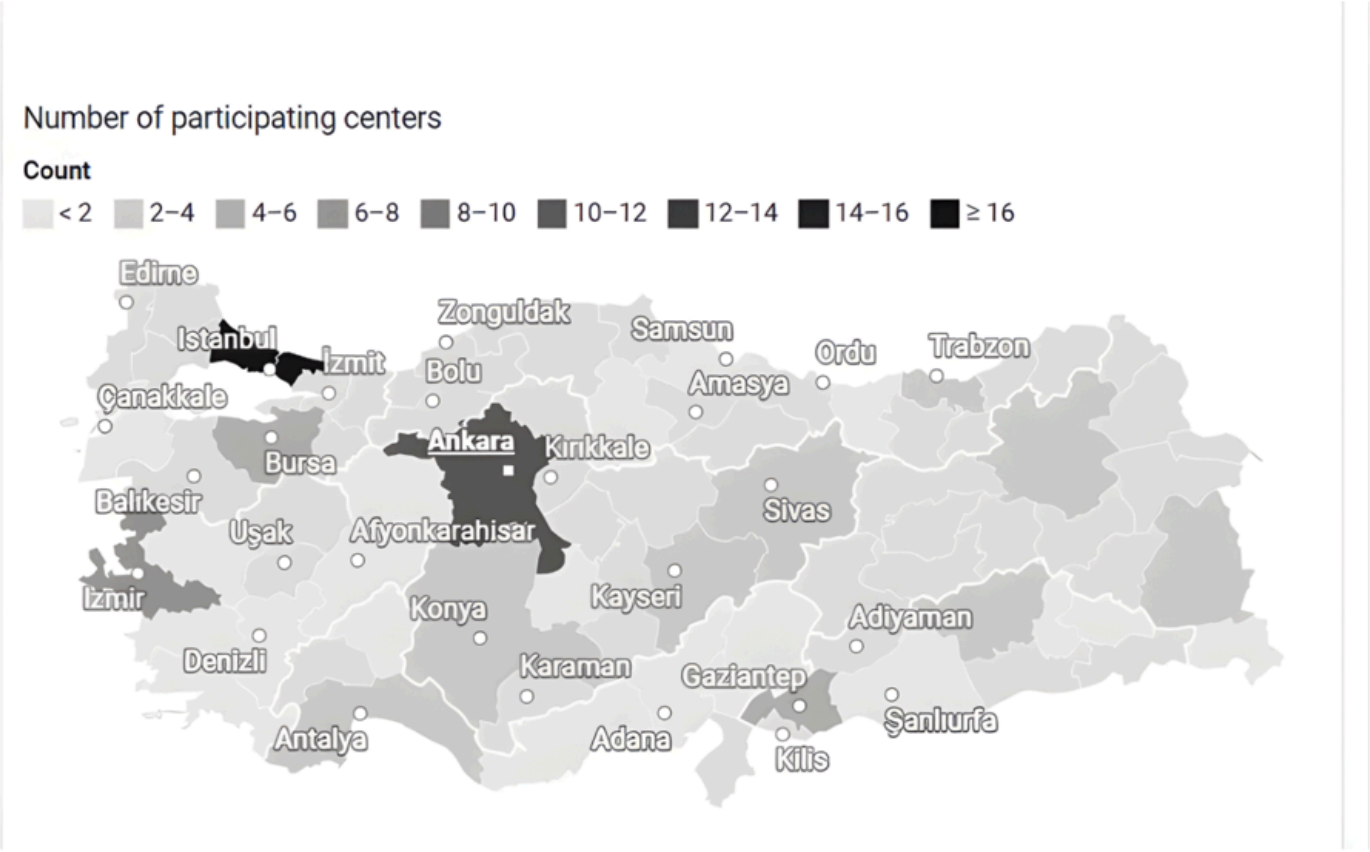


Figure 1

Provincial distribution of participating centers in Türkiye (82 centers across 33 provinces). Provinces are shaded according to the number of participating centers, with darker shading indicating higher participation.