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Universal Graf ultrasound with AI augmentation for early detection of DDH

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Abstract
Background: Developmental dysplasia of the hip (DDH) ranges from acetabular immaturity to dislocation; delayed diagnosis causes long-term morbidity. Clinical examination and selective imaging miss many clinically silent cases.
Objective: To synthesise evidence for universal Graf-standard ultrasonography, evaluate artificial-intelligence (AI) performance for DDH detection, and propose a practical, scalable screening framework.
Methods: Narrative synthesis of prospective universal sonography cohorts, meta-analyses of AI models, implementation studies of AI-augmented workflows, and consensus statements (searches to April 2025). Outcomes included sensitivity, specificity, detection of clinically silent DDH, recall/referral rates, treatment initiation and feasibility metrics.
Results: Clinical examination detected roughly 20% of sonographically confirmed DDH in reviewed cohorts. Universal Graf ultrasound markedly improved early detection and reduced late diagnoses. Pooled AI studies reported high performance (pooled sensitivity and specificity reported by recent meta-analyses). Primary-care implementations using AI-augmented handheld ultrasound showed feasible screening with recall rates stabilising around 10-14% after training and confirmed DDH incidence approximating expected population rates.
Conclusion: Universal Graf-standard ultrasonography, reinforced by AI-assisted imaging, offers a precise, scalable pathway for early DDH detection. Country-level implementation requires standardised acquisition, training, internal recall loops and governance to preserve specificity and equity.

Keywords: Developmental dysplasia of the hip; ultrasound; Graf method; artificial intelligence; neonatal screening; orthopaedics; paediatrics

Introduction
Developmental dysplasia of the hip (DDH) is a spectrum disorder ranging from mild acetabular under-coverage to complete dislocation. If untreated, DDH predisposes affected individuals to gait abnormalities, limb length discrepancy, chronic pain, and early-onset osteoarthritis [1, 2]. Early identification is crucial to allow conservative management, such as abduction harnessing or physiotherapy, which can prevent invasive interventions.

Population-level data from India are limited and largely regional. Prospective national prevalence estimates are scarce; available series report variable incidence across regions. Implementation of universal ultrasound in India faces practical challenges uneven distribution of ultrasound equipment, limited access to trained sonographers in many primary-care and rural settings, and competing newborn-care priorities. Handheld ultrasound devices with AI augmentation may offer a pragmatic, scalable approach for pilot programmes integrated into existing newborn follow-up and immunisation visits, but country-specific validation and cost-effectiveness data are required.

Clinical examination using the Barlow and Ortolani maneuvers is widely performed, often in combination with selective ultrasound screening based on risk factors, including breech presentation, female sex, or family history. However, studies have demonstrated that clinical examination alone misses a substantial proportion of DDH cases, particularly those with morphologic dysplasia without overt instability [3-5]. Risk-factor based selective imaging, while improving detection rates modestly, still fails to identify many clinically silent cases, leaving a large population at risk for late diagnosis [6, 7].

Graf-standard ultrasonography provides an objective method for early DDH detection through coronal-plane imaging and measurement of alpha and beta angles, which stratify hips into normal, immature, dysplastic, or dislocated [8, 9]. Evidence from long-term European cohorts indicates that universal ultrasound significantly reduces the incidence of late-diagnosed DDH and corresponding surgical interventions [10, 11].

Artificial intelligence (AI) has recently been applied to DDH screening to enhance detection accuracy, provide real-time feedback, and reduce operator dependency. Convolutional neural network (CNN)-based AI models can automatically segment hip structures, measure Graf angles, and classify hip type, facilitating deployment in primary care and resource-limited settings [12-14]. Early implementation studies suggest that AI-augmented workflows can maintain high sensitivity and specificity while enabling point-of-care diagnosis by non-expert operators.

This article aims to synthesize contemporary evidence on universal Graf-standard ultrasound and AI-assisted imaging, compare diagnostic performance across modalities, and propose a structured screening framework to enable early, equitable, and scalable DDH detection.

Materials and Methods

Study Design

A narrative synthesis was performed, integrating:

1. Prospective universal ultrasound cohorts using Graf-standard technique
2. Meta-analyses of AI models applied to ultrasound and radiography for DDH detection
3. Implementation studies of AI-assisted workflows in primary care
4. International consensus and guideline statements

Data Sources: Searches were conducted in PubMed, Embase, Scopus and the Cochrane Library to 30 April 2025 using terms including ‘developmental dysplasia of the hip’, ‘Graf ultrasound’, ‘universal screening’ and ‘artificial intelligence’. Two reviewers screened titles/abstracts; disagreements were resolved by consensus. Diagnostic accuracy studies were appraised using QUADAS-2 and cohort studies using the Newcastle-Ottawa Scale.

Inclusion Criteria

- Infants screened within the first six months of life
- Use of Graf-standard ultrasonography or equivalent imaging classification
- AI-assisted diagnostic models reporting sensitivity, specificity, or AUC
- Prospective or retrospective cohort studies, meta-analyses, and implementation trials

Outcomes

- Diagnostic performance (sensitivity, specificity, AUC)
- Detection of clinically silent DDH
- Treatment initiation and follow-up compliance
- Recall and referral rates
- Feasibility metrics: operator training, image adequacy, and auditability

Results

Clinical Examination vs Universal Ultrasound

Multiple studies indicate that clinical examination alone detects only ~20% of ultrasound-confirmed DDH, with specificity >98% [3, 5, 15]. More than half of infants with confirmed DDH had no identifiable risk factors or positive clinical signs in early life [4, 5]. Selective risk-based imaging increases detection modestly but remains insufficient for comprehensive early identification [6, 7].

Universal Graf-Standard Ultrasonography

Graf-standard ultrasound classifies hips based on alpha and beta angles:

- **Type Ia/Ib:** Normal
- **Type IIa:** Immature, usually resolves spontaneously
- **Type IIb/c, D, III, IV:** Dysplastic or dislocated requiring intervention [8, 9]

Prospective cohorts implementing universal screening report detection rates of 90-95% and near elimination of late-diagnosed cases [10, 11]. Early conservative measures physiotherapy, abduction harnessing successfully normalize minimally abnormal hips, reducing surgical intervention rates [16-18].

AI-Assisted Imaging

A 2024 meta-analysis (13 studies, 28 models, n=10,673) reported pooled sensitivity 99.0% (95% CI: 97-100%) and specificity 94.0% (95% CI: 89-96%), with CNN-based models outperforming non-CNN approaches [12]. AI workflows provide real-time classification, adequacy feedback, and Graf-aligned measurement, allowing non-expert operators to achieve diagnostic accuracy comparable to specialists [12-14].

Implementation studies in primary care (e.g., MEDO-Hip) show recall rates stabilize near 14% post-onboarding, with confirmed DDH incidence ~2% of screened infants, including those without risk factors [14, 15].

Table 1. Comparison of Screening Strategies for Developmental Dysplasia of the Hip

Strategy	Detection Rate	Advantages	Limitations
Clinical Examination only	≈20% sensitivity, >98% specificity	Low cost; bedside; detects unstable hips	Misses majority of cases; high false negatives
Selective Imaging (risk factors)	≈40-60% of DDH cases	Targets high-risk infants; fewer scans	Many cases occur without risk factors; inequitable
Universal Graf Ultrasound	≈90-95% detection	Objective classification; early treatment window	Requires training, equipment, follow-up
AI-Augmented Ultrasound	≈99% sensitivity; 94% specificity	Reduces operator dependency; scalable; auditability	Requires device validation; limited long-term outcome data

Abbreviations: DDH, developmental dysplasia of the hip; AUC, area under the curve. Data adapted from referenced cohort and meta-analysis studies

Table 2: AI-Assisted Imaging vs Conventional Approaches in DDH Diagnosis

Parameter	Conventional Ultrasound (Graf)	AI-Augmented Imaging
Sensitivity	≈85-90%	≈99%
Specificity	≈90-95%	≈94%
Operator Dependency	High (expert sonographer)	Low (real-time feedback + automated analysis)
Time to Classification	Several minutes + radiologist review	Instant/within minutes at point-of-care
Feasibility in Primary Care	Limited	Demonstrated with handheld devices (FDA-cleared)
Auditability	Dependent on storage policy	Built-in labeling, auto-stored frames

Table 3: Proposed Framework for Universal DDH Screening with AI Augmentation

Framework Element	Details
Screening Window	Target 4-6 weeks; earlier if risk factors; repeat for type IIa hips
Acquisition Standards	Graf-standard coronal sweep; AI adequacy feedback; labeled image storage
Classification & Action	Graf thresholds guide observation vs bracing vs referral
Internal Recall Loop	Repeat scans for technical/immature cases; recall ≈10-14% post-onboarding
Training	Concise modular sessions; mentored onboarding; periodic re-certification
Governance	Local champions; audit and quality assurance; consensus-aligned pathways

Discussion

Clinical Implications

Clinical examination alone is inadequate for early DDH detection, with a high false-negative rate that can delay intervention. Universal Graf-standard ultrasound addresses this gap, allowing timely conservative management and minimizing late surgical interventions [10, 11, 16]. Early identification reduces long-term sequelae, including gait abnormalities and early osteoarthritis.

For India, scalability depends on pragmatic integration with existing newborn and child-health services. Training packages for midwives, ANMs and primary-care physicians, coupled with remote supervision from tertiary centres, can mitigate the shortage of expert sonographers. Handheld, validated AI-augmented devices may allow screening within immunisation or newborn follow-up visits, improving coverage in semi-urban and rural areas. Formal pilot projects are needed to evaluate device performance on Indian infants, feasibility, workforce requirements and cost-effectiveness within government health programmes.

AI Integration

AI-assisted imaging provides automated measurements, classification, and quality feedback, reducing reliance on expert sonographers [12-14]. Implementation studies demonstrate feasibility in primary care, maintaining high sensitivity and specificity, reducing recall rates, and ensuring equitable access for infants without risk factors [14, 15]. Real-time decision support streamlines workflows, enabling immediate referral when required.

Equity Considerations

Universal screening ensures detection of clinically silent DDH across populations, avoiding bias associated with risk-based selective imaging. AI-augmented portable ultrasound expands screening to underserved areas, addressing disparities in access to expert imaging and timely intervention.

Limitations and Future Research

Evidence for long-term functional outcomes beyond early childhood is limited. Many AI models were developed in high-income countries; external validation in diverse populations and devices is necessary. Economic analyses tailored to different healthcare systems are lacking, and integration into routine care requires standardized training, governance, and audit.

Future research should evaluate multicenter AI validation, device-agnostic performance, cost-effectiveness, and parent-centered adherence strategies to ensure sustainable, equitable screening programmes.

A key limitation is the paucity of India-specific prospective data and cost-effectiveness analyses; transferability of AI models developed in high-income countries remains to be demonstrated.

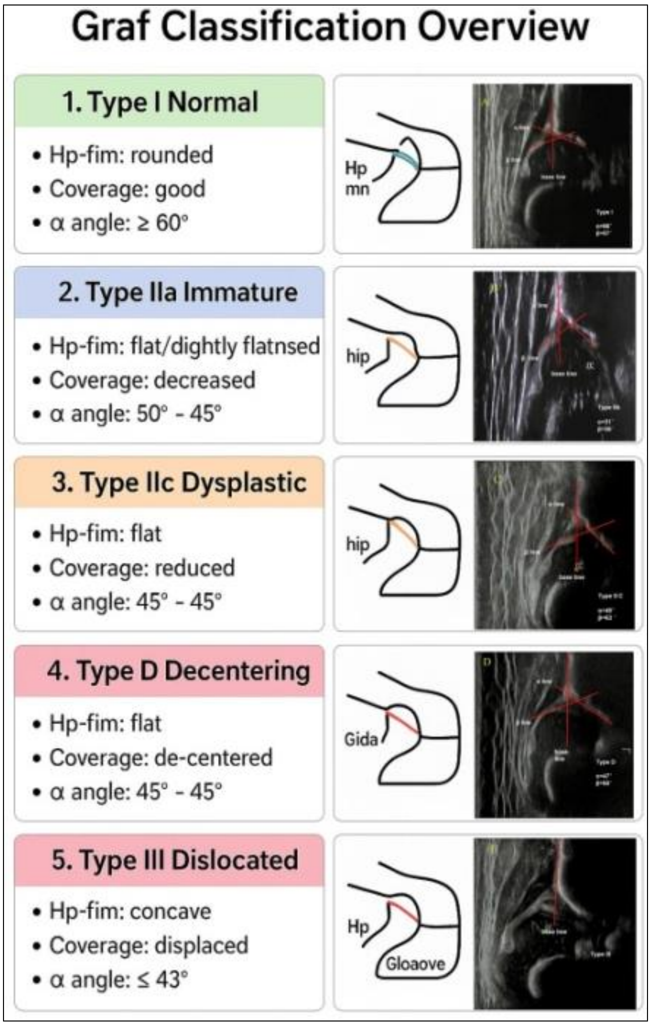

Fig 1: Graf classification of hip morphology showing alpha and beta angle thresholds distinguishing normal, immature, dysplastic, and dislocated hips.

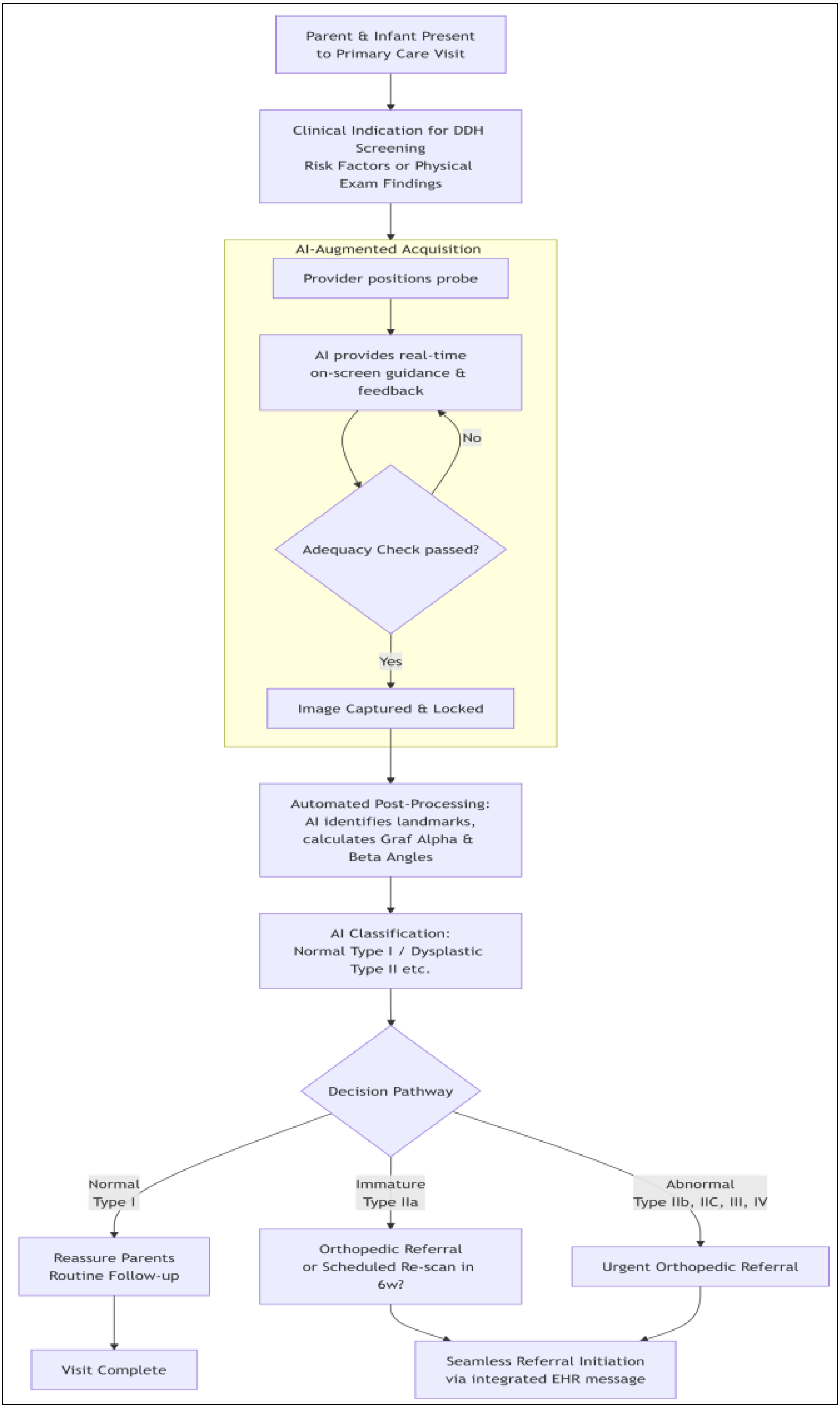

Fig 2: Schematic of AI-augmented handheld ultrasound workflow in primary care. Acquisition includes Graf-aligned coronal sweep with AI adequacy feedback and automated angle measurement; immediate classification is provided with recommended action (observe/brace/refer)

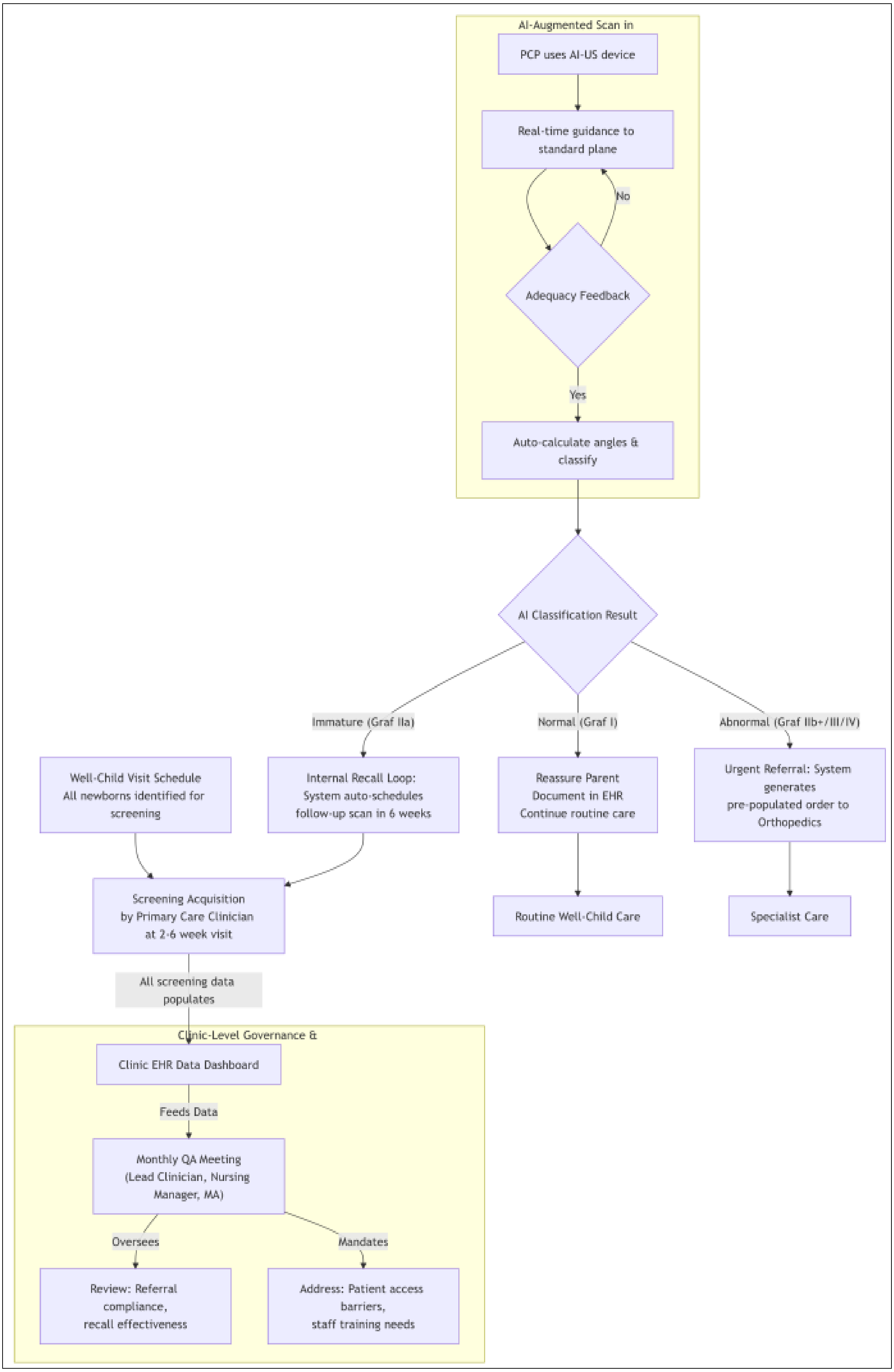

Fig 3: Proposed screening blueprint integrating universal ultrasound, AI augmentation, internal recall loop, and governance structure for equitable DDH surveillance.

Conclusion

Universal ultrasound screening using Graf-standard technique, augmented by AI-assisted imaging, provides a high-accuracy, scalable framework for early DDH detection. Adoption of this integrated approach allows early conservative intervention, reduces late diagnoses, and prevents avoidable disability. Structured implementation including standardized acquisition, internal recall loops, modular training, and governance is essential to preserve specificity and equity in screening.

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