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RESEARCH AND EDUCATION

A comparison of a handheld minicomputer and an external graphics processing unit in performing 3D intraoral scans

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ABSTRACT

Statement of problem. Whether the use of an external graphics processing unit (eGPU) and a handheld computer prolongs the operation time for 3-dimensional (3D) intraoral scanning or produces clinically unacceptable scans is unclear.

Purpose. The purpose of this in vitro study was to compare the 3D intraoral scan accuracy and scan time of a small portable device and an eGPU with desktop-grade workstations.

Material and methods. A handheld computer, a laptop, a desktop workstation, and an external graphics card were used to scan a 3D printed set of maxillary and mandibular casts 10 consecutive times using an intraoral scanner. The casts were provided by the manufacturers of the scanner, and the scanning process was conducted by a single operator following best-practice methods. The time required to scan and process the 3D models was analyzed via 1-way ANOVA. Dimensional similarity was assessed using the Hausdorff distance (HD) across the resultant 80 independent bimaxillary 3D scans. A dental desktop 3D scanner was used to scan the casts which served as the control reference. HD values were analyzed via multifactorial ANOVA (α=.05).

Results. In the real-time rendering of 3D intraoral scans, the laptop without an eGPU took significantly longer (146.41 ±10.66 seconds) (F=30.58, P<.001) compared with when connected to an eGPU (117.66 ±6.95 seconds) and handheld computer (114.84 ±7.20 seconds). Postprocessing times were more favorable on the desktop workstation (16.61 ±4.18 seconds) compared with the laptop with (27.85 ±8.89 seconds) and without an eGPU (32.37 ±7.16 seconds) connected, with the handheld computer and eGPU combination (14.66 ±7.37 seconds) producing the best results (F=14.60, P<.001). Dimensional similarity assessments showed high consistency (F=0.92, P=.44), with no discrepancies noted on the prepared tooth surfaces. The handheld minicomputer with an eGPU produced the best results across all 4 groups.

Conclusions. The handheld computer with an eGPU offered 3D intraoral scans comparable with output from a traditional workstation while preserving the details on the tooth preparations but at significantly faster scanning and processing rates. (J Prosthet Dent 2025;133:568-574)

In dentistry, the effectiveness of 3-dimensional (3D) scanning and computer-aided design and computer-aided manufacturing (CAD-CAM) relies heavily on the graphics processing unit (GPU) of a computer and its power consumption or thermal design power (TDP).[1–3] The performance of 2 devices with the same graphical capabilities can differ based on their power consumption, as lower power draw may lead to reduced performance.[4] Conversely, an older graphics card with higher power consumption might outperform a newer one in rendering 3D models in real-time.[2] The TDP of a GPU also determines its electricity consumption and the amount of heat it generates, with smaller devices typically drawing less power to prevent overheating, whereas desktop workstations can draw more power to support modular and upgradeable graphics cards.[2] However, earlier workstations were bulky, posing challenges in healthcare practices because of space limitations and restricted mobility. The impact of portable handheld devices on patient interaction remains largely undocumented.[5,6]

Dental practices often invest in expensive laptop workstations or desktop replacements to support their 3D intraoral scanners only to face hardware obsolescence associated with software program updates within a few years.[5] However, an externally powered GPU (eGPU) can address this issue by significantly enhancing the graphical

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Clinical Implications

Portable handheld computers paired with eGPUs produced 3D intraoral scans comparable with those obtained from conventional larger workstations but with reduced scanning and processing times. Thin-and-light personal computers equipped with eligible connectivity options can use eGPUs to enhance their capabilities in 3D rendering, thereby extending their service life in dental practice.

processing power of existing eligible personal computers, enabling smoother performance in graphically demanding tasks such as 3D rendering and digital imaging in the medical sciences.[7] Adding an eGPU not only extends the service life of capable older devices but also reduces e-waste. Eligible devices include connectivity ports, such as the Thunderbolt 4 port, that can transfer larger volumes of data at once. eGPUs also facilitate multitasking with multiple high-resolution monitors and accelerated computations,[8] while remaining upgradeable to keep pace with evolving hardware requirements. While thin-and-light laptops may be generally underpowered compared with desktop replacements, they provide dental offices with a practical way of obtaining radiographs and intraoral scans, offering space savings and enhanced portability.[6] Conversely, the latest handheld computers, introduced since early 2023, drew attention on social media platforms for their portability and computational power, which rivals that of heavier devices. These developments raise questions in academic dentistry regarding their efficiency in conducting intraoral scans on demand when paired with eGPUs.

Despite the advantages of portability and modularity, the investment in an eGPU or small form-factor handheld computer for dental practices may not be justifiable if they significantly prolong the time required for graphics-intensive tasks like intraoral scanning or if they produce scans for treatment planning with clinically unacceptable errors. The authors are unaware of studies that have investigated this aspect of dentistry. Therefore, this study aimed to assess the scanning time of smaller devices and eGPUs compared with desktop-grade workstations and to evaluate the similarity of resulting scans to standard desktop scans. The null hypothesis was that no significant differences in scanning duration and scan dimensional similarity would be found between smaller portable devices and established desktop standards.

MATERIAL AND METHODS

Data collection took place at a single center in South Australia using a 3D printed maxillary and mandibular jaw cast model provided by the manufacturer of the intraoral scanner (AoralScan 3; Shining3D). Similar to other brands, the current scanner acquired data by following the structured light principle with a fixed 16×12×22-mm field of view.[9] The technology involved confocal microscopy and optical scanning, where the scanner projected a series of structured light patterns onto the object; The camera lens captured images of the object illuminated by these patterns in real-time.[10] This model featured cast representations of teeth prepared for a complete gold crown, anterior ceramic veneer, and anterior malocclusion (Fig. 1). As the experiment did not involve human or animal participants, ethical review was unnecessary. The ambient temperature was regulated at 24 °C to ensure consistency, and precautions were taken to eliminate sunlight and ambient window light during scanning. Before the experiment, the scanner was calibrated using the manufacturer's recommended process and toolkit.

Three devices and an external graphics card were selected: a handheld minicomputer (ROG Ally Z1 Extreme; ASUSTek Computer Inc), a thin-and-light laptop with a dedicated graphics card (ROG Flow X13; ASUSTek Computer Inc), and a desktop computer powered by a desktop-grade workstation graphics card (TUF Nvidia RTX 4080; ASUSTek Computer Inc). To maintain consistency, an external graphics card (eGPU) dock (XG Mobile; ASUSTek Computer Inc) with a laptop-grade Nvidia RTX 4090 graphics card was chosen from the same manufacturer. Power draw capacity for each graphics processing unit was documented alongside the device. All devices ran on the most recent version of Windows 11 (Microsoft Corp) and graphics drivers, with identical software versions of the intraoral scanner (DentalLauncher v.1.0; Shining3D) installed across all platforms. The external graphics card was connected to the handheld computer and laptop, resulting in 4 data source groups: handheld computer with eGPU (Fig. 2A), laptop alone (Fig. 2B), laptop with eGPU connected (Fig. 2C), and desktop workstation (Fig. 2D). The technical specifications of the 4 device groups can be found in Table 1.

To simulate real-world clinic scenarios, all computers were connected to an external 60-Hz full high definition (FHD) monitor (P2422H; Dell Technologies) for external display output, and the devices were powered through their original charging docks.[5] The scanning process was conducted by a single operator (T.H.F.) with one year of experience of the specific scanner used by following established best-practice methods.[11] The operator sequentially scanned the occlusal, lingual, palatal, and buccal surfaces of the jaws, recording the time taken for each step.[12] After scanning, the time required for post-processing, finalizing the scans, and exporting them to standard tessellation language (STL) files was recorded.

Figure 1. Physical three-dimensionally printed casts of jaws used for evaluation.

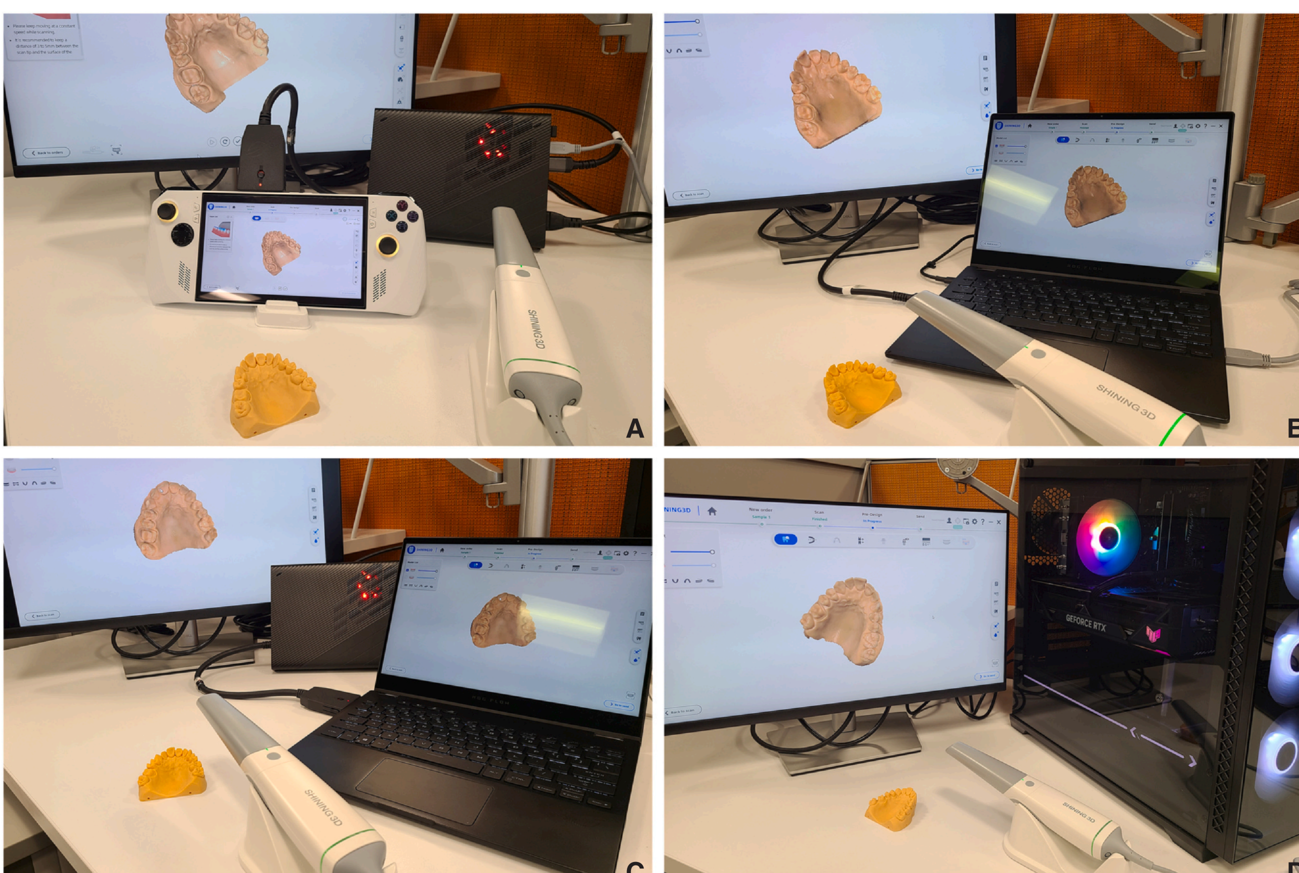

Figure 2. Scans of physical casts. A, Handheld computer with external graphics card attached. B, Thin-and-light laptop. C, Laptop with external graphics card attached. D, Desktop workstation.

Table 1. Comparisons of specifications across all four devices

Type of Device	Product Name	Central Processing Unit (CPU)	Graphics Processing Unit (GPU)	On-board Random Access Memory (RAM)	Graphics Card Thermal Design Power (TDP)	Commercially Available Since
Handheld computer with eGPU	ROG Ally RC71L	AMD Ryzen Z1E	ASUS XG Mobile -Nvidia RTX 4090 eGPU (16 GB DDR6)	16 GB LPDDR5	150 Watts	June 2023
Laptop alone	ROG Flow X13 GV301	AMD Ryzen 7 5800HS	ASUS Dedicated -Nvidia GTX 1650 max-Q (4 GB DDR6)	16 GB LPDDR4X	60 Watts	May 2021
Laptop with eGPU connected	ROG Flow X13 GV301 with eGPU	AMD Ryzen 7 5800HS	ASUS XG Mobile -Nvidia RTX 4090 eGPU (16 GB DDR6)	16 GB LPDDR4X	150 Watts	May 2021
Desktop workstation	-	Intel Core i7 13700k	ASUS Desktop -Nvidia RTX 4080 (16 GB DDR6)	64 GB DDR4	320 Watts	November 2022

AMD, Advanced Micro Devices; eGPU, external graphics processing unit; GTX, Giga Texel Shader Extreme; LPDDR, low-power double data rate; ROG, Republic of Gamers; RTX. Ray Tracing Texel Extreme.

Base formation and model repairs were excluded from the processing time calculations because of restricted access to these features without subscription access.[13] Based on published reports, the average Australian dentist typically practices for 6 hours per day,[14] which theoretically translates to seeing approximately 10 patients per day in routine practice. To emulate real-world stress, 10 consecutive scan sessions were carried out, each session capturing both the maxillary and mandibular arches without device cooldown to induce temporary cache buildups. The experimental design translated to an effect size of 0.40 (Cohen f[15]), α=.05, β=.200 resulting in at least 76 scans distributed across 4 groups. External cooling systems were not used during the experiment.

To validate the accuracy of scans across all 4 groups, the dimensional similarity of the 3D scanned meshes was assessed. Each device workflow produced twenty 3D casts, totaling 80 independent scans of the original cast. These casts were compared with corresponding casts generated by a computer-operated desktop 3D scanner (E4; 3Shape A/S) and served as a control reference to mitigate operator-dependent variability. The Hausdorff distance (HD) evaluation after iterative closest point (ICP) cloud registration was used to measure dissimilarity between the hand scans and the control.[16,17] The HD was measured using the open-source tool CloudCompare.[18] HD evaluates interpoint dissimilarity by comparing cloud points from handheld scanner models with their reference counterparts on the desktop-scanner generated output.[19] HD, tailored for 3D meshes, was preferred over the generalized root mean squared error (RMSE) estimation.[13] Subsequently, HD values from the 4 groups underwent 2-factor ANOVA analysis while the analyses of scan and processing time were evaluated through 1-way ANOVAs (α=.05) after confirmation of normal data distribution.

RESULTS

When analyzing scanning times (Table 2), the laptop without a high TDP graphics processing unit took significantly (*P*<.001) longer to render scans in real-time (146.4 ±10.7 seconds) compared with when connected to an external graphics processing unit (117.7 ±6.9 seconds). Conversely, the handheld computer was notably faster (114.8 ±7.2 seconds) at rendering scans when connected to the eGPU, outperforming the desktop workstation (123.6 ±7.4 seconds) (*P*<.001).

When assessing postprocessing (Table 3), the desktop workstation demonstrated superior performance (16.6 ±4.2 seconds) compared with the laptop with (27.8 ±8.9 seconds) and without the eGPU (32.4 ±7.2 seconds) and was only surpassed by the handheld computer connected to the eGPU (14.7 ±7.4 seconds) (*P*<.001).

The evaluation of dimensional similarity using the Hausdorff distance between the scans produced by the 4 devices and those performed by the desktop dental scanner revealed no significant differences (Table 4) (*P*>.05), indicating high overall similarity. However, notable discrepancies were observed along the mandibular buccal sulcus and the deepest point of the palate, although the veneer preparation on the anterior tooth and the complete gold crown preparation on the posterior remained consistent in dimensions across all 4 device groups (Fig. 3).

Table 2. Evaluation of time discrepancies (seconds) across four groups while rendering 3D models in real-time during scanning process

Type of Device	Mean ±SD (s)	F-stat (df)	*P*
Handheld computer with eGPU	114.84 ±7.20	30.58(3)	<.001 *
Laptop alone	146.41 ±10.66		
Laptop with eGPU connected	117.66 ±6.95		
Desktop workstation	123.65 ±7.39		

* Significant (*P*<.05),

df, degree of freedom; eGPU, external graphics processing unit; SD, standard deviation.

Table 3. Evaluation of time discrepancies (seconds) across four groups while processing 3D models

Type of Device	Mean ±SD	F-stat (df)	*P*
Handheld computer with eGPU	14.66 ±7.37	14.60 (3)	<.001*
Laptop alone	32.37 ±7.16		
Laptop with eGPU connected	27.85 ±8.89		
Desktop workstation	16.61 ±4.18		

* Significant (*P*<.05),

df, degree of freedom; eGPU, external graphics processing unit; SD, standard deviation.

Table 4. Multifactorial evaluation of scanning dissimilarities through Hausdorff distance (mm) across four groups when scanning maxillary and mandibular casts

List of Independent Factors				
		(Mean ±SD)	**F-stat (df)**	***P***
Type of device	Handheld computer with eGPU	0.54 ±0.06	0.92 (3)	.44
	Laptop alone	0.56 ±0.09		
	Laptop with eGPU connected	0.58 ±0.11		
	Desktop workstation	0.56 ±0.13		
Jaw scanned	Maxilla (n=40)	0.51 ±0.11	31.577 (1)	<.001*
	Mandible (n=40)	0.62 ±0.06		
Interaction effect	Type of device		3.585 (3)	.018*
	Jaw scanned			
Pairwise comparison				
		Maxilla (Mean ±SD)	Mandible (Mean ±SD)	
Handheld computer with eGPU		0.53 ±0.06	0.55 ±0.05	
Laptop alone		0.49 ±0.06	0.63 ±0.04	
Laptop with eGPU connected		0.55 ±0.14	0.62 ±0.06	
Desktop workstation		0.48 ±0.14	0.65 ±0.04	

* Significant (*P*<.05),
df, degree of freedom; eGPU, external graphics processing unit; SD, standard deviation.

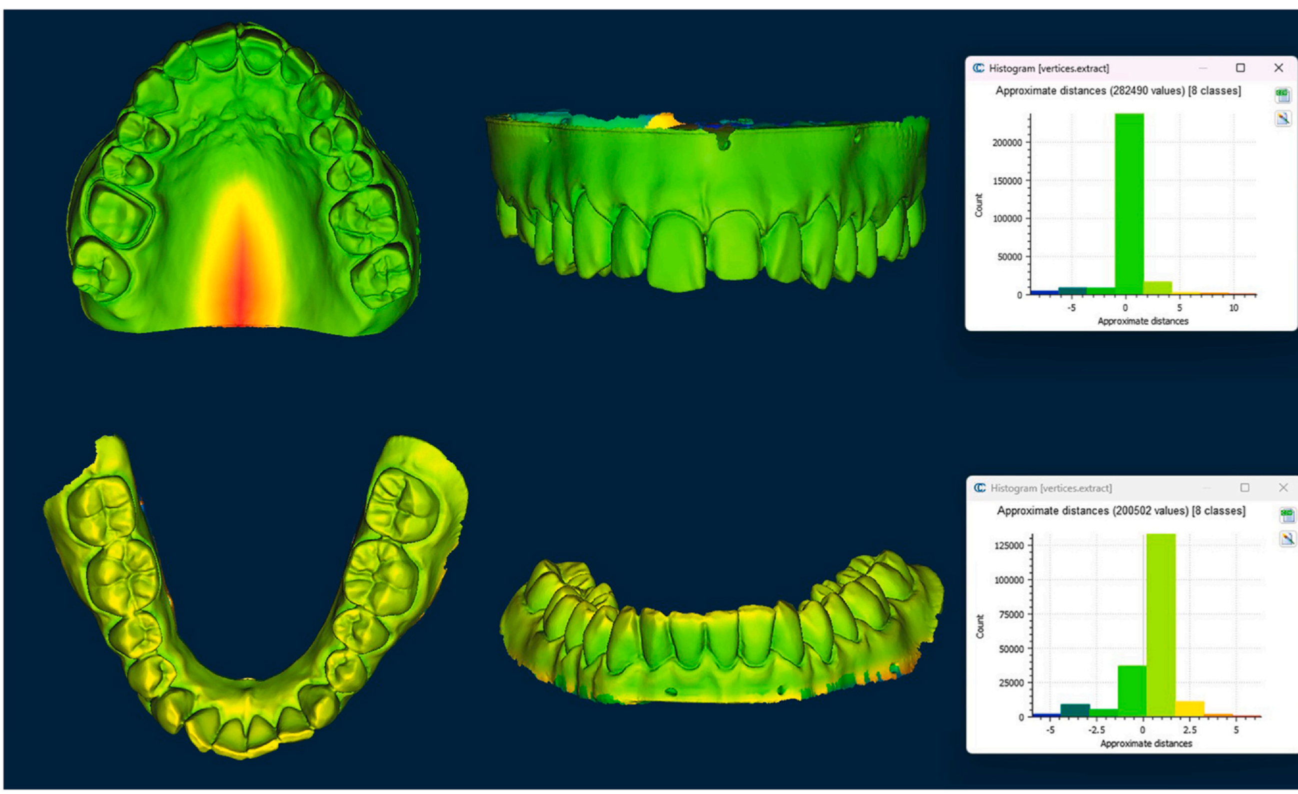

Figure 3. Overall Hausdorff distance between handheld scans and scans conducted by desktop scanner. "Count" represents average number of points assessed across each cast, while "distance" indicates approximate dissimilarities between two casts (mm).

DISCUSSION

The null hypothesis that no significant differences in scanning time and scan accuracy would be found between smaller portable devices and established desktop standards was rejected because there were significant differences across all the parameters evaluated. The handheld console and eGPU connection performed significantly better, suggesting the potential for ultraportable devices to handle scanning and data management simultaneously with proper infection control measures in place.

All scans closely matched standard desktop scans, indicating a remarkable advancement in computing performance for dental practitioners by offering improved portability and space efficiency without compromising scanning accuracy. Initial pilot experiments simulating multitasking conditions such as running several applications in the background yielded similar results but were not documented owing to a lack of standardization in the power draw from background applications. The default Windows background processes posed no issues, as all devices had freshly installed Windows 11 with identical software versions. Windows updates were manually disabled during data collection to ensure uniformity. However, a limitation was noted in the data read and write speeds of the solid-state drive (SSD) storage present on the device, which were previously reported to contribute to variations in scan saving times after postprocessing.[20] Therefore, the time taken to save the scans to the drive or read them afterwards was not assessed.

The current study design relied on devices available from a single manufacturer for standardization, although the reliance on a single handheld unit and on products from a single manufacturer are limitations of the study. However, both factors ensured compatibility with the devices and avoided biases induced by different manufacturers. The consumer market for graphics card has been largely dominated by Advanced Micro Devices (AMD) and Nvidia Corporation.[21] AMD-based graphics cards were not considered because most dental imaging devices rely on compute unified device architecture (CUDA), exclusively provided by Nvidia-based chipsets.[22]

It was observed that approximately 8 gigabytes of random access memory (RAM) were consumed throughout the scanning process across all 4 devices. Therefore, neither the additional RAM present in the workstation nor the added power draw provided any special advantages in accelerating scanning or processing times. From a practical perspective, larger workstations tend to offer better performance but at the expense of increased electricity consumption[2]; they also generate more heat, which, in a closed environment, may further heat the scanner, thereby affecting its performance.[23] Therefore, even if it were practically possible to do so, manipulating a large workstation that draws very high power may not be optimal for scan quality. To maintain the uniform distribution of low ambient temperature, the authors suggest using a device with the least wattage consumption to conserve power and prevent increasing the ambient temperature. The authors speculate that traditional recommendations for high-powered laptops to ensure smooth rendering may soon become outdated because of advancements in smaller form factors and the integration of neural cores supporting computer processing. An entry-level dedicated GPU like the GTX 1650 in the current study, typically not recommended by manufacturers, successfully performed 10 consecutive scan sessions in the present study without failure. When paired with an external GPU, its performance significantly improved, although, unsurprisingly, it was outperformed by the desktop workstation. Notably, the handheld computer connected to an eGPU surpassed all devices in performance metrics while also drawing much less power than the desktop counterpart. However, the ambient temperature changes across the devices were not evaluated in the current study and can be a topic for future explorations.

The decision was made to include an affordable standalone scanner suite that might make the evaluation relevant across a larger cohort of practitioners who are not keen on subscribing to yearly premiums to access postprocessing functionalities.[24] The scanner and its software suite used in the current study had no subscription components at the time of conducting the research, making the postprocessing workflow more accessible and standardizable. Future studies can integrate additional eGPUs and devices from other manufacturers to compare the performance across different interfaces and hardware versions. Additionally, the integration of neural cores within computer processors as of 2024 can simplify graphically intensive tasks and big data processing according to social media posts, further enhancing workflow efficiency. Future studies can include computer processors with neural cores to test whether such advances are advantageous for the 3D rendering tasks commonly observed in digital dentistry.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Portable handheld computers paired with eGPUs produced 3D intraoral scans comparable with those obtained from conventional workstations but with reduced scanning and processing times.
2. Thin-and-light personal computers equipped with eligible connectivity options can utilize eGPUs to enhance their capabilities in 3D rendering, thereby extending their usefulness in dental practice.

REFERENCES

1. Shi L, Liu W, Zhang H, et al. A survey of GPU-based medical image computing techniques. *Quant Imaging Med Surg*. 2012;2:188–206.
2. Price DC, Clark MA, Barsdell BR, et al. Optimizing performance-per-watt on GPUs in high performance computing: Temperature, frequency and voltage effects. *Comput Sci-Res Dev*. 2016;31:185–193.
3. Farook TH, Jamayet NBin, Abdullah JY, et al. Designing 3D prosthetic templates for maxillofacial defect rehabilitation: A comparative analysis of different virtual workflows. *Comput Biol Med*. 2020;118:103646.
4. Liu X, Wang R, Shi C, et al. Computing acceleration to genome-wide association study based on CPU/FPGA heterogeneous system. *ACM SIGAPP Appl Comput Rev*. 2024;23:16–26.
5. Farman AG, Levato CM, Gane D, Scarfe WC. In practice: How going digital will affect the dental office. *J Am Dent Assoc*. 2008;139:S14–S19.
6. Prgomet M, Georgiou A, Westbrook JI. The impact of mobile handheld technology on hospital physicians' work practices and patient care: A systematic review. *J am Med Inform Assoc*. 2009;16:792–801.
7. Gagoski B, Xu J, Wighton P, et al. Automated detection and reacquisition of motion-degraded images in fetal HASTE imaging at 3 T. *Magn Reson Med*. 2022;87:1914–1922.

8. Shah M, Kodali S, Rani A, Bharathi V. Seamless interfacing with Thunderbolt TM 4.0. *International Conference on Electrical, Computer and Energy Technologies (ICECET)*. 2022. IEEE,; 2022:1–6.
9. Nedelcu R, Olsson P, Nyström I, et al. Accuracy and precision of 3 intraoral scanners and accuracy of conventional impressions: A novel in vivo analysis method. *J Dent*. 2018;69:110–118.
10. Gupta M, Agrawal A, Veeraraghavan A, Narasimhan SG. Structured light 3D scanning in the presence of global illumination. CVPR 2011. IEEE,; 2011:713–720.
11. Kim J, Park J-M, Kim M, et al. Comparison of experience curves between two 3-dimensional intraoral scanners. *J Prosthet Dent*. 2016;116:221–230.
12. Richert R, Goujat A, Venet L, et al. Intraoral scanner technologies: A review to make a successful impression. *J Healthc Eng*. 2017;2017.
13. Farook TH, Ahmed S, Giri J, et al. Influence of intraoral scanners, operators, and data processing on dimensional accuracy of dental casts for unsupervised clinical machine learning: An in vitro comparative study. *Int J Dent*. 2023;2023.
14. Brennan DS, Chrisopoulos S, Teusner DN. Hours worked and patient visits provided by dentists in Australia. *Aust Dent J*. 2018;63:118–123.
15. Faul F, Erdfelder E, Lang A-G, Buchner AG*. Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39:175–191.
16. Zhang J, Yao Y, Deng B. Fast and robust iterative closest point. *IEEE Trans Pattern Anal Mach Intell*. 2021;44:3450–3466.
17. Farook TH, Jamayet NBin, Asif JA, et al. Development and virtual validation of a novel digital workflow to rehabilitate palatal defects by using smartphone-integrated stereophotogrammetry (SPINS). *Sci Rep*. 2021;11:1–10.
18. Girardeau-Montaut D. CloudCompare. *EDF RD Telecom ParisTech* 2016.
19. Farook TH, Abdullah JY, Jamayet NBin, Alam MK. Percentage of mesh reduction appropriate for designing digital obturator prostheses on personal computers. *J Prosthet Dent*. 2022;128:219–224.
20. Mielke NR, Frickey RE, Kalastirsky I, et al. Reliability of solid-state drives based on NAND flash memory. *Proceedings of the IEEE*. 2017;105:1725–1750.
21. Otterness N, Anderson JH. AMD GPUs as an alternative to NVIDIA for supporting real-time workloads. 32nd Euromicro Conference on Real-time Systems (ECRTS 2020). Schloss Dagstuhl-Leibniz-Zentrum für Informatik,; 2020.
22. Kim H, Cho H, Lee W, et al. Development of handheld optical coherence tomography based on commercial intra-oral scanner shape for extended clinical utility in dentistry. *Int J Imaging Syst Technol*. 2024;34:e23024.
23. Revilla-León M, Gohil A, Barmak AB, et al. Influence of ambient temperature changes on intraoral scanning accuracy. *J Prosthet Dent*. 2023;130:755–760.
24. Resnick CM, Doyle M, Calabrese CE, et al. Is it cost effective to add an intraoral scanner to an oral and maxillofacial surgery practice? *J Oral Maxillofac Surg*. 2019;77:1687–1694.

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