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Evaluation of the Forearm Dominancy Artery for Invasive Vascular Procedure with 3D-CT Angiography

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The aim of this study was to evaluate the vascular dominance in the forearm as a factor in determining the choice of invasive vascular procedures in arteries of the forearm, using 3D-computerized tomography (3D-CT) angiographies of 92 forearms. The diameters of the ulnar and radial arteries were measured just distal to the bifurcation of the brachial artery, at the midpoint between the bifurcation and the wrist, and at the wrist crease. In 79 cases, the ulnar artery was larger than the radial artery after the bifurcation of the brachial artery. However, no statistically significant difference was observed at either the mid-forearm or the wrist crease. In the remaining 13 cases, the diameter of the radial artery was larger or the same as that of the ulnar artery after the bifurcation, but at the more distal sites no regular pattern could be detected. The findings suggest that 3D-CT angiography offers valuable preoperative details of the forearm vessels for cases requiring invasive vascular procedures on the forearm.

Keywords: Radial Artery; Ulnar Artery; Vascular Dominance; 3D-CT Angiography

INTRODUCTION

According to the classic teaching based on anatomical studies the ulnar artery is the dominant artery of the human forearm. Because the radial artery is more superficial and non-dominant, the majority of invasive vascular procedures are performed using the radial artery (1). Even though recent studies have shown that the use of the ulnar artery is possible and safe and despite the low donor site morbidity, its use is still not very popular (1, 2). Complications and donor-site morbidities after invasive procedures of the radial artery have frequently been reported (3, 4), with complication rates greatly varying across the literature, even for that of hand amputations (5-8). Factors correlated with complications after such interventions are vascular damage, spasm, thrombosis, congenital vascular anomaly, infection, and use of dominant artery. Among these, the choice of the non-dominant artery of the forearm and the hand is one important factor.

Many researchers have evaluated the circulation of the forearm and the hand with several methods such as, physical examination (Allen test), cadaveric studies, noninvasive methods, and invasive methods. However, some of these methods are subjective, or observer dependent. Invasive procedures carry the risk of damaging the arteries, and some methods cannot detect any focal vascular abnormality in the forearm.

In the upper extremities, the 3D-computerized tomography (3D-CT) angiography previously obtained for tumor diagnosis, or for evaluation of the vascular state of the body, can serve as a tool for identifying the lesser of the two forearm arteries. The 3D-CT angiography is noninvasive and provides highly reliable and reproducible vascular anatomy. Because of these advantages it is frequently used in evaluation of free flaps to be used in reconstructions (9).

In order to minimize the complications after vascular procedures, we evaluated the vascular dominance of the forearm and the hand based on previously obtained data of 3D-CT angiography studies to evaluate, which of the forearm arteries was the dominant.

MATERIALS AND METHODS

A single-institutional retrospective review identified 109 consecutive 3D-CT angiographies of the whole upper extremity. Indications for imaging were preoperative vascular evaluations of patients requiring postoncologic reconstruction, vascular assessments in patients with lower extremity injury, and non-trauma related vascular evaluations. Upon review of medical charts, forearms were excluded for vasculitis, subclavian artery narrowing with calcified atherosclerosis of the aortic arch, pseudoaneurysms of wrist and forearm, presence of a metallic plate, segmental stenosis of the forearm or brachial arteries, and previous history of forearm vascular procedures, such as vessel anastomosis, arterial transsections, angiocentesis, and artificial arteriovenous fistula. With the exclusion criteria applied, bilateral forearm studies were available for 46 subjects.

In total, 92 forearm CT angiographies were used for the measurement of the forearm arteries and statistical analysis. Statis-

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Fig. 1. Locations of vessel diameter evaluations. P 1, at the origin of both arteries just distal to the bifurcation of the brachial artery; P 2, at the mid-point between the bifurcation and the wrist crease; P 3, at the wrist crease. CIO, common interosseous artery.

tical significance was evaluated using an ANOVA 2-way test, a Mann-Whitney test and a linear regression analysis. *P* values less than 0.05 were considered statistically significant. All data were expressed as a mean and standard deviation (SD) or standard error of means (SEM).

3D-CT angiography details

All examinations were performed with a 64-slice CT scanner (G.E VCT; General Electric, Milwaukee, Wisconsin, USA). Reconstructed images were loaded into the CT work station and measurements were obtained using calipers on a computer screen. The radial and ulnar artery diameters were obtained from each of the 46 forearms included. Transverse arterial diameters were assessed just distal to the bifurcation of the brachial artery (point 1), at the midpoint between the bifurcation and the wrist crease (point 2) and at the wrist crease (point 3) (Fig. 1).

One observer carried out all measurements. The rate of blood flow was considered to be proportional to the arterial radius to the 4th power (blood flow = velocity × radius^4), with the assumption that the velocity was constant in the measure points in each arm. Thus, the artery with the larger diameter was considered to be dominant in each forearm study assessed.

Ethics statement

The study was approved by the institutional review board of Inha Univeristy Hospital (IUH-IRB14-2711). Informed consent was exempted by the board. The data used for this study do not include any identifiable personal information.

RESULTS

The mean age of the 46 subjects was 57.71 yr (19-87). There were 25 males and 21 females. Of the 92 forearm CT angiographies, the ulnar arteries were larger than the radial arteries in approximately 86% of forearms (79/92), just distal to the point of bifurcation. In 14% of forearms (13/92), the diameter of the radial artery was larger or the same than that of the ulnar arteries at the same point. There was no pattern of the diameter of the arteries on the midforearm and at the wrist level.

Statistical results

In the 46 patients within the bilateral forearm studies, comparisons of the vessel diameters between the left and right forearm at the three measurement points did not reveal statistically significant differences ($P = 0.550$, $P = 0.579$, $P = 0.901$, $P = 0.397$, $P = 0.592$, $P = 0.582$) (Fig. 2A). Comparisons of vessel diameter between the radial and ulnar arteries of both forearms were performed using an ANOVA 2-way test (Fig. 2B). The diameter of the ulnar artery was significantly larger than that of the radial artery at the bifurcation ($P < 0.001$). No such significant difference was found at the mid-forearm or at the wrist crease ($P = 0.836$, $P = 0.857$, $P = 0.139$, $P = 0.359$). In linear regression analysis of the vessel diameter of both forearms according to age (Fig. 2C), vessel diameters were not associated with advancing age for all points of both forearms measured along the ulnar artery and the radial artery. In vessel diameters between the genders, the diameters of ulnar artery at mid-forearm ($P = 0.008$) and wrist crease ($P < 0.001$) and those of radial artery at the bifurcation ($P = 0.002$), mid-forearm ($P < 0.001$), and the wrist ($P < 0.001$) was larger in males than in females. No differences were observed for the ulnar diameter at the bifurcation ($P = 0.059$) (Fig. 2D). Comparisons between the ulnar and radial arteries within each gender using an ANOVA 2-way test (Fig. 2E). The diameter of the ulnar artery was significantly larger than that of the radial artery at the bifurcation in each gender ($P < 0.001$). No such significant difference was found at the mid-forearm or at the wrist crease ($P > 0.05$).

DISCUSSION

The arterial blood supply of the forearm and hand has been studied in cadaveric and angiographic studies (10). Previous studies have been divided concerning the dominance of the forearm arteries, reporting either the radial (11, 12) or ulnar artery (10) as the more dominant one. In 2003, Haerle et al. (1) reported that the ulnar artery was larger than the radial artery proximal to the interosseous branching point and that the converse was true distally with a cadaver study.

According to the conviction that the radial artery is the non-dominant blood supply to the forearm and hand, the radial artery was more often used or sacrificed for invasive procedures such as arterial catheterization, conduit harvests for coronary artery bypass surgery, AV fistula formation for hemodialysis,

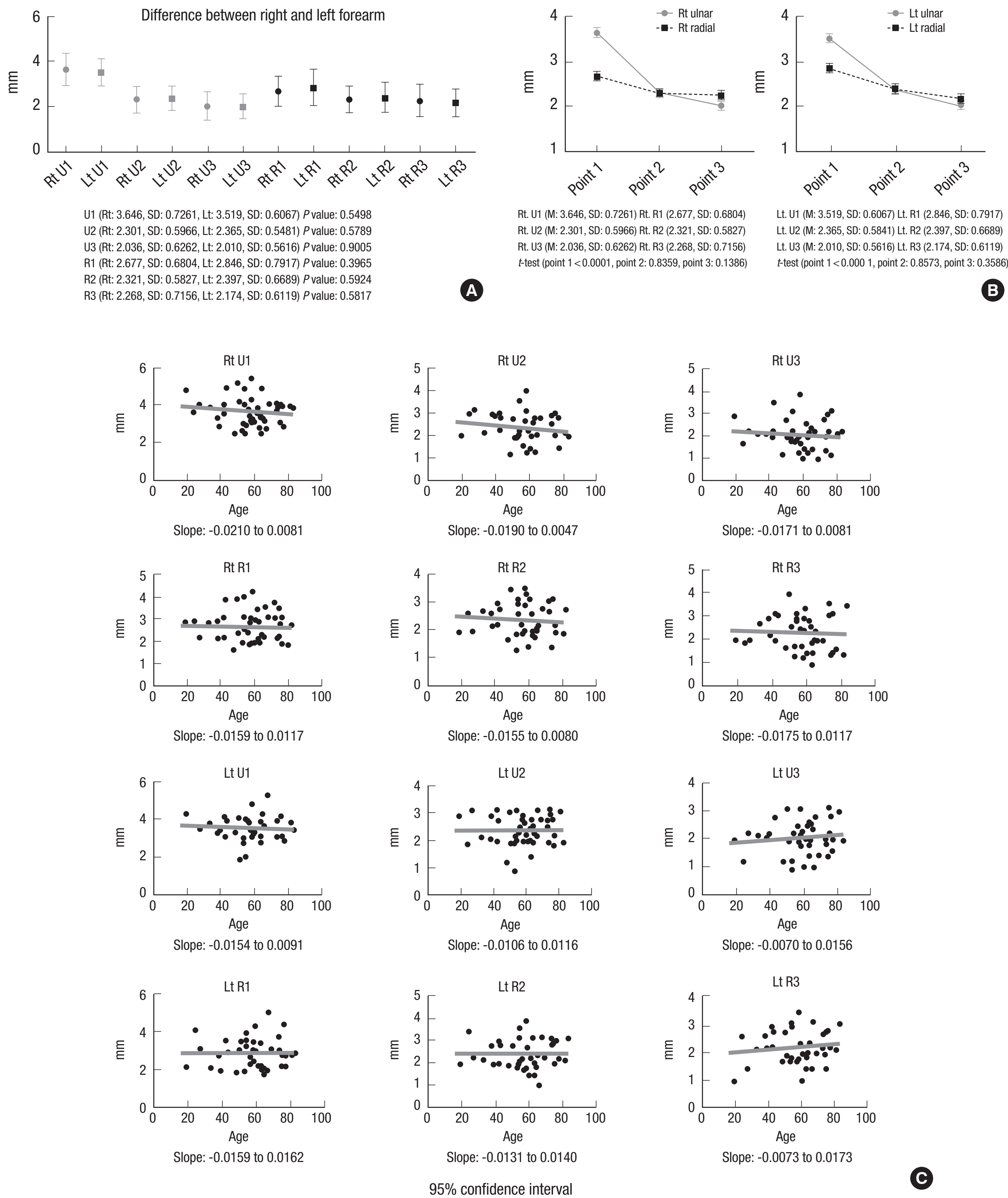

Fig. 2. Result analysis. (**A**) Comparison of vessel diameters between the left and right forearm. Rt, right; Lt, left; U1, ulnar artery point 1; U2, ulnar artery point 2; U3, ulnar artery point 3, R1, radial artery point 1; R2, radial artery point 2; R3, radial artery point 3. (**B**) Comparison of vessel diameters between the radial and ulnar arteries of both forearms. ANOVA 2-way and *t*-test. (**C**) Vessel diameters according to age. Linear regression analysis. (continued to the next page)

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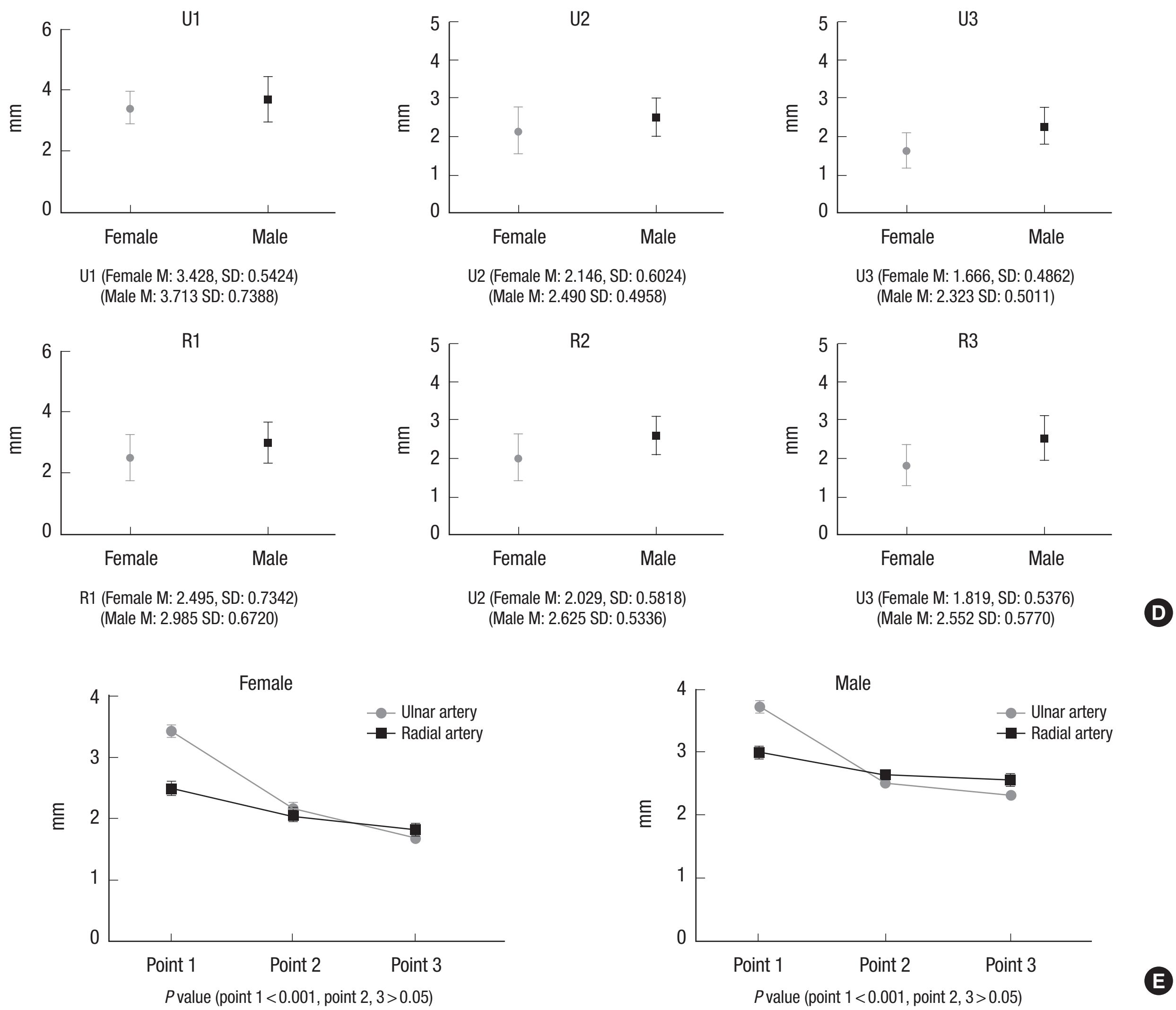

Fig. 2. (continued) (**D**) Comparison of vessel diameters between males and females. (**E**) Comparison of vessel diameters between the radial and ulnar arteries of each gender. ANOVA 2-way and *t*-test.

and radial forearm free flaps. Repeated arterial punctures into the forearm artery are performed to evaluate oxygen and carbon dioxide gas exchange, acid base balance, the cardiopulmonary evaluation of the patient and for a preoperative evaluation of an older person to be operated on. Arterial punctures, however, have the risk of creating arterial thrombosis, hematoma, arterial spasm, compartment syndrome, pseudoaneurysms or other arterial injuries (13). Common complications after vascular invasive procedures of the forearm include cold intolerance and pain (14). Postoperative vascular thromboses are reported to result in amputations of digits (5, 7, 8). Vessel variations rendering the radial artery the dominant blood supply, may even lead to necrosis of the hand necessitating its amputation, if unperceived before sacrificing the radial artery (15, 16). Mandel (6) reported that there were complications, such as tissue ischemia and necrosis, seen in 10% of patients after radial artery cannulations, resulting in hand gangrene in five of 600 cases. Thus, bearing in mind that invasive procedures on arteries, may result in vascular damage, it would be wise to spare the dominant artery of the forearm. In contrast, some studies of hemodynamic changes after such arterial invasive procedures differ in whether blood flow to the hand actually changes and those studies reported an opposite conclusion (17, 18).

While the Allen test is the most easily performed and least costly method of assessing redundant vascular supply and the collateral circulation of the hand, it is unable to evaluate the dominant artery, narrowing of the vessel, and focal vascular occlusion of the forearm artery and there is no "print-out" of the test results (17). Contrast injection angiography is reliable and accurate, but invasive and cannot avoid vascular damage. Pulse oximeters and plethysmography (19) are able to measure relative blood flow in the limb by pressing one and the other of the main arteries and will reflect the hemodynamic state and the collateral circulation of the hand, but not to detect any focal vascular abnormalities (20). Both methods fail to provide evaluation of the vascular anatomy of the whole forearm, such as arterial focal occlusion. Using the relationship between the radius of a pipe and laminar flow given by Poiseuille's Law, cadaveric studies have used vessel diameters as approximate indicators of in-vivo blood flow. However, this method does not reflect the hemodynamics of upper extremity vessels under neural and hormonal effects. Duplex ultrasonography is able to overcome this limitation and is likely the ideal method in assessing real-time hemodynamics – assuming that an experienced ultrasonographer is available at all times. However, a multitude of variables, such as the pressure of the probe on the vessel and consequent changes of the diameter, the low inter-observer reliability and other factors attribute to the low reliability of these methods (21). Magnetic resonance angiography (MRA) has the advantage of using neither ionizing radiation nor iodinated contrast agent, and it is an accurate cross-sectional vascular imaging modality, but its vascular images are not as accurate as 3D-CT angiography. MRA is expensive, and it is limited in the setting of metallic implants such as stents, metallic plate and external fixator. Conventional CT is a popular examination for the diagnosis and evaluation of trauma, benign and malignant tumors, and many other conditions requiring additional vascular enhancement (13). The 3D-CT angiography is a combined technology of a conventional CT scan with that of traditional angiography to create detailed images of vessels in the body. The 3D-CT angiography also allows noninvasive vascular assessment and is used widely in preoperative planning workups for patients requiring reconstructive surgery and in the evaluation of atherosclerosis and other vascular conditions. When the 3D-CT angiography is obtained for these purposed, it can simultaneously serve as a tool for determining the vascular dominance in the forearm.

In this study, the evaluation of the vascular dominance by 3D-CT angiography has revealed that the radial artery was equal to or larger than the ulnar artery in approximately 14% of forearms (13/92), and 26% of persons (12/46) at point 1, just distal to the point of bifurcation. Regardless of gender or aging, the ulnar artery was larger at the bifurcation but was not different from the radial artery at the mid-forearm and at the wrist crease, which is different from the findings of those reported by Haerle (1). This suggests that the blood supply to the common interosseous artery is diverted away from the ulnar artery. Distal to this branching point, the contribution of the ulnar and radial arteries to the blood supply of the distal forearm and the hand does not follow a regular pattern. The choice of vessel for an invasive vascular procedure on the forearm distal to the common interosseous branching point should depend on a thorough examination of vessel sizes. If a forearm flap is harvested, it should incorporate the non-dominant of the two vessels. The 3D-CT angiography can be helpful in determining the vessel diameters and thus serve as a valuable tool in the selection of the vessel to be incorporated in the flap or to be used for other invasive procedures.

However, the ulnar artery is located very close to the ulnar nerve and providing the vasa nervorum to this nerve, so invasive procedures on the ulnar artery may damage the ulnar nerve. Whereas skin perforators of the radial forearm free flap usually arise in the distal third of the forearm (22), the perforators of the ulnar free flaps arise throughout the whole length of the forearm (23). This difference in the distribution of skin perforators should be considered in addition to the vascular dominancy of the forearm arteries when selecting a forearm flap.

The limitation of this study is that neither 3D-CT angiography nor MRI angiography can measure actual hemodynamic variations of blood flow resulting from hormonal or neuronal effects. Follow-up studies are needed to evaluate the clinical significance of the study findings.

DISCLOSURE

None of the authors has received a financial interest in the products, devices, or drugs mentioned in this article.

AUTHOR CONTRIBUTION

Conception of the study and Coordination: Ki SH, Choi JH. Acquisition of data: Choi JH. Data review, manuscript preparation: Ki SH. Statistical analysis: Ki SH, Choi JH. Manuscript approval: all authors.

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